Case Study

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Making it transparent: A worked example of articulating programme theory for a digital health application using Intervention Mapping

Tamika A. Marcos[1,2], Rik Crutzen[2,3], Veronika Leitner[2], Jan D. Smeddinck[2], Eva-Maria Strumegger[2], Daniela Wurhofer[2] and Stefan T. Kulnik[2]

Abstract

Objective: Digital health interventions for behaviour change are usually complex interventions, and intervention developers should 'articulate programme theory', that is, they should offer detailed descriptions of individual intervention components and their proposed mechanisms of action. However, such detailed descriptions often remain lacking. The objective of this work was to provide a conceptual case study with an applied example of 'articulating programme theory' for a newly developed digital health intervention.

Methods: Intervention Mapping methodology was applied to arrive at a detailed description of programme theory for a newly developed digital health intervention that aims to support cardiac rehabilitation patients in establishing heart-healthy physical activity habits. Based on a Predisposing, Reinforcing, and Enabling Constructs in Educational Diagnosis and Evaluation (PRECEDE) logic model of the problem, a logic model of change was developed. The proposed mechanisms of action were visualised in an acyclic behaviour change diagram.

Results: Programme theory for this digital health intervention includes 4 sub-behaviours of the main target behaviour (i.e. habitual heart-healthy physical activity), 8 personal determinants and 12 change objectives (i.e. changes needed at the determinant level to achieve the sub-behaviours). These are linked to 12 distinct features of the digital health intervention and 12 underlying behaviour change methods.

Conclusions: This case study offers a worked example of articulating programme theory for a digital health intervention using Intervention Mapping. Intervention developers and researchers may draw on this example to replicate the method, or to reflect on most suitable approaches for their own behaviour change interventions.

Keywords

Behavior and behavior mechanisms, Cardiac rehabilitation, Cardiovascular diseases, Digital health, Health promotion, Public health, Secondary prevention, Telemedicine

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Introduction

Ischaemic heart disease is a major cause of mortality and morbidity, accounting for 16% of global deaths[1,2] and representing the most frequent cause for disability-adjusted life years in age groups 50 years and older.[3] Regular heart-healthy physical activity (PA) is a crucial behaviour for the primary and secondary prevention of ischaemic heart disease and other cardiovascular diseases (CVDs). For example, a recent study demonstrated that every

[1]Department of Work and Social Psychology, Maastricht University, Maastricht, The Netherlands
[2]Ludwig Boltzmann Institute for Digital Health and Prevention, Salzburg, Austria
[3]Department of Health Promotion, Care and Public Health Research Institute, Maastricht University, Maastricht, The Netherlands

Corresponding author:
Stefan T. Kulnik, Ludwig Boltzmann Institute for Digital Health and Prevention, Lindhofstrasse 22, 5020 Salzburg, Austria.
Email: tino.kulnik@dhp.lbg.ac.at

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increase in PA by 500 metabolic equivalent of task minutes per week results in a 14% and 7% risk reduction in mortality in the secondary and primary prevention of CVD, respectively.[4] Therefore, exercise-based cardiac rehabilitation is a central component of secondary CVD prevention. Exercise-based cardiac rehabilitation is a multi-disciplinary programme targeting multi-factorial cardiovascular risk factors with a specific focus on physical inactivity.[5] As a general recommendation, patients with CVD should carry out aerobic PA on at least 3 days per week at moderate to high intensity, and muscle strength training twice per week. PA should provide an energy expenditure of 1000 to 2000kcal/week.[6]

Importantly, patients with CVD should establish ongoing (and life-long) PA habits, to reduce their risk of recurring cardiovascular events and death, and to improve their physical functioning and quality of life. However, this remains a major challenge. In the 2017 EUROASPIRE V survey of 8261 patients with CVD who were interviewed at median 1.1 years following an acute coronary event, only 34% of patients reported performing regular PA (i.e. $\geq$ 30 min on average 5 times a week); only 35% reported performing planned PA to increase physical fitness; 42% of patients did not perform regular PA and had no intention to do so in the next 6 months; and 46% of patients did not recall having received personal advice on PA.[7] Moreover, a systematic review of 26 randomised controlled trials (8593 patients) showed that completion of a cardiac rehabilitation programme did not result in a clear positive impact on sustained heart-healthy PA behaviour compared with patients who did not participate in such a programme.[8] Thus, there is an urgent need to develop effective support for CVD patients' behaviour change and habit formation for regular heart-healthy PA.

Digital health interventions have the potential to offer suitable solutions that contribute to addressing this problem. For example, in a recent systematic review of 14 randomised controlled trials (1497 patients), digital health interventions showed positive effects for promoting PA following completion of a cardiac rehabilitation programme (pooled effect size assessed as standardised mean difference (SMD) = 0.35; 95% confidence interval (CI) 0.02–0.70; p = 0.04).[9] Moreover, several systematic reviews support patient safety of digital health interventions in cardiac rehabilitation, for example the studies by Wongvibulsin et al.[10]and Antoniou et al.[11] However, it is notable that digital health interventions for CVD secondary prevention are typically very heterogeneous – including building blocks such as websites, text messages, wearable sensing devices, smartphone apps and virtual reality programmes – and little information is available on their underlying programme theory; that is, what intervention components are expected to lead to which changes.[9] This runs contrary to methodological recommendations and reporting guidelines for behaviour change interventions, such as the United Kingdom Medical Research Council's framework for developing and evaluating complex interventions,[12] the Template for Intervention Description and Replication (TIDieR) checklist,[13] the Workgroup for Intervention Development and Evaluation Research (WIDER)[14] and others.[15,16]

Digital health interventions that aim to support behaviour change are often complex interventions, in the sense that they may combine a number of components and target a number of behaviours.[12] Developers of complex interventions should 'articulate programme theory'[17]; that is, they should describe all individual intervention components ('active ingredients') and their proposed mechanisms of action, and they should make transparent the rationale(s) for intervention components and proposed mechanisms of action, including underpinning theories and/or empirical evidence. Such an explicit description of the complex intervention and its (proposed) workings can be helpful to communicate the importance and function of intervention components to others,[13] and to select appropriate evaluation designs that capture the relevant processes and outcomes.[12] At a wider scientific and societal level, detailed intervention descriptions support transparency, reproducibility and the reduction of waste in research.[18,19] However, despite available guidance, the articulation of programme theory for complex behaviour change interventions remains lacking.[20,21] It may be presumed that the reasons for this include lack of time and resources, lack of awareness, and lack of methodological knowledge, but there is little data to explain why this problem persists. However, one contributing factor may be the limited availability of applied ('worked') examples that demonstrate how this can be realised in practice. Such applied examples can arguably raise awareness, offer methodological guidance, and possibly reduce the cost and effort required for intervention descriptions, by providing practical examples to relate to.

In this article, we therefore describe a conceptual case study with an applied example of 'articulating programme theory' for our newly developed digital health intervention **aktiv**plan. **aktiv**plan is a web-based application designed to support cardiac rehabilitation patients in establishing regular heart-healthy PA behaviour following completion of a cardiac rehabilitation programme. In our example, we draw on Intervention Mapping (IM), an established approach for the systematic development, evaluation and implementation of behaviour change interventions[22] to make transparent the (proposed) active ingredients and mechanisms of action underlying **aktiv**plan. We hope that this conceptual case study and worked example will raise awareness of the importance of methodologies for articulating programme theory, such as IM, and will support developers of complex behaviour change interventions in applying similar approaches to developing and reporting their own work. This work did not involve any recruitment or data collection from research participants or patients and therefore did not require participant/patient consent.

Methods

We present a conceptual (descriptive) case study with an applied example, describing the retrospective application of IM to articulate programme theory for an existing digital health intervention. This work was conducted in spring 2023 at the Ludwig Boltzmann Institute for Digital Health and Prevention in Salzburg, Austria.

The aktivplan digital health intervention

The **aktiv**plan digital health intervention was developed by our team at the Ludwig Boltzmann Institute for Digital Health and Prevention in Salzburg, Austria, to address the abovementioned challenge of establishing regular heart-healthy PA habits in patients with CVD following completion of a cardiac rehabilitation programme. Starting in summer 2020, we applied a user-centred design process, working with cardiac patients and involving experts from software design, human computer interaction, cardiac rehabilitation and psychology.[23]The development process was iterative and included a comprehensive initial needs analysis and repeated rounds of formative user testing and heuristic evaluation, to arrive at a mature prototype which is currently under evaluation in a clinical pilot study (https://www.clinicaltrials.gov/study/NCT06025526). For illustration, a previous user study with seven cardiac rehabilitation patients[23] demonstrated average (satisfactory) usability of **aktiv**plan according to the System Usability Scale[24] (mean 65.4, SD 17.3, possible score range 0–100). In the dimensions of the Unified Theory of Acceptance and Use of Technology questionnaire,[25] **aktiv**plan achieved mean scores of 2.6 (SD 0.6) for performance expectancy, 3.5 (SD 0.3) for effort expectancy, 3.5 (SD 0.7) for facilitating condition, 2.9 (0.7) for behavioural intention to use, and 1.4 (SD 0.5) for technology anxiety (possible score range 1–5), demonstrating overall fair to good usability and acceptability of the tool.

A digital planning calendar for regular heart-healthy PA and exercise is a central component of the **aktiv**plan digital health intervention. Cardiac rehabilitation healthcare professionals (HCPs) access this planning calendar via the **aktiv**plan website (view for HCPs, Figures 1(a) and 1(b).

In clinical practice, the **aktiv**plan planning calendar is introduced to the cardiac rehabilitation patient by an HCP trained in exercise prescription for cardiac rehabilitation (e.g. an exercise physiologist, sports scientist or physiotherapist) towards the end of a cardiac rehabilitation programme. During a PA counselling session lasting approximately one hour, the HCP and patient discuss and devise a PA plan for the patient to carry out during the weeks following completion of the cardiac rehabilitation programme. During this counselling session, the HCP applies a participatory communication style that supports principles of shared decision making.[23] For this, the HCP can use an optional integrated conversation guide that provides prompts and example phrases for shared decision making. The HCP enters the agreed-upon PA plan into the planning calendar via the **aktiv**plan website (view for HCPs, Figures 1(a) and 1(b), assists the patient in setting up the **aktiv**plan app on their personal device, and talks the patient through the features of the app.

Patients can view the planning calendar via the **aktiv**plan app on their smartphone, tablet or computer (patient view, Figure 2(a)). They can check-off planned physical activities and exercise sessions to indicate that these have been completed. When checking off completed activities, patients indicate their rate of perceived exertion for the activity (Borg rating of perceived exertion scale, Figure 2(b)). The patient can also enter additional unplanned physical activities and exercise sessions. Via the **aktiv**plan app, the patient can access short videos with exercise instructions (Figure 2(c)) and export a report documenting all performed physical activities and exercise sessions. This report can be used for the patient's own feedback and reflexion, or it can be handed to the HCP for their information and documentation. The HCP can access the planning calendars of all patients under their care via the **aktiv**plan website and can monitor patients' adherence with the agreed-upon PA plan on a traffic light display (Figure 1(a)).

Further functions of the **aktiv**plan digital health intervention are automated messages to the patient, delivering reminders of planned physical activities and exercise sessions, motivating and humorous messages, and evidence-based information (Figure 2(d)); personalised goal setting, with the patient's individual timed goals displayed in the **aktiv**plan app (Figure 2(a)); and the possibility for the HCP to message the patient via the app (push notification), to give the patient feedback on their performance and to make contact, for example if adherence is low. At follow-up appointments with the HCP, the patient can reflect on their documented physical activities, exercise sessions and achievements, and discuss the further plan, which can then again be added to the **aktiv**plan planning calendar by the HCP.

Intervention Mapping

IM is a six-stepped approach (Figure 3) for the systematic development, implementation and evaluation of health promotion programmes.[26] The six steps are each broken up into smaller tasks. Upon completion, these smaller tasks provide a basis from which the subsequent step is started.

The first step of IM starts by forming a planning group that consists of the programme planners, community members and programme beneficiaries among others.

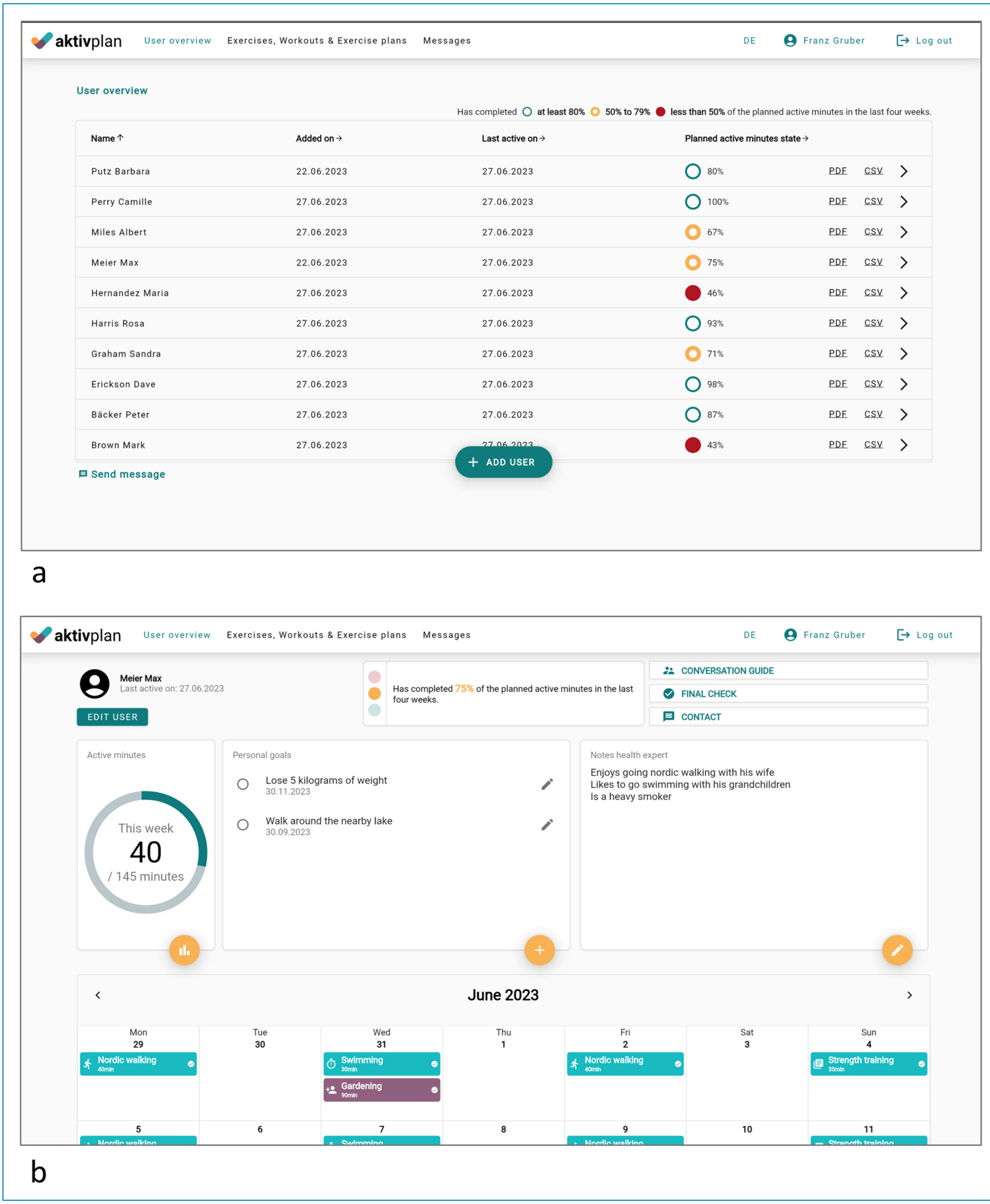

Figure 1. The healthcare professional's view of the **aktiv**plan application: (a) overview of the healthcare professional's caseload, with traffic light display indicating patient adherence; and (b) physical activity planning page with calendar view for individual patient.

This mirrors the group of contributors in a user-centred design process, for example, patients and experts from different disciplines in our development of the **aktiv**plan digital health intervention. A diverse planning group ensures the problem is looked at from multiple stakeholder perspectives, which can enhance the effectiveness of the intervention. Hereafter, a needs assessment is conducted using the PRECEDE (Predisposing, Reinforcing, and

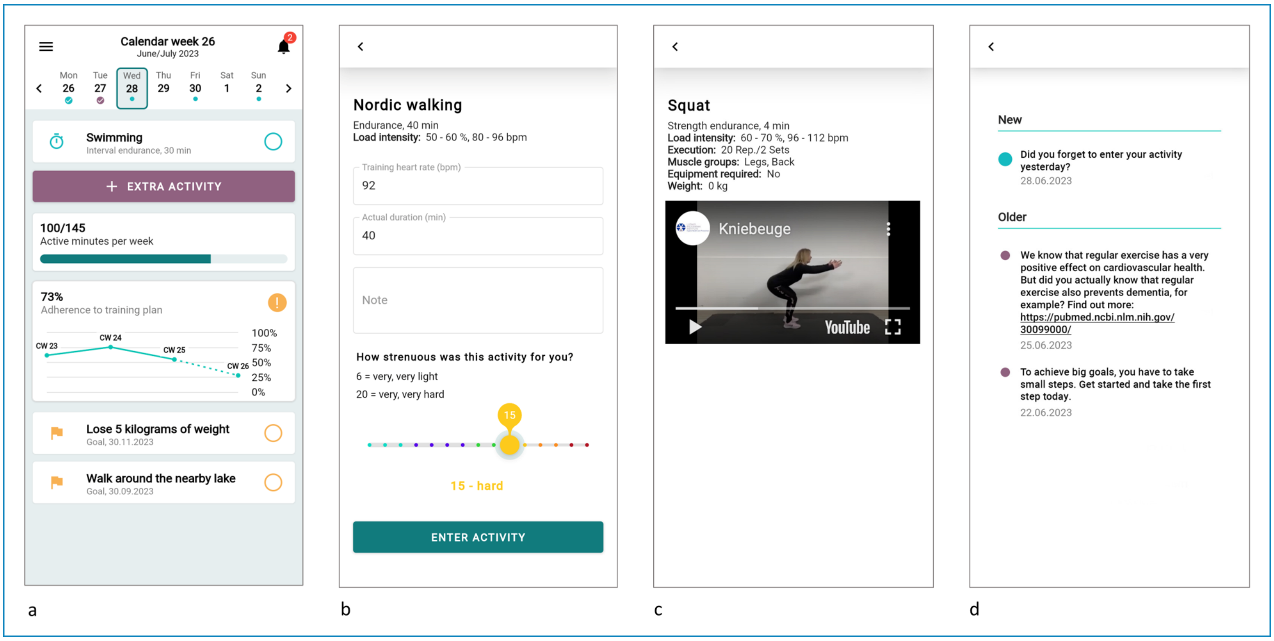

Figure 2. The patient's view of the **aktiv**plan application: (a) physical activity plan; (b) confirming completion of a planned activity; (c) short video with exercise instruction; and (d) automated messages.

Enabling Constructs in Educational Diagnosis and Evaluation) model developed by Green at al.[27] The context for the intervention is described, and programme goals are established. The final product of the first step of IM is a logic model of the problem.

The second step comprises of stating behavioural and environmental outcomes, specifying performance objectives (POs) and change objectives (COs), selecting determinants for the behavioural and environmental outcomes, and constructing matrices of change. POs are the sub-behaviours necessary to perform a desired target behaviour, and COs are specific changes needed at the determinant level to achieve those sub-behaviours. These COs result from crossing POs with their related personal determinants. The final product of the second step is a logic model of change.

The third step consists of generating programme themes, components, scope and sequence. Matching the previously generated COs with theory-based and evidence-based behaviour change methods and selecting or designing practical applications to deliver the change methods conclude the third step.

The fourth step starts off by refining programme structure and organisation, whereafter plans for programme materials are drafted. Programme messages, materials and protocols are developed in collaboration with designers. The final task of the fourth step is to pre-test, refine and produce programme material. After the fourth step, the development of the intervention programme is finalised.

Step 5 relates to the implementation of the programme. It is a repetition of the first three steps of IM and starts off by identifying programme adopters, implementers and maintainers, for whom outcomes, POs and COs are developed in terms of programme use. This step is finalised by constructing matrices of change and designing implementation interventions.

The sixth and final step of IM concerns the evaluation of the programme. The evaluation is split into effect and process evaluation. First, questions in regard to the evaluation are formed. Then, indicators and measures for assessment are developed, the evaluation design is specified and finally, the evaluation plan is completed.

Within each IM step, many planning questions will be raised. These are answered using the core processes of IM. Core processes are a helpful and systematic way to answer planning questions during intervention development, supporting a complete understanding of the problem, which is imperative for finding effective and appropriate solutions.[26,28] The six core processes need to be conducted in order and are as follows: (1) posing questions, (2) brainstorming potential answers, (3) reviewing findings from empirical literature, (4) reviewing theories, (5) assessing and addressing needs for new data, and (6) developing a working list of answers.[26]

Applying Intervention Mapping to articulate programme theory for aktivplan

The six steps of IM as described in section *Intervention Mapping* lay out the entire sequence of developing and evaluating a health promotion programme (or behaviour change intervention) anew, from initial conceptualisation to intervention development, implementation planning,

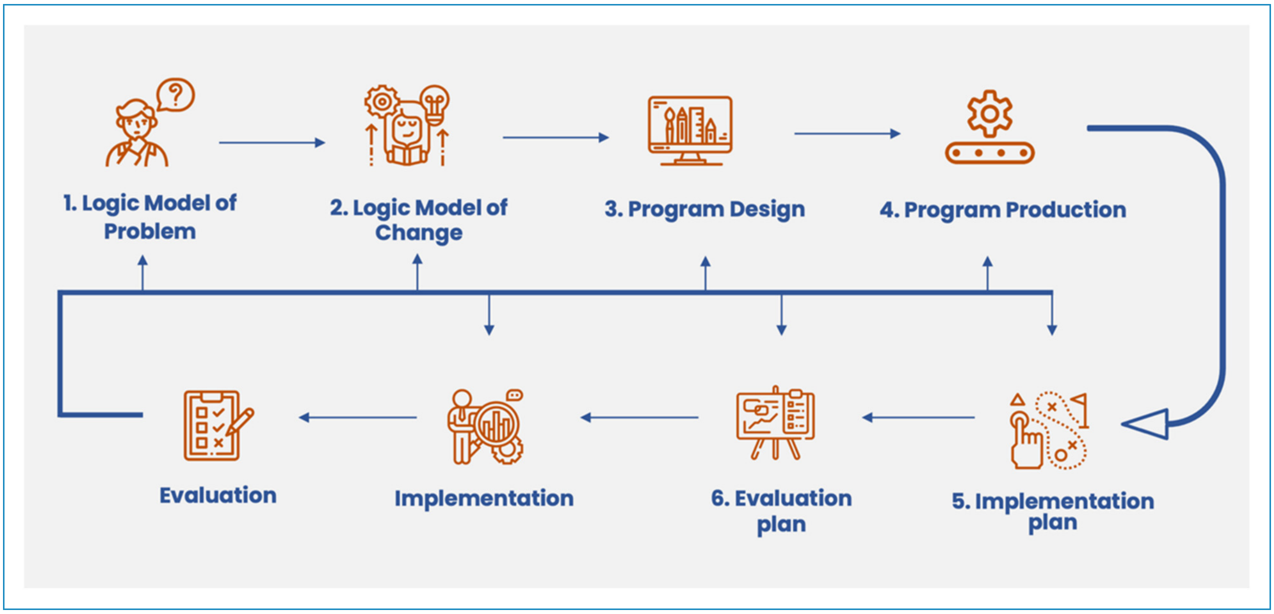

Figure 3. The six steps of Intervention Mapping.

and formative and summative evaluation. Orienting ourselves on this IM sequence, our **aktiv**plan digital health intervention could be positioned at the completion of step 4 – because the intervention has been fully developed, pretested and refined following a user-centred co-design methodology – but having 'skipped' the systematic conceptualisation and description of its underlying theory and evidence that would usually be conducted in IM steps 1, 2 and 3. We therefore set out to retrace these missing steps and 'retro-fit' the programme theory for **aktiv**plan, using the usual IM steps and core processes.

First, the target population and main behavioural outcome were defined. Because user-centred design methodology includes a thorough needs assessment and close involvement of intended users (cardiac patients and rehabilitation professionals), we had rich data to inform the PRECEDE model and to devise the logic model of the problem (IM step 1).

Before moving on to IM step 2, we sought to ascertain all psychological determinants addressed in **aktiv**plan. For this, we defined all distinct **aktiv**plan features (which correspond to practical applications in IM) and mapped these to behaviour change methods, related personal determinants and linked behaviour change theories.[26] This linking of intervention features with theory-based and evidence-based behaviour change methods usually takes place in IM step 3, 'working forwards' by devising a new intervention based on the logic model of change that was defined in IM step 2. In our case, however, it was more suitable at this point to 'work backwards' from our existing intervention, to most efficiently contextualise the programme features that have been incorporated in **aktiv**plan.

We then completed the tasks of IM step 2. Based on the different **aktiv**plan features, the main behavioural outcome, and known associations between certain behaviours, determinants and the main behavioural outcome, we defined the POs, determinants and COs, and we constructed a matrix (logic model) of change.

Lastly, we combined all these aspects in an acyclic behaviour change diagram (ABCD) matrix. ABCD matrices assist in more clear and transparent communication of processes in intervention development.[29] The ABCD matrix provides a complete overview and enables the creation of a graphical representation of the 'logic chain' between any single **aktiv**plan feature and its underlying theory and evidence in relation to the desired PO(s) and the main behavioural outcome.

Results

The logic model of the problem

Figure 4 shows the logic model of the problem which the **aktiv**plan digital health intervention intends to address. This specifies the target (at-risk) population, defined as 'patients who had an acute cardiac event and who are attending a cardiac rehabilitation programme'. To present a holistic picture of the problem, we have also included two environmental agents in our logic model of the problem, that is, HCPs in cardiac rehabilitation and people in the patient's interpersonal environment. (Environmental agents are individuals who through their own behaviour can influence the behaviour of the target population, at the level of interpersonal interaction with the target population, or at an organisational, community

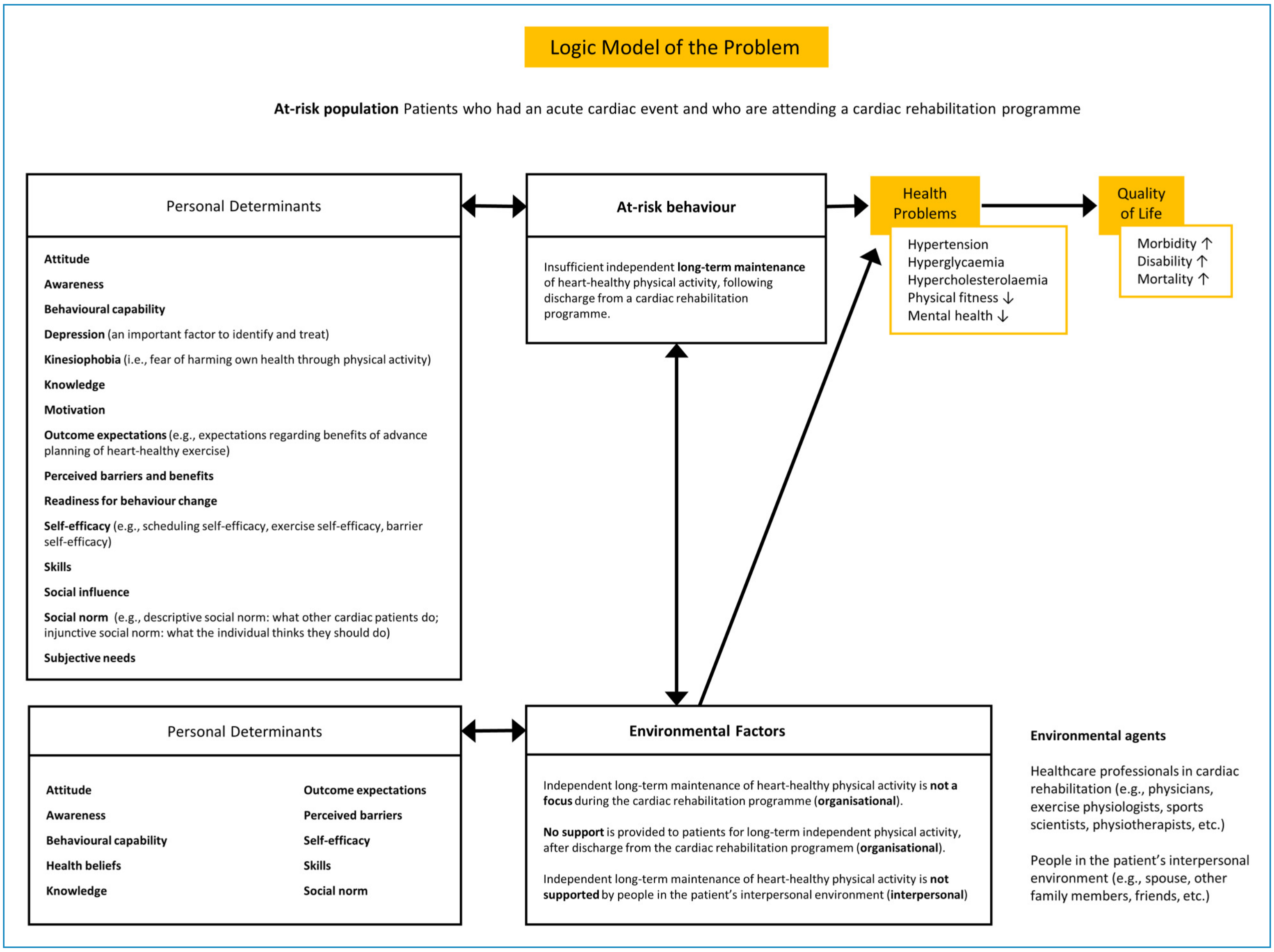

Figure 4. Logic model of the problem.

or societal level. While there are many environmental agents who can impact our defined target population, we do not include environmental agents in the following, as they are not the focus of the **aktiv**plan intervention.)

Based on the logic model of the problem, we define the main programme goal (the main behavioural outcome) as 'following discharge from a cardiac rehabilitation programme, cardiac patients independently and regularly carry out the recommended amount of heart-healthy PA over months and years'.

aktivplan features mapped to behaviour change methods

The **aktiv**plan application incorporates several behaviour change techniques to achieve the desired behavioural outcome. Table 1 provides an overview of all **aktiv**plan features, the behaviour change methods these features employ, the related determinants, and underlying psychological theories.

As one important aspect of the application, **aktiv**plan facilitates a collaborative dialogue between HCPs and patients through shared decision making. This is achieved by including a 'shared decision making conversation guide' in the **aktiv**plan website (HCP's view) which serves as a reminder for HCPs to articulate key aspects of shared decision making during the PA counselling session (e.g. stating that the patient *should* express and decide their preferences regarding the PA plan, etc.). Shared decision making empowers the patient to actively include and combine their personal goals and preferences with the HCP's professional expertise when discussing the PA plan.[6, 23, 57] Moreover, shared decision making facilitates desired behaviour change through goal setting and public commitment, in addition to increasing motivation of the patient.[23,58] Accordingly, the recent European Association of Preventive Cardiology position paper on exercise prescription in cardiovascular rehabilitation explicitly recommends to incorporate shared decision making when devising PA plans with patients with CVD.[6]

Within this collaborative relationship between HCP and patient, **aktiv**plan leverages the reputable authority of HCPs to support and motivate the patient. The patient gains validation and support from a trustworthy

Table 1. aktivplan features mapped to behaviour change methods, determinants and theories.

Feature	Behaviour change method	Related determinant	Related theories
Physical activity planner	Shared decision making	Motivation[30] Behavioural capability[31]	• Social Cognitive Theory • Theory of Planned Behaviour • Self-Determination Theory • Health Belief Model[32–35]
	Tailoring	Self-efficacy[31, 36, 37]	• Trans-Theoretical Model • Precaution Adoption Process Model • Protection Motivation Theory • Communication-Persuasion Matrix[38–41]
Goal setting	Goal setting	Motivation[30] Skills[44] Self-efficacy[30, 45, 46]	• Goal Setting Theory • Theories of Self-Regulation[42, 43]
Adherence visualisation	Self-monitoring	Self-efficacy[45] Skills[44]	• Theories of Self-Regulation[43]
Active minutes			
Perceived exertion rating			
Messages with evidence-based information	Arguments	Outcome expectations[47]	• Communication-Persuasion Matrix • Elaboration Likelihood Model[41, 48]
Reminder messages	Feedback	Awareness[42, 49, 50] Motivation[30]	• Trans-Theoretical Model • Theories of Learning • Goal Setting Theory • Social Cognitive Theory[42, 49–52]
Adherence monitoring by HCP	Monitoring by others	Motivation[30]	• Self-Determination Theory[34]
Personal messages from HCP to patient	Feedback	Knowledge[53] Self-efficacy[30, 45, 46]	• Theories of Learning • Goal Setting Theory • Social Cognitive Theory[42, 49, 50]
	Reinforcement	Motivation[30] Self-efficacy[30, 45, 46]	• Theories of Learning • Social Cognitive Theory[49, 50, 54]
Exercise videos	Modelling	Self-efficacy[30, 36, 45, 46]	• Goal setting Theory • Theories of Self-Regulation[49, 50]
Timing of implementation	Teachable moment	Readiness for behaviour change*	• Trans-Theoretical Model[52]
Physical activity counselling session	Guided practice	Skills[55] Self-efficacy[43]	• Social Cognitive Theory • Theories of Self-Regulation[43, 50]
	Active learning	Skills[55]	• Social Cognitive Theory • Elaboration Likelihood Model[50, 56]

*Of note, the intervention does not aim to change readiness for behaviour change, but rather the intervention is purposively timed to coincide with a moment when patients are likely to be receptive to behaviour change.
HCP, healthcare professional.

source by including professional expertise and guidance within the app, which enhances the desired behaviour change.[59]

Additionally, the **aktiv**plan application puts emphasis on tailoring the PA plan to the individual patient. A lack of tailoring has been shown to have a negative impact on cardiac rehabilitation attendance.[60] Furthermore, the possibility to tailor or individualise PA within interventions has been found to facilitate engagement in PA among cardiac patients.[61] In the same systematic review, the authors concluded that tailoring also increased the patients' self-efficacy in managing bothersome symptoms that could be barriers to PA. This was the case for both home-based and centre-based interventions.[61]

Goal setting is another major factor of the **aktiv**plan application. Patients can add both individually chosen goals and goals formulated in collaboration with their HCPs. Goal setting positively influences motivation and its use enhances PA levels.[62,63] Through the visualisation of their daily, weekly and monthly active minutes and adherence to their planned PA, patients can self-monitor their behaviour. Self-monitoring is known as an effective behaviour change method that increases self-efficacy and promotes the maintenance of PA after discharge from a cardiac rehabilitation programme.[64]

aktivplan uses readily composed messages containing evidence-based information on PA and its health benefits. Additionally, patients receive reminders to enter their PA, if they were due a session and have not yet entered it to the app. These automated messages provide patients with relevant information whilst simultaneously serving as reminders of the importance of PA. Furthermore, the HCPs can monitor all their registered patients' adherence and initiate personal messages. These messages can serve as opportunities for the HCPs to provide feedback and reinforcement. Feedback and reinforcement have been found to be effective methods to tackle psychological determinants related to PA such as positive attitude and outcome expectations towards PA, increased self-efficacy to perform exercises, motivation and problem solving skills to overcome barriers to PA.[65,66]

Furthermore, **aktiv**plan provides users easy access to training videos containing exercises and short workouts that can be completed at home with limited or no additional equipment. These training videos are an example of the behaviour change method modelling, which is known to enhance exercise-related self-efficacy.[67]

In terms of its implementation in the cardiac rehabilitation patient pathway, **aktiv**plan utilises the time window during which patients with CVD are often observed to be receptive to behaviour change ('teachable moment'), because of their recent experience of a significant or even life-threatening medical episode that has prompted referral to a cardiac rehabilitation programme.[68,69]

In addition to the individual effectiveness of these behaviour change methods, in their systematic review on lifestyle modification programmes for patients with coronary heart disease, Janssen et al.[70] reported on the synergetic effects of behaviour change methods, including goal setting, self-monitoring, planning and feedback, in changing lifestyle behaviours. All these methods are effectively incorporated into the **aktiv**plan application, for example, feedback on one's own performance (adherence visualisation, active minutes and perceived exertion rating) to facilitate self-monitoring; and guided practice and active learning during the PA counselling session to reinforce the use of these features.

The logic model of change for aktivplan

We defined four POs for the target population. In sum, these four sub-behaviours contribute to the main behavioural outcome of the target population:

- PO.1 Patients plan their weekly PA sessions in the **aktiv**plan application with their HCP[61, 71];
- PO.2 Patients complete their minimum recommended amount of weekly PA;
- PO.3 Patients monitor their PA using the **aktiv**plan app[8, 61, 62, 64, 72, 73] and
- PO.4 Patients adapt PA plans according to their own capabilities in collaboration with their HCP.[61]

After defining these POs, we conducted literature searches on the personal determinants associated with these behaviours. Thereafter, we conducted a comparative analysis between the identified determinants and those addressed by the **aktiv**plan application. COs were consecutively developed for all overlapping determinants. The evidence-based justification for selected determinants and the cross-tabulation of POs, determinants and COs can be found in the online supplemental file, under the tabs 'Justification of determinants' and 'CO matrix – patients', respectively.

The acyclic behaviour change diagram for aktivplan

The ABCD in Figure 5 gives a complete overview of all POs, COs, determinants, behaviour change methods, and practical applications (i.e. the corresponding features of **aktiv**plan). This makes transparent the intended – or hypothesised – mechanisms of action of the **aktiv**plan digital health intervention, linking through from the behaviour change methods to the main behavioural outcome.

For example, the **aktiv**plan feature 'PA planner' utilises the behaviour change methods tailoring and shared decision making. Both methods target the determinants behavioural capability and self-efficacy to influence PO.1 (patients plan their weekly PA session in the **aktiv**plan application with their HCP), which is a contributing sub-behaviour to achieve the main behavioural outcome. The corresponding COs (BC.1 and SE.1 in Figure 5) articulate how the success of this feature can be observed, that is, the impact on behavioural capability can be observed by patients demonstrating their ability to plan their weekly PA (BC.1), and the impact on self-efficacy can be observed by patients expressing confidence in planning their weekly PA (SE.1).

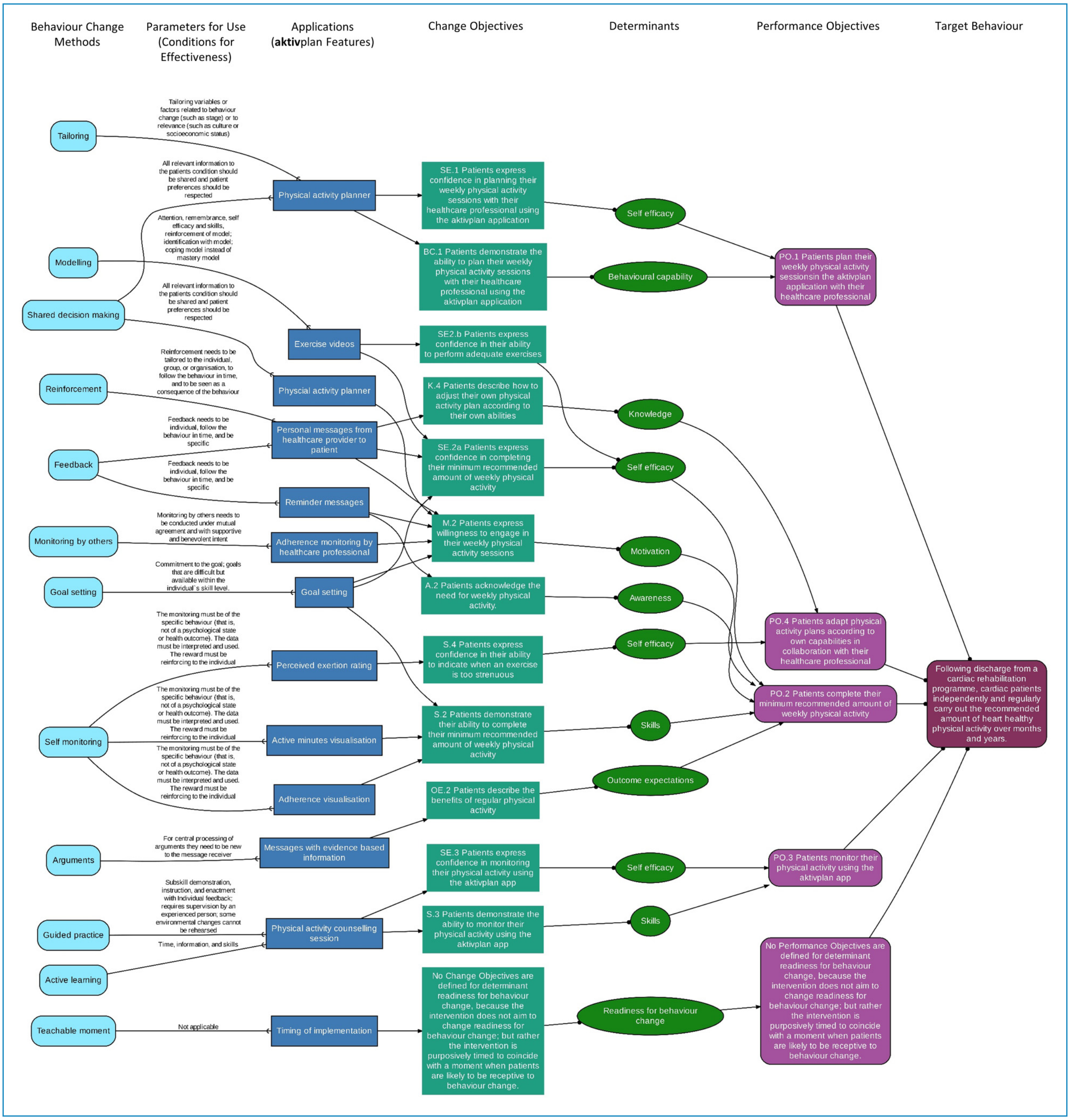

Figure 5. Acyclic behaviour change diagram (ABCD) for the **aktiv**plan digital health intervention.

The ABCD matrix in the online supplemental file (tab 'ABCD – patients') gives a tabular presentation of the content in Figure 5.

Discussion

We applied the IM approach to 'articulate programme theory' for our digital health intervention **aktiv**plan, to make transparent the (proposed) active ingredients and mechanisms of action underlying the intervention. Working backwards from the mature intervention prototype, we re-traced IM steps 1, 2 and 3 and 'retro-fit' a comprehensive logic model of change for **aktiv**plan. The logic model of change includes four POs (i.e. sub-behaviours of the main target behaviour), 8 personal determinants (i.e. factors that influence these sub-behaviours) and 12 COs (i.e. changes needed at the determinant level to achieve the sub-behaviours), which are linked to 12 distinct features of the **aktiv**plan digital health intervention, and their 12 underlying behaviour change methods (Table 1). This creates a detailed map of all individual components of the **aktiv**plan intervention and their proposed or hypothesised influence on a cardiac patient's personal determinants, sub-behaviours and finally the main target behaviour of regular heart-healthy physical activity (Figure 5).

Practical use of the logic model

As already stated, at a wider scientific and societal level, detailed intervention descriptions support transparency, reproducibility and the reduction of waste in research.[18,19] At a more immediate level, one practical use of the **aktiv**plan logic model of change is to arrive at a thorough understanding of the intervention ourselves. Because **aktiv**plan features emerged organically, based on needs analysis and decision making in the user-centred iterative design process, the work of explicitly drawing apart all individual features and developing a logic model around them helped us to reflect on what is – and what is not – part of our **aktiv**plan intervention. Notably, for example, the formulation of implementation intentions as a behaviour change method is finding increasing application in physical activity promotion,[74] but it had not explicitly been considered in **aktiv**plan. Similarly, social support has been associated with greater leisure-time physical activity in older adults,[75] but **aktiv**plan did not include any features to increase or leverage social support. For us as intervention developers, this makes apparent further development opportunities, that is, aspects which could be addressed in future iterations of **aktiv**plan or in separate new interventions. It also helps us reflect on why certain aspect were not incorporated in the development, for which there can of course be valid reasons such as deliberate design decisions to avoid overloading the application with features and components.

Another practical use for our logic model is to support our communication about **aktiv**plan components to other stakeholders such as researchers, rehabilitation providers and prospective users (both healthcare professionals and patients).[13] The logic model serves to describe the specific functions of **aktiv**plan features and their importance, by linking each with their underlying psychological rationales and behaviour change methods. Anecdotally, the graphical representation of the 'logic chain' (ABCD, Figure 5) has proven particularly helpful to relate the workings of this behaviour change intervention to colleagues from the biomedical domain, by drawing a parallel with biomedical pathway models such as the coagulation cascade. For potential users who wish to select a suitable digital tool from a range of options, such a depiction of which aspects of behaviour change are (not) addressed within the **aktiv**plan intervention can be helpful to meet the specific needs of individual patients or service user groups. Importantly, ABCDs may be regarded as 'stand alone' tools and complementary to intervention development frameworks such as IM. ABCDs offer intervention developers an operational means to help optimise transparent development and reporting of interventions by visualising the active components of behaviour change interventions.[29] The causal logic that is depicted in ABCDs, while well-reasoned and supported by available scientific evidence, of course represents the intervention developer's proposition of mechanisms of action of the intervention and requires verification, for example through data collected in an evaluation study.

With regard to the evaluation of the **aktiv**plan intervention, the logic model offers a comprehensive scaffold against which to select appropriate evaluation designs that capture the relevant processes and outcomes.[12] As the COs defined in the logic model essentially present targets for evaluation outcomes, the model can be used to inform the selection of outcome measures for specific COs, or the development of instrument items for specific COs if no existing measures are available. Additionally, the behaviour change methods and determinants incorporated in the logic model signpost towards associated outcome measures (e.g. self-efficacy questionnaires) which may be appropriate to use. Changes in these outcome measures, in combination with automatically logged usage data for the different features of the tool, provide a descriptive indication of the relative impact of individual features and may also allow for more complex statistical assessment through mediation analysis.[76] Moreover, this can support the use of objective and subjective measures to capture user engagement, and the use of large amounts of real-time data generated by a digital health intervention[77] to test and advance models of behaviour change, as specified in recent recommendations for developing and evaluating digital interventions to promote behaviour change in health and healthcare.[78]

Possible disadvantages of developing a detailed logic model

There are some considerations which might preclude developing such a detailed logic model as presented in this article. The required expertise in the IM methodology or the required time resources might not be available. From a design perspective, such an analytic dissection of the intervention as presented in this example might take away from the more creative 'designerly intuition' and 'abductive reasoning' that is characteristic for co-design approaches.[79] In the retrospective development of the logic model, initial design intentions might be misrepresented, and intervention components mapped inappropriately. Similarly, one could get lost in the details of the logic model and lose sight of a clear design focus and vision. In any case, intervention developers should work up *a* type of logic model for their digital health intervention, and approaches that require less detailed description and justification of psychological mechanisms and theories than in the example presented here are available (see section *Other approaches for the retrospective development of a logic model*).[17]

User-centred iterative co-design meets Intervention Mapping

As demonstrated in this work, user-centred design and IM can both be integrated in the development of digital health interventions for behaviour change, building on the strengths of both methodologies, each underpinned by complementary principles. User-centred design, with stakeholder involvement and iteration as key tenets, emphasises the involvement of end-users at every stage of the design process, fostering a deep understanding of user needs and preferences.[80] This approach aligns closely – and is often used in conjunction – with co-design, which involves stakeholders, including users, in the creative process to ensure that the outcomes are both usable and meaningful.[81] IM, a systematic approach for health promotion programme planning, encompasses six iterative steps as detailed above: needs assessment, formulation of change objectives, selection of theory-based methods and practical strategies, programme design, adoption and implementation planning, and evaluation planning.[22] Similarities between user-centred design/co-design and IM are their iterative nature and shared commitment to a systematic, user- (or human-)focused approach. Both methodologies highlight the understanding of user context and needs, albeit with different emphasis – user-centred design/co-design through direct user involvement and iterative testing, and IM through a structured analysis of the problem and possible solutions together with the target population and other relevant stakeholders. Both approaches complement each other in their theoretical underpinnings and scope. While user-centred design and co-design are grounded in design theory and primarily focus on product usability and satisfaction, IM initiated from the field of health promotion and encompasses a broader range of considerations, including the effectiveness of interventions in changing (health) behaviours. This is critical in the context of digital health interventions, where the convergence of these approaches can leverage the strengths of each – user-centred design/co-design enhancing user engagement and adherence in close interplay with digital health intervention feature design, and IM ensuring the intervention's theoretical robustness and practical effectiveness in behaviour change.[82, 83]

Other approaches for the retrospective development of a logic model

As stated above, there are approaches to constructing a logic model for a complex intervention that require less detailed description and justification of psychological mechanisms and theories than in the example presented here. O'Cathain et al.[17] describe a more basic structure for a logic model of a complex intervention, which starts from 'principles' and links sequentially to 'actions to consider', 'intervention', 'outputs', 'short term effects' and 'long term effects'. A similarly basic logic model structure is described in the frequently cited 'Logic Model Development Guide' by the Kellogg Foundation[84] which takes 'resources/inputs' as a starting point and links sequentially to 'activities', 'outputs', 'outcomes' and 'impact'. Diagrammatic representations of such logic models are often seen in scientific publications of complex interventions, for example, in Cook et al.[85] Nevertheless, for a digital behaviour change intervention even such a basic logic model will need to include reference to behaviour change methods and/or theory.[13] To achieve this in retrospect, an approach applied in the systematic review by Patterson et al.[86] can be appropriate, by which descriptions of digital health interventions according to the TIDieR checklist were mapped against a comprehensive classification of behaviour change methods and theories – in this case the behaviour change technique taxonomy developed by Michie et al.[87] As described in section *Practical use of the logic model*, an ABCD may also be developed as a 'stand alone' tool, to offer a visual representation in support of a logic model that has been developed via a framework other than IM.[29]

Another approach for 'reverse-engineering' a logic model for an existing intervention has been described by Walker et al.[16] Termed 'Evidence-Based Intervention (EBI) Mapping', this approach is similar to our example, as it also applies IM methodology retrospectively. However, the primary motivation for EBI Mapping is to support uptake of interventions with proven efficacy or effectiveness (EBIs) in practice, whereas our approach prioritises systematically analysing existing interventions regardless of their evidence base to understand their components and logic, offering necessary insights for their evaluation, potential adaptation or enhancement. In EBI Mapping, the suggestion is that a detailed description of an EBI's goals, components and theory of change will help potential adopters judge and decide whether the EBI could be suitable for their particular population and context. Walker et al. define four stepwise tasks – identifying the who, what, why and how of an EBI – to arrive at a logic model that lists practical applications, change methods, determinants, health behaviour, health outcome and health problem. In contrast to our example, EBI Mapping does not include an ABCD with its detailed specification of POs and COs and its depicted (proposed) causal linkage between individual behaviour change methods, applications, COs, determinants and POs; and the suggested use of EBI Mapping is mainly to inform potential adopters of an EBI about suitability of the intervention and adaptation needs for their particular setting.[16]

Strengths and limitations

A strength of our work is the comprehensive and practical description of the retrospective application of IM to 'articulate programme theory', providing readers with sufficient detail to replicate the approach. Moreover, because IM is a well-established and actively taught methodology, readers seeking further guidance on the application of IM may draw on current scientific publications and educational resources about IM. Another strength of our approach is its compatibility with user-centred design/co-design, enabling synergies between this prevalent paradigm in modern design thinking and the psychologically and theoretically informed underpinning logic of a behaviour change intervention that is generated through IM.

We acknowledge limitations to our work. The approach may be limited by lack of access to intervention contents and materials, especially when the development of the logic model is conducted by persons who are outside the intervention development team and who may rely on scientific publications and other publicly accessible information about the intervention. Differing conceptual understandings and definitions of terms may add to this difficulty. Another limitation concerns the possibility that the delineation of intervention features, determinants, behaviour change methods and theories may not be obvious or straightforward, and decisions may to some extent require judgement calls or group consensus. We recommend that an attempt is made to create a suitable stakeholder group, ideally including representatives from the intervention development team, so that access to intervention contents and materials is granted and accounts of the 'history' of intervention development can be provided. This stakeholder group may then constitute the forum in which concepts, definitions and decisions are discussed and agreed upon.

While the example presented in this article only addressed the behaviour of the at-risk populations (i.e. patients who had an acute cardiac event), a logic model may also extend to include various environmental agents. However, the roles of environmental agents can sometimes overlap with those of implementers (i.e. the persons involved in the adoption, implementation and maintenance of an intervention),[26] creating potential for lack of conceptual clarity in this respect.[16]

Recent literature calls for introducing more flexible and dynamic logic models to incorporate elements of interaction between an intervention and the context within which it is deployed[15, 88] including considerations of potential intervention harms and their mechanisms of action.[89] We acknowledge that this is not accounted for in our example.

Conclusion

It is important to make transparent the indented – or hypothesised – workings of digital health interventions, by 'articulating programme theory'. This article offers a conceptual case study and a worked example, applying IM to retrospectively develop a detailed logic model of an existing, co-designed digital behaviour change intervention for physical activity in cardiac rehabilitation. Intervention developers and researchers may draw on this example to replicate the method, or to reflect on most suitable approaches for 'articulating programme theory' for their own interventions. Publications of similar case studies and worked examples from other clinical use cases can enrich and support researchers' practice of articulating programme theory.

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Guarantor: STK

ORCID iD: Stefan T. Kulnik https://orcid.org/0000-0001-5419-6713

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