A systemic approach to identifying sustainable community-based interventions for improving adolescent mental health: a participatory group model building and design protocol

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Abstract

Background

The deteriorating mental health of children and young people in the United Kingdom poses a challenge that services and policy makers have found difficult to tackle.

Kailo responds to this issue with a community-based participatory and systems-informed strategy, perceiving mental health and wellbeing as a dynamic state shaped by the interplay of broader health determinants. The initiative is active in two contrasting locales: theurban London borough of Newham and the rural district of Northern Devon in the Southwest United Kingdom. These divergent areas were intentionally selected to examine the role of local context in shaping the factors influencing young people's mental wellbeing.

Kailo unfolds in three stages within each locale. These stages encompass: ‘Early Discovery’, ‘Deeper Discovery and Co-Design’, and ‘Implementation’. This document delves into the participatory group model building and design protocol occurring in the ‘Deeper Discovery and Co-Design’ stage of the project.

Methods

The engagements begin early in the Deeper Discovery and Co-Design phase, aiming to gain a more thorough understanding of the systemic behaviours driving the locally identified opportunity areas from Early Discovery.

Participatory methods, such as group model building, are effective in building consensus on complex issues like the social determinants of adolescent mental health. This paper describes the application of group model building in two local areas to develop causal loop diagrams and pinpoint leverage points related to this issue. It also suggests a method for considering modifications to delivery within a unique project context and in alignment with participants' needs.

This paper sets out to define the approach and clarify the objectives these engagements aim to fulfil. The method adapts existing Group Model Building (GMB) protocols for use in a community setting. The engagements will involve groups of local young people and existing community members.

To assess the success of the session's implementation post-delivery, the study utilises existing frameworks for fidelity evaluations, which define a core and flex model.

Discussion

The method described enables an integration of diverse local understandings of complex processes which provides a platform for creating co-designed interventions. The strengths and limitations of the approach are discussed.

Introduction

This paper addresses adolescent mental health and wellbeing as a dynamic and systemic concern and introduces a research and design framework named Kailo that facilitates local partnerships in devising systemic, youth-centred, and evidence-based policy and practice solutions. The principal focus of this protocol paper is to outline the rationale and methods for a series of engagements using a participatory group model building approach, which occur early in the Deeper Discovery phase of Kailo. It clarifies the reasons for selecting these methods, provides details on the methods employed in the sessions, and establishes criteria for evaluating the success of the sessions in relation to their objectives. In doing so, it also seeks to record an approach to participatory group model building in youth-led community settings. A subsequent paper will then detail adherence to the protocol, where modifications might be necessary, and the results and outcomes of the process.

Background (problem context)

In the United Kingdom, an expanding body of evidence highlights a persistent decline in children and young people's wellbeing and mental health across recent decades (Newlove-Delgado et al, 2022; The Children's Society, 2020). This trend persists despite significant investments in public health and social care (Department for Health and Department for Education, 2017), revealing that services struggle to meet the growing demand (Gunnell, Kidger, and Elvidge, 2018).

Historically, these investments have favoured mental health models that mirror pathological models of physical health, advocating for individualised treatment (Richter and Dixon, 2022). As a result, services, interventions, and therapies predominantly target diagnosed mental disorders, neglecting a holistic model of mental wellbeing that includes a variety of social, individual, and community factors (Foulkes, 2021). Furthermore, public health initiatives aimed at tackling the sociological determinants of mental health often focus on macro-level factors, overlooking the intricacies of local contexts (Marmot et al, 2020). The dynamic and multifaceted nature of this issue, coupled with the diversity of system stakeholders and their differing objectives, presents a complex systemic challenge (Farrell et al, 2021). This complexity underlines the need for a community-focused, complexity-aware approach to understanding the local factors contributing to the decline in adolescent mental health.

The Kailo Programme (programme context)

Background

In response to the necessity of adopting a systemic perspective to tackle the social determinants of young people's mental health, our research group has developed and is executing Kailo. This is a five-year research and design programme financed by the UK Prevention Research Partnership (UKPRP). Kailo is a structured framework that assists local partnerships in comprehending the specific social and environmental factors affecting young people's mental health, identifying priorities, and then collaboratively designing youth-centred, evidence-based policy and practice solutions (Hobbs et al, 2023).

It is initially being applied in the London borough of Newham and the rural region of Northern Devon in the Southwest United Kingdom: two distinctly different areas intentionally chosen to examine the impact of local context on young people's mental health and wellbeing. The Kailo framework encompasses three main phases in the local regions—'Early Discovery', 'Deeper Discovery and Co-Design', and 'Prototyping, Implementation, and Testing' (see figure 1) (Hobbs et al, 2023). These work phases are carried out by local Kailo teams in each location (workstream 1) and are supported by research experts throughout the programme (workstream 2). Alongside the development and execution of the framework, an evaluation team (workstream 3) is performing a theory-based formative evaluation to examine the presuppositions of the underlying programme theory of Kailo (Kennedy et al, forthcoming).

Early Discovery phase of Kailo

The primary goal of the Early Discovery phase was to comprehend the local factors and priorities affecting young people's mental health from a social determinants perspective (Santana de Lima, et al, forthcoming). During this stage, researchers collaborated with local stakeholders to identify and prioritise specific concerns that both the community and the Kailo team believed could be effectively tackled (ibid). This involved qualitative engagements with over 500 individuals, including young people and community professionals across Northern Devon and Newham (Santana de Lima et al, forthcoming).

This stage also included a scoping review of existing literature on the social determinants of adolescent mental health. It focused particularly on the systemic and interdependent factors contributing to young people's mental health and wellbeing in the UK, such as poverty, housing, transport, school exclusion, social connection, discrimination, safety, knowledge and norms related to mental health, future opportunities, and sense of belonging (Compton and Shim, 2015; Hartas, D., 2019). This body of knowledge helped to establish a shared understanding of local priorities, including areas where needs might be intensified.

These qualitative engagements, combined with the literature review, nurtured a mutual understanding of local priorities and pinpointed potential avenues for "systemic change" (Dreier, Nabarro, Nelson, 2019). The outcomes were delineated as Opportunity Areas (OAs) for systemic change concerning social determinants of young people's mental health and wellbeing. In Northern Devon, key priorities identified included: (i) how might strong and supportive community relationships enhance mental health literacy?; and (ii) how might local partners provide a varied range of opportunities for young people (such as education, employment, and leisure activities)? These were supported by a cross-cutting theme of fostering a sense of identity and belonging within the local community. In Newham, the identified priorities were: (i) how might communities promote safety for young people amidst broader issues of violence and crime?; and (ii) how might local community infrastructure be strengthened to ensure a varied range of activities that support young people's wellbeing? These identified opportunity areas, in line with evidence about the social determinants of young people's mental health, were deemed by local young people, community partners, and system leaders as crucial to enhancing young people's mental health and wellbeing and were agreed to be advanced to the 'Deeper Discovery and Co-Design' phase of Kailo.

Deeper Discovery and Co-Design

The second phase of the Kailo framework – the Deeper Discovery and Co-Design phase – utilises a community-based participatory approach involving a diverse group of stakeholders with varied lived, professional, and academic experiences. By amalgamating this wide array of knowledge and experience within local systems, the programme enables communities to devise meaningful, sustainable enhancements in young people's mental health and wellbeing (Forrester, JW., 1992).

The Deeper Discovery and Co-Design phase capitalises on a variety of methodologies, including Rapid Realist Reviews of evidence, Participatory Action Research led by young peer researchers and community partners, Community Based System Dynamics, and creative design methods from the fields of user-centred design and 'design thinking' (Jagosh, 2019; Saul, Willis, Bitz, et al., 2013; Shamrova and Cummings, 2017; Hovmand, P. S., 2014).

This phase employs these techniques to develop and trial strategies concerning the OAs to bolster young people's wellbeing; engage and collaborate with key community stakeholders; bridge gaps in engagement and knowledge; and enhance local capacity for transferring ownership of interventions from the Kailo team to community-led partnerships (Santana de Lima, et al, forthcoming).

Further information on Deeper Discovery will be detailed in an upcoming paper.

Implementation: Testing, Embedding and Learning

The final stage of the Kailo framework – Prototyping, Implementation, and Testing – follows from the deeper discovery and co-design process. This work is anticipated to occur from April 2024 through October 2026. The objective of this phase of work is to facilitate local system integration, prototyping, and iterative refinement of the interventions developed in the previous phase of work (Hobbs et al, 2023). This will be achieved through three rounds of 'low fidelity' prototyping and testing of interventions, followed by subsequent rounds of 'high fidelity' sustained implementation of local designs (Hobbs et al, 2023). Within this testing process, the Kailo team will also endeavour to transfer ownership of the design process to local system leaders. Ultimately, this phase of work is designed to support interventions to become locally embedded and sustained, enabling them to enhance youth mental health and wellbeing outcomes within the local area (Hobbs et al, 2023).

Group Model Building within in the Kailo Framework

Kailo stands out by adopting a systemic, evidence and community-informed approach to identify, understand, and design interventions to enhance the social determinants of young people's wellbeing and mental health. Whereas traditional research methods often concentrate on a limited set of factors

and perceive relationships between variables as linear, systemic frameworks facilitate the recognition of interconnected, dynamic relationships among a broad array of factors (Savona, et al, 2021; Finegood, 2012). This fosters a more comprehensive understanding of systemic challenges, enabling various system actors to implement actions that tackle the systemic drivers of these challenges (Savona, et al, 2021).

The distinctiveness of this approach is supported by the incorporation of participatory group model building (GMB) within the deeper discovery and co-design phase of the Kailo framework. Group model building (GMB) is a methodology grounded in the discipline of system dynamics that combines the tenets of systems thinking with participatory techniques to tackle complex issues (Savona, et al., 2022). GMB aids in the identification and illustration of both underlying causes and sequences of causation leading to social problems. This enables participants, researchers, and broader system stakeholders to gain a clearer understanding of how initiatives can spark change and assists in the prioritisation of areas for action for the co-creation of community-based interventions within the Kailo framework (Savona, et al., 2022).

While participatory applications of group model building, such as community-based system dynamics, are well-established in similar contexts, their application with young people, though increasing, remains rare (Langellier et al., 2019). GMB has been deployed in research contexts akin to the Kailo project, encompassing studies on social determinants of health (Reumers et al., 2022), adolescents' perspectives on public health in the UK (Sanova et al., 2022), the formulation and influence of local policy (Currie, Smith and Jagals 2018), and forthcoming research on youth mental health (Freebairn et al., 2022).

In the subsequent sections of this paper, we will outline the participatory group model building approach that will be applied for Kailo. In doing so, we will discuss the rationale for group model building; provide an overview of the aims, participants, settings, facilitation team, and considerations pertinent to the group model building context; detail the planned approach and session activities; and consider the evaluation and measures of success related to the GMB process. Finally, the discussion will elaborate on the distinctiveness of the approach, modifications related to core and flexible elements of participatory GMB, and any potential risks from the research design and process.

Methods

Rationale for Group Model Building

Why Group Model Building?

GMB was selected as a key method for the Kailo Deeper Discovery and Co-Design phase because it provides a structured and collaborative means to engage with a variety of participants. It aids in elucidating the underlying system dynamics and drivers of the issues at hand and can pinpoint potential interventions or leverage points for changes in policy or practice. Stemming from system dynamics, GMB seeks to depict a system by drawing on the diverse perspectives of

stakeholders. The core principle of GMB is that capturing a comprehensive understanding of a systemic problem necessitates the amalgamation of various mental models of the issue (Vennix, 1996). While it traditionally utilised quantitative methods, GMB now increasingly incorporates qualitative, participatory techniques for modelling systemic problems (Barbrook-Johnson and Penn, 2022), as demonstrated by Community-Based System Dynamics (CBSD) (Hovmand, 2014). When applied to young people, GMB can unveil context-specific systemic drivers of a problem they find most pertinent. Through this approach, it develops and clarifies a collective hypothesis of the connections between these drivers (Savona et al., 2021).

Core Components of Group Model Building

GMB sessions usually adhere to pre-defined scripts that are accessible on open-source platforms like Scriptapedia (Hovmand et al., 2012). These scripts are organised by the purpose of the activity (presentation, divergent information, convergent information, and evaluation) and are distinguished as either "established" or "promising".

Workshop outcomes are often synthesised and refined in an iterative manner (see Werner, Arnold and Crea, 2021). This refinement may occur if participants were uncertain about the modelling activity, encountered difficulties in diagramming during the session, mentioned an element not captured in the model, or changed the meaning of a variable during modelling. Any adjustments to the model by the research team are then shared with the group for feedback or review (Hovmand, 2014).

Group model building functions through two main mechanisms: the models it produces and the collective modelling process itself (Siokou, Morgan and Shiell, 2014). This approach promotes team learning, fosters consensus on systemic challenges, ensures multi-stakeholder commitment to action, and reveals power dynamics from which diverse perspectives emerge (Vennix, 1999). As a qualitative modelling method, participatory group model building is well-suited for exploratory research into systemic issues. It has proven effective in developing a shared understanding of a systemic problem, providing deeper insights into and agreement on points of intervention, and impacting both local and national policy shifts and interventions (Siokou, Morgan and Shiell, 2014; Rouwette, Vennix and Mullekom, 2002).

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Group Model Building for Kailo: Overview

Aim

In alignment with the objectives of the Deeper Discovery phase of Kailo, the group model building sessions aim to:

- Engage and collaborate with key stakeholders and actors related to the identified opportunity areas, encompassing young people, youth and community organisations, local commissioners, and other pivotal actors;
- Develop a more detailed understanding of the prioritised opportunity areas as delineated and experienced by young people and the wider local communities; and
- Acquire a more thorough understanding of the systemic behaviours influencing the identified opportunity areas and identifying leverage or intervention points for meaningful change.

Participants

Workshop participants consist of a carefully chosen group of 16–20 local system stakeholders, with a particular emphasis on reflecting the lived experience of young people (see Table 1). This emphasis on lived experience aids both the conceptualisation of the systemic challenge from the viewpoint of those encountering the challenge and enhances the validity of the session outputs (Kumar, et al, 2016). The

young people were engaged through connections formed during the Early Discovery phase of Kailo (Santana de Lima, forthcoming) and were chosen because of how the system impacts them and to represent underheard voices (Barbrook-Johnson and Penn, 2022). Recruitment depends on the local organisations, practitioners, and community members who have pre-existing relationships with young people with lived experience pertinent to the opportunity area and mental health. These local partners encourage and facilitate young people's participation throughout the engagements, which is vital for ensuring diverse representation and fostering meaningful involvement in the co-design process.

The co-design participants are compensated for their time in the sessions and have travel expenses covered in acknowledgment of their expertise and contribution to Deeper Discovery.

Each workshop builds on the insights from the previous one, progressing from defining the systemic challenge to pinpointing potential areas for change. Participants remain the same throughout the sessions to preserve a continuity of perspectives and guarantee a developing understanding of the matters at hand.

Setting

The workshops take place in community venues provided or secured through local community partners (such as youth clubs or community centres) in both Newham and Northern Devon. These venues are chosen because they are familiar to many of the young people participating in the sessions; their use signifies the ongoing commitment of local partners and, practically, ensures they can be consistently available for sessions. Community partners chosen to host the workshop sessions are also included in the development and facilitation of the workshops to offer additional familiarity and continuity between workshop sessions.

Facilitation team

The facilitation team primarily consists of individuals involved in leading the entire 'Deeper Discovery and Co-Design' phase of Kailo (workstream 1). This allows the team to leverage existing relationships established within the local area and among the workshop participants, and aids in advancing the co-design process by integrating insights from the GMB workshop sessions. Regular meetings with the lead facilitators, researchers, and system experts across the local areas are organised to exchange learnings across sites throughout the implementation phase. Additionally, a member of the Kailo evaluation team participates in each workshop session to contribute to the formative evaluation of the Kailo framework (Hobbs et al, 2023). This evaluation team member is not part of the facilitation team.

Prior to the GMB workshops, the facilitation team receives training in core concepts of systems thinking and group model building. This equips the team to fulfil their roles within the workshop sessions. The core modeller facilitators also develop facilitation guides adapted from Scriptapedia to support the choreography of each session (Hovmand et al, 2012).

During the workshops, the facilitation team assumes different roles to ensure the smooth execution of the process (see Table 2). These roles, adapted from the open-source online resource, Scriptapedia (Hovmand,

et al., 2012), may include but are not limited to:

- Lead Facilitator: Guides the process, ensuring all participants are engaged and the objectives are met.
- Recorder/Note-Taker: Documents the proceedings and key insights from the workshops.
- - Modeller: Creates a visual representation of the discussions in real-time, helping to clarify and connect ideas.
- Timekeeper: Ensures the workshop stays on schedule.
- Gatekeeper: Ensures all voices are heard and that no one person or group dominates the conversation.

By incorporating these various roles, Kailo aims to ensure the workshops are productive, inclusive, and focused, allowing for effective exploration of the systemic drivers of local opportunity areas / priorities.

Table 1
facilitation team roles and responsibilities.

Role	Tasks
Meeting Convenor and Closer (site co-lead)	Primarily responsible for initiating the session, welcoming participants to the exercise, ensuring that participants comprehend the purpose of the exercise within the context of their organisation or community, and introducing the facilitators. This individual will also conclude the session and express gratitude to participants for their time. This is someone who already maintains an established relationship with the group (such as the Kailo site lead for each local area).
Community Facilitator(s)	The community facilitator's main responsibility is to utilise their social capital to assist the community in collaborating with the modeller. facilitator(s). This individual is well-acquainted with the local understanding of the problem being modelled and is familiar with community norms. The facilitator is equipped with basics on group facilitation and some exposure to system dynamics through the planning process and training session or workshop. For the Kailo project, this will likely involve young researcher(s) who will be recruited as part of the wider research team before the formation of the small circle. This young individual will be from the local area and might have lived experience with the opportunity areas discussed. Where feasible, the Kailo project will also involve a community partner as part of the facilitation team.
Modeller Facilitator	Bears the main responsibility for system dynamics modelling and group model building process. This individual is skilled in systems thinking/system dynamics modelling with expertise in instructing and guiding groups in the application of community-based system dynamics. The person will also have experience in facilitating groups and leading group model building sessions. The modeller facilitator(s) is also tasked with introducing the rest of the facilitation team to the work—including basic training on system methods employed for each session. They may also utilise outputs from the group session to design or digitise learning (such as by converting handwritten causal loop diagrams into digital formats using Stella Architect modelling software). This can involve refining causal mechanisms to reflect the behaviour described during the sessions, to be shared back with the group.
Production Coordinator/note taker	The production coordinator's main responsibility is to ensure that the information gathered during the exercises, including diagrams, notes, electronic versions of diagrams, etc., are collected, appropriately archived, and made accessible. This involves noting major themes, points of discussion, etc., that might be overlooked by the modellers.

Considerations

Given the variety of opportunity areas, Kailo facilitation team experience, and differences in local contexts, some variation in participants and the facilitation team roles is anticipated. A degree of flexibility and adaptability will be essential for operating within a highly participatory and community-focused setting. Additionally, working with young people will necessitate extra considerations and potential adaptations to

ensure proper safeguarding measures are implemented. Where such adaptations may occur, the Kailo team will aim to prioritise firstly the safeguarding of young people and secondly achieving the core objectives of Deeper Discovery and Co-Design outlined above.

Engagement Design

The group model building sessions unfold over four workshops with the co-design groups in community venues. The workshops are scheduled for two to three hours on weekday evenings to accommodate the schedules of young people engaged in college or work.

Each engagement includes an introduction to the session, followed by a series of activities introduced through plenary input and then undertaken in small, facilitated groups.

Sessions and Activities

There are four sessions, comprising one preparation session and three GMB sessions, which involve systems activities and the attendance of the modeller (see Table 3). To optimise time in the sessions, one group model building activity—hopes and fears—is conducted in the preparatory small circle session before the main sessions start. This provides participants with the chance to express their initial visions for systemic change and any concerns that might need addressing in the sessions (Luna-Reyes et al, 2006).

The workshops are structured to build upon one another, following a structured collaborative process that leads participants through the steps necessary to develop causal loop diagrams (CLDs) (Hovmand, 2014) and pinpoint leverage points for systemic change (Savona, et al, 2021). Between workshops, the facilitation team led by the modeller synthesises and examines some of the insights from the previous workshop. This work is then shared at the start of the subsequent workshop, and the outputs are distributed around the room to be expanded upon with the new activities.

See appendix for detailed facilitation guides.

Table 2
An overview of the systems sessions' aims and activities.

Session	Aims	Activities
Prep Session	Fosters relationship development, establishes a grounding in the vision for change, and surfaces any concerns that may need addressing in GMB sessions.	Hopes and Fears (Luna-Reyes et al, 2006)
(1) Co-Defining the Opportunity Area	Develops an understanding of the historical behaviour and systemic contributors to the specific opportunity areas	Graphs over time (Andersen, D. F. and Richardson, G. P., 1997) Variable Elicitation (Luna-Reyes et al, 2006) Connection Circles (Ford, 2019)
(2) Exploring connections	Identifies and explores the connections within the system to uncover the underlying behavioural mechanisms driving the "opportunity area" for change. Surfaces and negotiates various mental models from the different stakeholder groups (including young people, community organisations, and academic researchers).	Causal Loop Diagrams (Hovmand, P. S. and Kraus, A., 2013)
(3) Identify leverage points and action areas for systemic change	Investigates the connection between existing resources within the system and impact areas to feed into co-designing local interventions with key system stakeholders.	Places to intervene (Meadows, 1999) Action Ideas (Meadows, 1999)
Participatory Group Model Building Tools		

Participatory group model building tools are essential for facilitating the process of systems change work. Each tool serves a distinct purpose within the broader process.

Table 3
overview of participatory group model building scripts

Script name	Description	Output
Hopes and Fears	This affinity sorting exercise surfaces group expectations and aspirations regarding future changes. It establishes group expectations about the system change work and envisions what the change can resemble. This exercise is crucial for broadening and shifting underlying mental models about the systemic issue. (Luna-Reyes et al, 2006)	List of participants hopes and fears.
Trends over time	These are simple line graphs that illustrate the pattern of change for a specific variable or systemic issue over time. The graphs are useful for defining boundaries around the opportunity area, narrowing the scope, audience, and timeframe of an issue (Ford, 2019). Graphs over time are also beneficial for developing an understanding of a problem through a systemic lens. Complex, or systemic, issues are challenges that relate to every part of a system. These are often issues that are dynamic, include multiple stakeholders with different objectives, involve time delays between action and outcome, provoke unintended consequences, and have accumulations or a history of dependence (Farrell et al 2021). By considering how a problem has evolved in the past, workshop participants and key system stakeholders are better equipped to think about the factors that may have influenced that change.	Graphs of dynamic variable trends related to the opportunity area.
Variable Elicitation	This tool draws on insights from initial understandings about the systemic challenge at hand (Luna-Reyes et al, 2006). It provides a deeper understanding of the patterns observed in the graph over time activity. By identifying variables related to the systemic challenge and clustering observations into themes, it becomes easier to analyse, map, and utilise key insights. The themes identified in the variable elicitation exercise can then be built upon for subsequent system mapping activities as a "word bank".	Prioritised list of themes and variables related to the opportunity areas.
Connection Circles	Connection circles are a visual tool that can help to identify connections and directionality of relationships between variables endogenous to a system. A connection circle helps stakeholders to uncover some "causal relationships" and begin to consider how these connections create feedback relationships—when the effect of a causal impact comes back to influence the original cause of that effect (Ford, 2019).	Initial identification of causal relationships between variables related to the opportunity area.
Causal Loop Diagram	Causal loop diagrams (CLDs) are a method of conceptualising and diagramming feedback behaviours in a system to understand and articulate complex system behaviour. Critically, CLDs are a tool for surfacing, visualising, and exploring underlying mental models of stakeholders (Barbrook-Johnson and Penn, 2022). Through mapping CLDs, stakeholders are better positioned for identifying points of leverage—places where sustainable change can occur—within the system. They are also an important tool for consensus building and shifting mental models, through negotiating and engaging the perspectives of multiple stakeholders in the system (as defined by the makeup of participants within the workshop sessions).	Causal loop diagram(s) related to the opportunity area.

Script name	Description	Output
Places to intervene	An advantage of systems thinking and mapping is utilising an understanding of the structure of a system to consider what interventions, or leverage points, would have the greatest influence on systemic change. Defined by Donella Meadows, leverage points are the "places within a complex system where a small shift in one thing can produce big changes in everything" (Meadows, 1999). Placed within the context of local resourcing, the "places to intervene" activity challenges stakeholders to consider the types of interventions that may be utilised to create the changes they are seeking locally. This will build into a prioritisation exercise as part of "action ideas" identified below.	List of recommended places to intervene within the system related to the opportunity area(s).
Action Ideas	Action ideas is an activity aimed at identifying and prioritising actions after a systems map or model has been created. This is done through mapping intervention ideas onto a cross-sectional grid that ranges from "high impact" to "low impact" and "high resource" to "low resource". It is a way to translate learning from the insights gathered in the process thus far into action for systems change (Meadows, 1999).	Priotised list of action ideas related to the opportunity area(s).

As detailed in Tables 2 and 3, each workshop generates a variety of outputs from the activities. Any discussion from participants not captured through the activities is supplemented with facilitator notes. These outputs are then reviewed by the facilitation team, led by the modeller, between sessions using thematic analysis and system dynamics principles as follows:

- **Workshop 1**: Identifying key, connected variables and any emergent feedback loops.
- **Workshop 2**: Constructing causal loop diagrams, including identifying additional feedback loops, multi-loop structures, and potential leverage points.
- **Workshop 3**: Reviewing prioritised feedback loops in the integrated system map.

This is then presented back to the co-design groups for reflections and amendments, and subsequent analysis is carried out through the cumulative activities.

Analysis and integration are undertaken by the facilitation team using Miro, an online whiteboard and workshop tool (see Zellner et al, 2023; Zucca et al, 2023). Refined CLD outputs are designed using Stella Architect, a specialist system dynamics software (Hovmand, 2014).

A refined causal loop diagram with the identified and prioritised leverage points for each opportunity area is presented to the workshop participants and wider system stakeholders to further discussion and action planning. In this manner, the causal loop diagrams are intended to act as a visualisation of the lived experiences and mental models of the workshop participants that can be communicated outwardly to influence action related to addressing young people's mental health and wellbeing locally.

The prioritised action areas (in accordance with their leverage in the system) will be used as a guide for co-designing interventions within the small circle for the remaining sessions of the Deeper Discovery phase

(Santanta de Lima, et al, forthcoming). This process is intended to support developing interventions that are systemically informed and locally owned. This is a critical component to the Kailo framework for addressing the systemic problem of declining mental health and wellbeing for young people living in the United Kingdom (Newlove-Delgado et al, 2022; The Children's Society, 2020).

Adaptations

Given the evolving outcomes from each workshop, the imperative of safeguarding participants, and the innovative nature of the application, the protocol has already and it is anticipated that the it will continue to undergo responsive adaptations (Moore et al., 2021). As such, both the facilitation and research teams anticipated modifications to the workshop plan during its execution. These changes might included alterations to the scripts used in the GMB sessions, adjustments to the duration or sequencing of activities in line with time limitations, and seeking additional feedback from participants outside the GMB sessions. This latter step ensures that a broad spectrum of viewpoints is integrated into the model, enriching its depth and relevance.

To ensure that the fundamental mechanisms of group model building are preserved, and that the project's key outputs are realised, the facilitator team employ an analytical framework. This framework guides them in assessing whether the in-session adaptations maintain the core mechanisms. This assessment is grounded in theoretical insights derived from realist evaluation (Evans et al., 2021). Such a structured approach ensures that while the protocol remains flexible and adaptive, it doesn't deviate from its primary objectives or compromise the integrity of the group model building process. Every alteration made to the protocol will be meticulously documented, providing transparency and a clear trail for future reference and replication.

Evaluation

As part of the overarching Kailo framework, a developmental realist evaluation is conducted to support learning and improvement of the framework. This evaluation enables us to better understand how, why, and for whom Kailo functions as an initiative; the conditions necessary for place-based systems change to be achieved; and the outcomes prioritised in the process (Kennedy et al, forthcoming). This includes an assessment of the contributions of GMB to achieve the objectives of Kailo. The evaluation also considers the contribution of GMB within the entirety of the three phases of Kailo (Hobbs, et al., 2023). This allows for evaluation not only of the success of the individual components of each GMB session and how it works with other methods used within the Kailo framework, but also a consideration of the wider contribution of participatory GMB for improvements in adolescent mental health and changes in wider social determinants (Hobbs, et al, 2023).

Discussion

The application of group model building

This paper outlines the objectives and methods of a series of participatory group model building sessions within the Kailo programme. The aims – to engage with and collaborate alongside key stakeholders, to explore deeper into the social determinants of poor mental health, and to gain a comprehensive insight into systemic behaviours – align with the methods described earlier. Participants are selected to ensure commitment from essential local partners and to include a spectrum of viewpoints, especially those often overlooked.

The methods draw from established group model building scripts, leading to a series of outcomes that culminate in a theoretical model of drivers for the opportunity area, represented as a causal loop diagram. The chosen activities aim to bring forth voices that are underrepresented in existing literature, offering a broader and more detailed understanding of the issue. This protocol advances research and tools in the field of community-based system dynamics, acknowledging the value of a participatory approach to modelling complex systems (Freebairn et al., 2022).

Novelty of Approach and Justification (for writing a protocol)

This paper enhances the existing literature on group model building approaches by outlining their application in a novel context: focusing on social determinants of health and involving young people through group model building to shape co-designed local responses.

Furthermore, it presents a new approach to assessing the success of implementation by concentrating on the mechanisms through which group model building operates. This is informed by realist evaluation methodologies, which distinguish between what is essential when adapting interventions to a new context, what alterations are needed for that context, and what changes are permissible during delivery.

Measures of success core/flex

The participatory and evolving nature of this work necessitates adaptability to foster trust, psychological safety, and understanding amongst participants involved in the group model building sessions. Consequently, the core research team might adjust the protocol to cater to these emerging needs. To promote psychological safety, the individual support needs of participants will be assessed during one-on-one sessions prior to the group model building workshops. Such assessments might lead to necessary changes in the workshop protocol. Moreover, as the sessions will occur in two distinct settings (Newham and Northern Devon), additional adaptations might be needed to align with the capabilities of local resources and stakeholders. All changes to the research protocol will be meticulously documented and communicated in subsequent findings.

Given that group model building methods are often customised to a specific project or community, evaluating the success of a CBSD process presents challenges (Hovmand, 2014). This paper proposes using a realist evaluation framework, which highlights the importance of retaining mechanisms that contribute to successful implementation while allowing flexibility in tailoring the method to specific

contexts or in response to emerging needs (Evans et al., 2021). The key mechanisms include consensus building, commitment to action, and the exposure of power dynamics..

Limitations and risks

A key limitation of this method is that the causal loop diagrams and areas for intervention exploration do not fully represent the broader population. Consequently, the dynamics, interventions, and leverage points identified in one setting might not be relevant in others. While this can be seen as a limitation, it also highlights the strength of the approach, offering in-depth insights relevant to specific community contexts.

The intensive engagement required for the group model building process limits the number of participants who can attend the sessions. Moreover, the recruitment of these select participants heavily relies on local community partners and their existing relationships with young individuals and community venues. In this way, it's challenging for the group to truly reflect the diversity of the localities, potentially biasing the overall research findings (Savona, et al., 2021).

While community-based system dynamics prioritises training and empowering group model building participants, the technical nature of the activities and the conceptualisation of variables linked in feedback structures can deter engagement. This concentrates significant influence with the modeller, who has a deeper expertise in the language of causal loop diagrams and conceptual modelling (Barbrook-Johnson and Penn, 2022).

Additionally, system dynamics as a methodology operates on a core assumption that feedback mechanisms inherently outweigh even strong linear causal relationships (Barbrook-Johnson and Penn, 2022). This poses a risk that the models generated might overemphasise feedback structures at the expense of linear relationships. Moreover, CLDs developed through group model building are challenging to validate (ibid), even when compared to behaviour-over-time graphs created by the same group, given the difficulty in determining which feedback loop prevails at specific points in the map.

Conclusions

This paper introduces a participatory group model building approach aimed at understanding the systemic drivers of poor mental health among adolescents in Newham and Northern Devon. Drawing from existing literature on similar group model building sessions, it elaborates on the workshop designs and the activities to be employed, explaining how they align with the session's objectives. The outcomes of this process are designed to guide the co-creation of innovative local interventions that address the social determinants of adolescent mental health. By adopting a systemically informed perspective from community-based system dynamics, these interventions should target the fundamental drivers of the identified opportunity areas and aim to alter the underlying mental models of key stakeholders responsible for rolling out the devised interventions. Additionally, this paper enriches the literature by incorporating a framework from feasibility and implementation evaluation. This framework will scrutinise implementation

and adaptation based on the delivery of the session's core components, noting any modifications and their reasons.

Abbreviations

CBSD
community–based system dynamics
CLD
causal loop diagram
GMB
group model building
OA
opportunity areas

Declarations

Ethical approval and consent to participate

This study has been ethically approved by the University College London (UCL) Research Ethics Committee (REC), from the 24th March 2023 until 1st September 2024.

Project ID/Title: 18773/002: A system approach to improving adolescent mental health - Deeper Discovery and Co-design Phase.

Consent for publication

N/A

Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Competing Interests

The authors declare they have no competing interests.

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Authors Contributions

MK was the primary designer of the group model building protocol and was the main contributor in writing the manuscript. LF was the secondary designers of the group model building protocol and was a major contributor in writing the manuscript. ESDL provided oversight to the design of the overarching Kailo framework and contributed to writing the early discovery and background of the manuscript. KP was a primary designer of the deeper discovery framework and contributed to writing the deeper discovery methods and approach. TH is the research co-director of the Kailo programme one of the primary designers of the overarching Kailo framework. TH reviewed multiple iterations of the manuscript. EB provided consultation for the system dynamics theory underpinning the approach and reviewed multiple iterations of the manuscript. PF is the research co-director of the Kailo programme and provided multiple rounds of feedback in the development of the manuscript. All authors read and approved the final manuscript.

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References

1. Andersen, D. F., and Richardson, G. P. (1997). 'Scripts for group model building.' System Dynamics Review, 13(2), 107–129.
2. Barbrook-Johnson, P. and Penn, A. S. (2022). 'Causal Loop Diagrams.' In *Systems Mapping*, Barbrook-Johnson, P. and Penn, A. S. (eds.). Cham, CH: Palgrave Macmillan.
3. The Children's Society. (2020). *The Good Childhood Report 2020*. London: The Children's Society.
4. Compton, M.T. and Shim, R.S. (2015). 'The Social Determinants of Mental Health'. Clinical Synthesis. 13(4), 419–425.
5. Currie, D. J., Smith, C. and Jagals, P. (2018). 'The application of system dynamics modelling to environmental health decision-making and policy - a scoping review.' BMC Public Health, 18: 402.
6. Department for Health and Department for Education (2017). *Transforming Children and Young Peeple's Mental Health Provision: a Green Paper*. December
7. Dreier, L., Nabarro, D., Nelson, J. (2019). *Systems Leadership for Sustainable Development: Strategies for Achieving Systemic Change*. Harvard Kennedy School.
8. Evans R. E., Moore G., Movsisyan A., The ADAPT Panel, *et al.* (2021). 'How can we adapt complex population health interventions for new contexts? Progressing debates and research priorities.' Journal of Epidemiology and Community Health. 75:40–45.
9. Farrell, A., Hu, M., Evbuoma, E.I., Liem, W. and Ballard, E. (2021). *Characteristics of Complex Problems. Methods Brief Series 1.02: Systems Thinking Foundations*. St. Louis, MO: Social System Design Lab.

10. Finegood, DT. (2012). *The importance of systems thinking to address obesity*. Nestle Inst Workshop Ser. 73:123 – 37; discussion 139 – 41.
11. Freebairn L., Occhipinti J., Song Y.J.C., Skinner A., Lawson K., Lee G.Y., Hockey S.J., Huntley S. and Hickie I.B. (2022) 'Participatory Methods for Systems Modelling of Youth Mental Health: Implementation Protocol' JMIR Research Protocols, 11(2): e32988.
12. Ford, D. N. (2019) 'A system dynamics glossary.' System Dynamics Review, 35(4): 369–379.
13. Forrester, JW. (1992). Policies, decisions, and information sources for modeling. Eur J Oper Res.;59(1):42–63.
14. Foulkes, L. (2021). *Losing Our Minds: What Mental Illness Really Is - and What It Isn't*. New York, NY: St. Martin's Publishing Group.
15. Gunnell, D., Kidger, J. and Elvidge, H. (2018). 'Adolescent mental health in crisis.' *BMJ*, 361: k2608.
16. Hartas, D. (2021) The social context of adolescent mental health and wellbeing: parents, friends and social media, Research Papers in Education, 36:5, 542–560.
17. Hobbs, T. *et al*. (2023) *Kailo: a systemic approach to addressing the social determinants of young people's mental health and wellbeing at the local level*. Wellcome Open Research.
18. Hovmand, P. S. (2014) *Community Based System Dynamics*. New York, NY: Springer.
19. Hovmand, P. S. and Kraus, A. (2013). 'Creating Causal Loop Diagram from Connection Circles.' *Scriptapedia*. [web resource] https://en.wikibooks.org/wiki/Scriptapedia/Creating_Causal_Loop_Diagram_from_Connection_Circles (retrieved on 28/04/2023).
20. Hovmand, P. S., Andersen, D. F., Rouwette, E., Richardson, G. P., Rux, K., & Calhoun, A. (2012). Group model building "scripts" as a collaborative tool. Systems Research and Behavioral Science, *29*: 179–193.
21. Jagosh, J. (2019). 'Realist Synthesis for Public Health: Building an Ontologically Deep Understanding of How Programs Work, For Whom, and In Which Contexts'. Annual Review of Public Health. Vol. 40:361–372.
22. Kennedy, L., March, A., Harris J., Allen, K., Hanley Santos, G., Davies, K., Malhotra, T., Joshi, K., Hobbs, T., Fonagy, P., Pilling, S., Berry, V. (forthcoming) 'How does Kailo work to improve adolescent mental health? A developmental realist evaluation protocol.'
23. Langellier, B. A., Kuhlberg, J., Ballard, E. A., Slesinski, S. C., Stankov, I., Gouveia, N., Meisel, J. D.,. Kroker-Lobos, M. F., SarmientoO. L., Caiaffa, W. T., Diez Roux, A. V. and SALURBAL Group. (2019). 'Using community-based system dynamics modeling to understand the complex systems that influence health in cities: The SALURBAL study.' Health and Place. 60: 102215.
24. Luna-Reyes, L. F., Martinez-Moyano, I. J., Pardo, T. A., Cresswell, A. M., Andersen, D. F. and Richardson, G. P. (2006). 'Anatomy of a group model-building intervention: Building dynamic theory from case study research.' System Dynamics Review, 22(4): 291–320.
25. Kumar, P., Chalise, N., & Yadama, G. N. (2016). 'Dynamics of sustained use and abandonment of clean cooking systems: Study protocol for community-based system dynamics modeling.' International

Journal for Equity in Health. *15*(1), 70.

26. Marmot M., Allen J., Boyce T., Goldblatt P. and Morrison J. (2020). Health Equity in England: The Marmot Review 10 Years On. London: The Health Foundation.
27. Meadows, D. (1999). *Leverage points: places to intervene in a system*. Hartland, VT: The Sustainability Institute.
28. Moore G., Campbell M., Copeland L., Craig P., Movsisyan A., Hoddinott P. *et al*. (2021) 'Adapting interventions to new contexts—the ADAPT guidance.' *BMJ*. 374:n1679.
29. Newlove-Delgado T., Marcheselli F., Williams T., Mandalia D., Davis.J, McManus S., Savic M., Treloar W. and Ford T. (2022). *Mental Health of Children and Young People in England, 2022*. Leeds: NHS Digital.
30. Richter, D. and Dixon, J. (2022). 'Models of mental health problems: a quasisystematic review of theoretical approaches.' Journal of Mental Health, 1–11.
31. Reumers, L. and Bekker, M., Hilderink, H., Jansen, M., Helderman, J. K. and Ruwaard, D. (2022). 'Qualitative modelling of social determinants of health using group model building: the case of debt, poverty, and health.' *International Journal for Equity in Health*, 21(72).
32. Rouwette, E. A., Vennix, J. A., and Mullekom, T. V. (2002). 'Group model building effectiveness: a review of assessment studies.' System Dynamics Review, *18*(1): 5–45.
33. Santana de Lima, E., Rehill, N., Preece, C., Harris, J., Hobbs, T., Fonagy, P. (forthcoming). 'Codesigning strategies to support young people's mental health in Newham and Northern Devon'.
34. Saul, J.E., Willis, C.D., Bitz, J. *et al.* (2013) 'A time-responsive tool for informing policy making: rapid realist review'. Implementation Sci 8, 103.
35. Savona, N., Brown, A., Macauley, T., Aguiar, A., Hayward, J., Ayuandini, S., Habron, J., Grewal, N. K., Luszczynska, A., Mendes, S., Klepp, K. I., Rutter, H., Allender, S. and Knai, C. (2022). 'System mapping with adolescents: Using group model building to map the complexity of obesity.' Obesity Reviews, 24(S1): e13506.
36. Savona, N., Macauley, T., Aguiar, A., Banik, A., Boberska, M., Brock, J., Brown, A., Hayward, J., Holbæk, H., Rito, A. I., Mendes, S., Vaaheim, F., van Houten, M., Veltkamp, G., Allender, S., Rutter, H., & Knai, C. (2021). Identifying the views of adolescents in five European countries on the drivers of obesity using group model building. *European journal of public health*, *31*(2), 391–396.
37. Savona, N., Macauley, T., Aguiar, A., Banik, A., Boberska, M., Brock, J., Brown, J., Hayward, J., Holbæk, H., Rito, A. I., Mendes, S., Vaaheim, F., van Houten, M., Veltkamp, G., Allender, S., Rutter, H. and Knai, C. (2021). 'Identifying the views of adolescents in five European countries on the drivers of obesity using group model building.' European Journal of Public Health. *31*(2): 391–396.
38. Shamrova, D.P. and Cummings, C.E. (2017). 'Participatory action research (PAR) with children and youth: An integrative review of methodology and PAR outcomes for participants, organizations, and communities', Children and Youth Services Review, Volume 81, 400–412, ISSN 0190–7409, https://doi.org/10.1016/j.childyouth.2017.08.022.

39. Siokou C., Morgan R. and Shiell A. (2014) 'Group model building: a participatory approach to understanding and acting on systems.' Public Health Research and Practice. 25(1): e2511404.
40. Vennix JA. (1999). 'Group model-building: tackling messy problems.' System Dynamics Review, 15(4):379–401.
41. Vennix, J. A. M. (1996). *Group Model Building: Facilitating Team Learning Using System Dynamics*. Chichester: Wiley.
42. Vennix and Mullekom, 2002
43. Werner, K., St. Arnold, G., and Crea, T. M. (2021). 'Using a community-based system dynamics approach for understanding inclusion and wellbeing: A case study of special needs education in an eastern African refugee camp.' Conflict and Health. 15(1), 58.
44. Zellner, M., Massey, D., Rozhkov, A. and Murphy, J.T. 'Exploring the Barriers to and Potential for Sustainable Transitions in Urban–Rural Systems through Participatory Causal Loop Diagramming of the Food–Energy–Water Nexus.' *Land*. 12(3): 551.
45. Zucca, C., McCrorie, P., Johnstone, A., Chambers, S., Chng, N. R., Traynor, O. and Martin, A. 'Outdoor nature-based play in early learning and childcare centres: Identifying the determinants of implementation using causal loop diagrams and social network analysis.' Health and Place. 79: 102955.

Figures

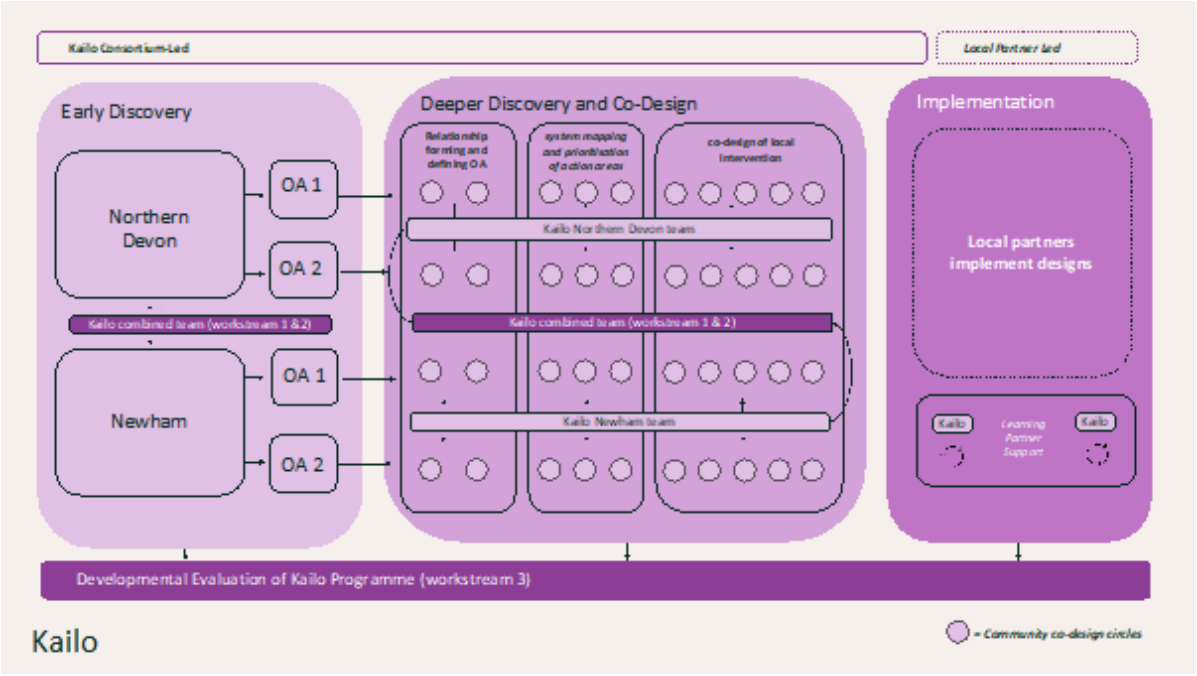

Figure 1

The Kailo Implementation framework

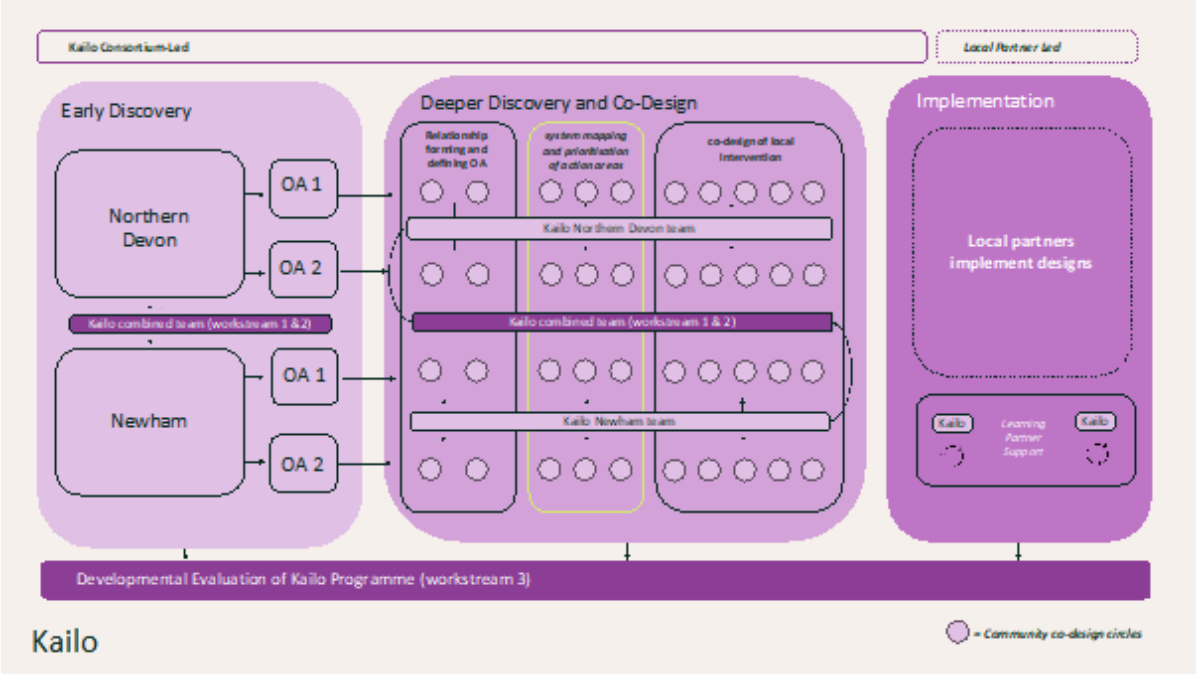

Figure 2

Group Model Building within Kailo Process

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