RESEARCH ARTICLE

Development of an Ontology of Engagement with Behaviour Change Interventions

[version 1; peer review: awaiting peer review]

Ailbhe N. Finnerty Mutlu[1*], Paulina M. Schenk[2*], Emily J. Eymery[2], Candice Moore[2], Kirsty Atha[3], Emma Norris[4], Marta M. Marques[5], Micaela Santilli[2], Robert West[2], Janna Hastings[6,7], Lisa Zhang[2], Susan Michie[2]

[1]Social Research Institute, University College London, London, England, UK
[2]Centre for Behaviour Change, University College London, London, England, UK
[3]Department of Psychology, Royal Holloway University of London, Egham, England, UK
[4]Department of Health Sciences, Brunel University London, London, England, UK
[5]National School of Public Health, Comprehensive Health Research Centre, Universidade NOVA de Lisboa, Lisbon, Portugal
[6]Institute for Implementation Science in Health Care, Faculty of Medicine, University of Zurich, Zurich, Switzerland
[7]School of Medicine, University of St Gallen, St Gallen, Switzerland

* Equal contributors

v1 **First published:** 04 Aug 2025, **10**:409
https://doi.org/10.12688/wellcomeopenres.24239.1
Latest published: 04 Aug 2025, **10**:409
https://doi.org/10.12688/wellcomeopenres.24239.1

Abstract

Background

Participants' engagement with behaviour change interventions is crucial for their effectiveness. However, engagement is conceptualised and measured inconsistently across research domains, limiting the ability to compare and synthesise evidence about engagement and identify strategies to enhance engagement. This study aimed to develop an ontology—a classification framework—to precisely specify and define aspects of engagement with behaviour change interventions.

Methods

The Intervention Engagement Ontology was developed in seven steps: (1) specifying the ontology's scope, (2) reviewing intervention reports to identify key classes (categories) of engagement, (3) refining the ontology through literature annotations, (4) a stakeholder review on the ontology's clarity and comprehensiveness, (5) testing inter-rater

Open Peer Review

Approval Status *AWAITING PEER REVIEW*

Any reports and responses or comments on the article can be found at the end of the article.

reliability in applying the ontology for annotations, (6) specifying relationships between classes, and (7) making the ontology machine-readable.

Results

Participant engagement with interventions was defined as "*An individual human activity of an intervention participant within one or more parts of the intervention*." Through Steps 1–4, an initial ontology with 48 classes was developed, including 37 engagement-specific and 11 structurally supporting classes (e.g., emotional process). Inter-rater reliability for applying these engagement classes was 'acceptable' for researchers familiar (α = 0.71) and unfamiliar (α = 0.78) with the ontology. After further refinements (Steps 6-7), the published ontology included 54 classes - 44 engagement-specific and 10 supporting classes. The engagement classes were structured around three key engagement types: (1) behavioural, (2) emotional, and (3) cognitive. Behavioural engagement aspects, such as frequency and duration, were also represented in the ontology.

Discussion

The Intervention Engagement Ontology provides a structured framework for specifying and defining participant engagement with behaviour change interventions, facilitating clearer communication, comparison and evidence synthesis across research studies and domains. Future work will refine the ontology based on further feedback and empirical validation, enhancing its applicability.

Plain language summary

Engaging with behaviour change interventions is essential for their success, but researchers define and measure engagement in different ways. This lack of consistency makes it hard to compare studies and find the best ways to improve engagement. To address this, we developed a structured framework that clearly defines different aspects of engagement, called the Intervention Engagement Ontology.

The ontology was developed by defining engagement and being clear about what the ontology covers; reviewing published studies; consulting stakeholders; testing whether researchers can consistently apply the ontology to describe engagement with interventions; and making the ontology computer readable and available online.

The Intervention Engagement Ontology includes 54 classes. It categorises engagement into three types: behavioural (e.g., how often and for how long someone participates), emotional (e.g., feelings towards the intervention), and cognitive (e.g., thinking and decision-making related to the intervention).

This framework enables researchers and practitioners to describe engagement more precisely, making it easier to compare studies and improve behaviour change interventions. Future updates will refine the ontology based on feedback and research.

Keywords
engagement, behaviour change interventions, ontology, classification framework, machine-readable

This article is included in the Human Behaviour-Change Project (including the APRICOT project) gateway.

Corresponding authors: Ailbhe N. Finnerty Mutlu (a.finnerty@ucl.ac.uk), Paulina M. Schenk (paulina.schenk.13@ucl.ac.uk)

Author roles: Finnerty Mutlu AN: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Resources, Software, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Schenk PM**: Data Curation, Formal Analysis, Investigation, Project Administration, Resources, Software, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Eymery EJ**: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Moore C**: Data Curation, Formal Analysis, Investigation, Resources, Software, Validation, Visualization, Writing – Review & Editing; **Atha K**: Conceptualization, Data Curation, Formal Analysis, Investigation, Resources, Software, Validation, Visualization, Writing – Review & Editing; **Norris E**: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Resources, Validation, Writing – Review & Editing; **Marques MM**: Data Curation, Formal Analysis, Investigation, Methodology, Validation, Writing – Original Draft Preparation, Writing – Review & Editing; **Santilli M**: Data Curation, Formal Analysis, Investigation, Software, Validation, Writing – Original Draft Preparation, Writing – Review & Editing; **West R**: Conceptualization, Formal Analysis, Funding Acquisition, Methodology, Supervision, Validation, Writing – Review & Editing; **Hastings J**: Formal Analysis, Software, Supervision, Validation, Writing – Review & Editing; **Zhang L**: Formal Analysis, Investigation, Validation, Writing – Review & Editing; **Michie S**: Conceptualization, Formal Analysis, Funding Acquisition, Methodology, Supervision, Validation, Writing – Review & Editing

Competing interests: Robert West undertakes paid training and consultancy for Everyone Health, a company that is commissioned by English local government to support people to change their behaviour to improve their health. He undertakes paid consultancy for Godot, a Japanese-based company that harnesses AI in support of behaviour change to improve wellbeing, Qnovia a company that is developing a novel nicotine inhalation device to aid smoking cessation, and Public Health Wales' Behavioural Insights Team. He is an unpaid director of the Unlocking Behaviour Change Community Interest Company. He is an unpaid member of the Scientific Advisory Board of the Smoke Free mobile application. Susan Michie undertakes paid consultancy for Godot, a Japanese-based company that harnesses AI in support of behaviour change to improve wellbeing, and is an unpaid director of the Unlocking Behaviour Change Community Interest Company.

Grant information: This work is supported by the Wellcome Trust through a collaborative award to the Human Behaviour-Change Project [201524] and the National Institutes of Health through an award to the Advancing Prevention Research In Cancer through Ontology Tools (APRICOT) Project [1U01CA291884-01].
The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

How to cite this article: Finnerty Mutlu AN, Schenk PM, Eymery EJ *et al.* **Development of an Ontology of Engagement with Behaviour Change Interventions [version 1; peer review: awaiting peer review]** Wellcome Open Research 2025, **10**:409 https://doi.org/10.12688/wellcomeopenres.24239.1

First published: 04 Aug 2025, **10**:409 https://doi.org/10.12688/wellcomeopenres.24239.1

Introduction

Behaviour change interventions help us address societal challenges that impact health, wellbeing and sustainability, such as antimicrobial resistance, pandemics and climate change (Michie *et al.*, 2017a). For such interventions to be effective, people must actively engage with them (Bijkerk *et al.*, 2023; Hankonen, 2021; Yardley *et al.*, 2016). ***Engagement*** with interventions is therefore critical to consider when designing, reporting and evaluating interventions (see glossary of bold, italicised terms in Table 1). For example, for interventions targeting physical activity to be effective, participants need to actively engage with component ***behaviour change techniques*** (BCTs), such as learning the skills demonstrated during the intervention (Hankonen, 2021; Palsola *et al.*, 2020). When engagement levels are low, participants may receive inadequate exposure to interventions or they may disengage completely, reducing or nullifying their impact on behaviour (Karekla *et al.*, 2019; Morawska & Sanders, 2006). Understanding and prompting 'effective' levels of engagement are key to developing interventions that are more likely to change behaviour (Michie *et al.*, 2017b; Yardley *et al.*, 2016).

Aspects of interventions can be designed and delivered to improve engagement. For example, intervention designers may use colourful and eye-catching graphics on intervention material, apply gamification techniques to improve engagement with the content, limit the duration of an intervention or change the intervention dose for better engagement (Alrashidi *et al.*, 2016; Bright *et al.*, 2015; Kreyenbuhl *et al.*, 2009; Nahum-Shani *et al.*, 2022; Perski *et al.*, 2017). When designing intervention content and delivery, a 'person-centred approach' can help consider participants' needs, motivations and interests and so make this content or delivery more engaging to participants (Yardley *et al.*, 2020). Particularly tailoring interventions is a widely recognised strategy for enhancing engagement and improving the effectiveness of behaviour change interventions, with digitalisation offering new opportunities for personalisation (Morrison *et al.*, 2014; Noar *et al.*, 2007; Yardley *et al.*, 2016; Yardley *et al.*, 2020). However, for intervention designers to be able to identify effective strategies to target and increase engagement, we need a clearer conceptualisation of what engagement is and how it can be evaluated.

Engagement has been conceptualised and operationalised differently across research studies and domains (Ben-Eliyahu *et al.*, 2018; Bijkerk *et al.*, 2023; Perski *et al.*, 2017). In face-to-face mental health interventions, engagement is commonly captured through participation rates, such as session attendance (Holdsworth *et al.*, 2014; Lakind *et al.*, 2022). By contrast, digital interventions often rely on usage metrics as proxies for engagement (Saleem *et al.*, 2024). Other types of engagement, such as cognitive and emotional engagement, are often overlooked in intervention studies (Bijkerk *et al.*, 2023), whereas many communication campaigns recognise that attention, understanding, acceptance, recall and active processing are all crucial for engagement (Wijaya, 2012).

A systematic review of engagement in Human-Computer Interaction literature (Doherty & Doherty, 2018) identified 102 definitions of engagement across a corpus of 351 papers. In another review of 117 articles relating to engagement with digital interventions, the authors found that engagement is a multidimensional and interdisciplinary concept (Perski *et al.*, 2017) Based on the reviewed literature, they proposed an overarching definition for engagement with digital behaviour change interventions: "*(1) the extent (e.g. amount, frequency, duration, depth) of usage and (2) a subjective experience characterised by attention, interest and affect*" (Perski *et al.*, 2017; p., 258). The complexity of defining and operationalising engagement means that its reporting is often partial or lacking in reports of behaviour change interventions (Perski *et al.*, 2017; Walton *et al.*, 2017).

Engagement as an evaluated construct

Perski *et al.* (2017) proposed a conceptual model that posits that participants' engagement moderates the influence that interventions have on the target behaviour. Assessing the extent and nature of participants' engagement is crucial for understanding intervention success or failure. (Hightow-Weidman & Bauermeister, 2020; Perski *et al.*, 2017; Walton *et al.*, 2020; Weston *et al.*, 2022). Engagement has behavioural, cognitive and emotional dimensions (Bijkerk *et al.*, 2023; Perski *et al.*, 2018; Walton *et al.*, 2017). These dimensions can be investigated through what people say about their perceptions and experiences (e.g., through interviews) and through objective data (e.g., usage data, completion rates and biometric data) (Bijkerk *et al.*, 2023; Perski *et al.*, 2017; Walton *et al.*, 2017). Digitalisation has introduced opportunities for more objective, ecologically valid and real-time measurements of engagement, e.g., logins to an app, views of content and time spent on an app (Michie *et al.*, 2017b; Short *et al.*, 2018). However, the proliferation of measures, as well as the complex nature of engagement, can create confusion for researchers in operationalising and selecting measures. This can lead to focus on certain aspects of engagement (e.g., attendance frequency), and insufficient consideration of others (e.g., emotional engagement) in intervention studies (Bijkerk *et al.*, 2023; Lakind *et al.*, 2022).

Evaluating participants' engagement is further complicated by the complexity of many interventions (Bijkerk *et al.*, 2023; Schubart *et al.*, 2011; Walton *et al.*, 2017). Interventions often incorporate multiple intervention components (e.g., BCTs), some of which need to work together to be effective (Dusseldorp *et al.*, 2014; Harris *et al.*, 2023; Lorencatto *et al.*, 2013). While certain intervention components may have an effect even when participants are passive recipients, most require some engagement to work as intended (Hankonen, 2021). Fully understanding intervention engagement requires assessing participants' engagement levels with each intervention component. An added challenge it that participants' engagement levels will vary over time and in response to their personal contexts (Ellis *et al.*, 2013; Hawkes *et al.*, 2023; Perski *et al.*, 2017; Short *et al.*, 2018). Therefore, the reporting of engagement evaluations is often partial or even omitted (Walton *et al.*, 2020).

The conceptual model developed by Perski *et al.* (2017) provided a clear and explicit overarching definition of engagement and its relationship to other components of behaviour change

interventions. Building on this model to support research, the development of a representational framework could help define more specific aspects of engagement and their links to behaviour change interventions. Researchers can use such a framework to define what engagement entails and identify key aspects that should be evaluated and reported. Such a framework provides a more cohesive and organised language around engagement, allowing clear communication and reporting, comparison across studies and scenarios and evidence synthesis, all of which will inform future strategies to enhance engagement.

Behaviour Change Intervention Ontology

A method for precisely specifying and classifying interventions is an ***ontology*** (Arp *et al.*, 2015) (see glossary of bold, italicised terms in Table 1). An ontology is a representational framework that specifies and structures knowledge within a given scope,

Table 1. Glossary of terms. (Michie *et al.*, 2017a).

Term	Definition	Source
Annotation	Process of coding, or tagging, parts of documents or data sets to identify the presence of ontology classes or items of information.	Michie *et al.* (2017a)
Annotation guidance manual	Written guidance on how to identify and tag pieces of text from intervention evaluation reports with specific codes relating to classes in the ontology, using for example EPPI-Reviewer software.	Michie *et al.* (2017a)
Basic Formal Ontology (BFO)	An upper-level ontology specifying foundational distinctions between different types of entity, such as between continuants and occurrents, developed to support integration, especially of data obtained through scientific research.	Arp *et al.* (2015)
Class	Classes in ontologies represent types of entities in the world. The terms 'entity' and 'class' are often used interchangeably to refer to the entities represented in an ontology. Classes can be arranged hierarchically by the specification of parent and child classes (see definition of **parent class**)	Arp *et al.* (2015)
Entity	Anything that exists or can be imagined, including objects, ***processes***, and their attributes. This includes mental process, i.e., the process and content of cognitive representations, and emotions.	Arp *et al.* (2015)
EPPI-Reviewer	A web-based software program for managing and analysing data in all types of systematic review (meta-analysis, framework synthesis, thematic synthesis etc. It manages references, stores PDF files and facilitates qualitative and quantitative analyses. It also has a facility to annotate published papers.	Thomas *et al.* (2010; 2020) EPPI-Reviewer 4: http://eppi.ioe.ac.uk/eppireviewer4/ EPPI-Reviewer Web Version: https://eppi.ioe.ac.uk/eppireviewer-web/
GitHub	A web-based platform used as a repository for sharing code, allowing version control.	https://github.com/
Inter-rater reliability	Statistical representation of degree of similarity and dissimilarity of coding between two or more coders. If inter-rater reliability is high this suggests that ontology class definitions and labels are being interpreted similarly by the coders.	Gwet (2014)
Interoperability	Two systems are interoperable to the extent that the information in one system can be used in the other system. An ontology is interoperable with another ontology if it can be used together with the other ontology.	http://www.obofoundry.org/principles/fp-010-collaboration.html

Term	Definition	Source
Issue tracker	An online log for problems identified by users accessing and using an ontology.	https://obofoundry.org/principles/fp-020-responsiveness.html BCIO Issue Tracker: https://github.com/HumanBehaviourChangeProject/ontologies/issues
Open Biological and Biomedical Ontology (OBO) Foundry	A collective of ontology developers that are committed to collaboration and adherence to shared principles. The mission of the OBO Foundry is to develop a family of interoperable ontologies that are both logically well-formed and scientifically accurate.	Smith *et al*. (2007) www.obofoundry.org/
Ontology	A standardised representational framework providing a set of classes for the consistent description (or 'annotation' or 'tagging') of data and information across disciplinary and research community boundaries.	Arp *et al*. (2015)
Parent class	A class within an ontology that is hierarchically related to one or more child classes (subclasses) such that all members of the child class are also members of the parent class, and all properties of the parent class are also properties of the child class.	Arp *et al*. (2015)
Process	Something that takes place over time.	Arp *et al*. (2015)
Relationship	The manner in which two classes are connected or linked. The terms 'relationship' and 'relation' can be used interchangeably.	Arp *et al*. (2015)
ROBOT	An automated command line tool for ontology workflows.	Jackson *et al*. (2019) http://robot.obolibrary.org
Uniform Resource Identifier (URI)	A string of western characters that uniquely identifies a document or item of information. It is used in ontologies to identify individual classes and relations within the ontology. URIs are limited to the western alphabet; the extension of these identifiers including non-western alphabet are called Internationalised Resource Identifiers (IRI). All ontology entries should have URIs that form part of *URLs*.	http://www.obofoundry.org/principles/fp-003-uris.html
Uniform Resource Locator (URL)	A type of IRI that specifies a web address for a document or locatable resource on the internet. Ontology entries should all have individual URLs so that they can easily be referenced and located.	http://www.obofoundry.org/principles/fp-003-uris.html
Versioning	A process that involves keeping a record of different versions of files (e.g., about ontologies). Ontologies that have been released are expected to change over time as they are developed and refined, leading to a series of different files. Consumers of ontologies must be able to specify exactly which ontology files they used to encode their data or build their applications and be able to retrieve unaltered copies of those files in perpetuity. Versioning is one of the OBO Foundry principles.	http://www.obofoundry.org/principles/fp-004-versioning.html
Web Ontology Language (OWL)	A formal language for describing ontologies. It provides methods to model classes of 'things', how they relate to each other and the properties they have. OWL is designed to be interpreted by computer programs and is extensively used in the Semantic Web where rich knowledge about web documents and the relations between them are represented using OWL syntax.	https://www.w3.org/TR/owl2-quick-reference/

facilitating communicating and sharing data across domains, sectors and academic disciplines (Arp *et al.*, 2015). Ontologies include representations of ***entities*** (i.e., ***classes***), their labels, definitions and computer readable IDs (i.e., ***Uniform Resource Identifier [URI]***) and specify ***relationships*** between these entities. Ontologies help integrate knowledge across different data types and research domains, and ensure greater clarity in reporting (Gene Ontology Consortium, 2019; Michie *et al.*, 2020). Because ontologies are readable by both humans and machines, they can be used for ***annotation*** (i.e., coding or tagging information), evidence synthesis and automating or semi-automating these processes (Arp *et al.*, 2015; He *et al.*, 2018; West *et al.*, 2024). Annotations that have been structured with ontologies can also be applied in computer applications to identify evidence gaps and make predictions about novel scenarios (Hastings *et al.*, 2023; Michie *et al.*, 2024). Thereby, ontologies can enable complex data integration, syntheses and analyses to advance knowledge about an area of study, such as behaviour change interventions.

To structure knowledge about behaviour change interventions, the Behaviour Change Intervention Ontology (BCIO) was developed; this was as part of the Human Behaviour-Change Project (Michie *et al.*, 2017a) and is now being extended as part of the APRICOT (Advancing Prevention Research In Cancer through Ontology Tools) Project (Michie *et al.*, 2024). The upper level of the BCIO consists of 42 classes, one of which is related to participants' engagement with behaviour change interventions (Michie *et al.*, 2020). A simplified schematic representation of the BCIO's upper level is shown in Figure 1. The white boxes each show an upper-level class that captures one or more lower-level ontology part of the BCIO, and the lower-level ontologies are shown in blue boxes. In line with principles for 'good' ontologies proposed by the ***Open Biological and Biomedical Ontology (OBO) Foundry***, the BCIO and its lower-level ontologies will continue to be updated and maintained based on evolving evidence and user feedback (Arp *et al.*, 2015; He *et al.*, 2018).

Here we report the development of an ontology to specify and describe participants' engagement with behaviour change interventions (highlighted with a red box in Figure 1). Such an ontology can structure research and facilitate evidence synthesis on engagement with behaviour change interventions. Organising the evidence base more effectively will identify aspects of engagement to target to achieve 'effective' engagement levels, as well as highlight research gaps in this area. The Intervention Engagement Ontology can be explicitly linked to BCTs and other aspects of interventions in the wider BCIO, allowing the efficient organisation of more complex questions about and analyses of interventions.

Aim

We aimed to develop an ontology of engagement with behaviour change interventions to provide a clear and precise framework to specify and describe aspects of participants' engagement.

Methods

The Intervention Engagement Ontology was developed in seven steps, following the method for ontology development used within the HBCP (Wright *et al.*, 2020). These steps are reported following the Minimum Information for Reporting an Ontology (MIRO) guidelines (Matentzoglu *et al.*, 2018).

Step 1: Specifying the scope of the ontology

To define behaviour change intervention engagement and thereby specify the ontology's scope, we reviewed the descriptions of engagement in the relevant frameworks and literature.

We searched for engagement definitions in ontologies, taxonomies and controlled vocabularies using ontology browsers such as Ontology Lookup service (European Bioinformatics Institute, 2019) and BioPortal (https://bioportal.bioontology.org/ontologies). We reviewed the PICO Ontology (Mavergames *et al.*, 2019), CONSORT (Moher *et al.*, 2010) and RE-AIM

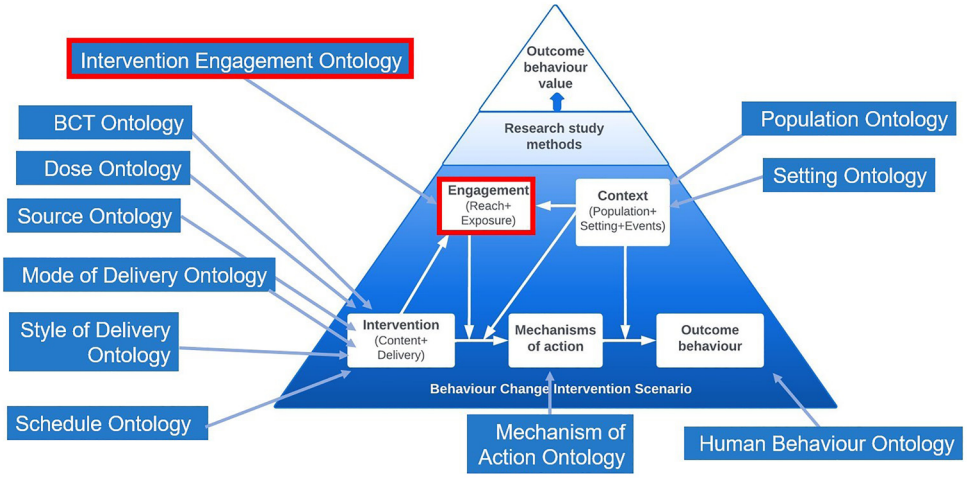

Figure 1. Schematic representation of the upper-level BCIO, with its lower-level ontologies and the Intervention Engagement Ontology highlighted.

Guidelines (Glasgow *et al.*, 2019) for existing definitions of engagement.

The research team discussed the definitions or descriptions proposed by these sources to formulate a definition of behaviour change intervention (BCI) engagement. This definition was iteratively refined during the ontology's development based on the principles for ontological definitions, such as defining a class by specifying its ***parent class*** followed by features that make a class distinct from its parent and unique among other subclasses of that same parent class (Michie *et al.*, 2019).

Step 2: Identifying key classes and developing their preliminary definitions

To identify classes for the preliminary version of the ontology, we aimed to review information about aspects of engagement in reports of 100 randomised control trials (RCTs); this was part of a larger dataset of behaviour change intervention reports previously annotated for behaviour change entities, covering a range of health behaviours (Carey *et al.*, 2019). However, after reviewing 40 of these trial reports, we found that engagement was rarely reported and continuing with these papers would not provide enough data on engagement to develop the preliminary version of the ontology. The search was therefore expanded to include 85 studies from reviews of engagement specific to behaviour change interventions (Perski *et al.*, 2017; Walton *et al.*, 2017), resulting in 125 papers for review (https://osf.io/mreyj).

Three researchers (AFM, KA & EE) independently reviewed the 125 papers, identifying extracts that captured aspects about behaviour change intervention engagement. Extracts were independently grouped by two researchers and then discussed to form classes for the ontology. The researchers proposed a preliminary hierarchical structure for the ontology's classes by specifying the parent classes of each class. Classes were labelled and defined following principles for ontological definitions (Michie *et al.*, 2019). The definition format consisted of "a [parent class] that [specification of characteristics that set the class apart from other members of the parent class]". The labels, definitions and structure of the classes were reviewed by the wider research team and refined according to their feedback.

The ontology's classes and structure were iteratively reviewed by other senior members of the research team to ensure it was clear and aligned with its scope. The ontology was aligned with the structure of a related BCIO lower-level ontology, the Schedule Ontology (Marques *et al.*, 2024a), as both ontologies included classes relating to timing (e.g., frequency and duration of participants' engagement).

Step 3: Refining the ontology through an iterative process of literature annotation, discussion and revision

Two researchers (EH & CM) individually annotated 76 reports on behaviour change interventions using ***EPPI-Reviewer*** 4 software (Bond *et al.*, 2024; Thomas *et al.*, 2020) with the preliminary Intervention Engagement Ontology. The 76 reports were identified through two routes:

1. 51 reports of randomised controlled trials identified through the reference lists or forward searching of five systematic reviews. These reviews were identified through searches of Google Scholar as being relevant to engagement with behaviour change intervention and additional recommendations from the research teams: Murray *et al.*, 2018; Perski *et al.*, 2017; Short *et al.*, 2018; Walton *et al.*, 2017; Yardley *et al.*, 2016.

2. 25 behaviour change intervention reports were identified by searching PubQuest Central using the following search string in April 2021: *"((ab(Behaviour) OR ab(behavior)) AND ((ti(RCT) OR ti(randomised control*) OR ti(randomized control*)) AND engag*) AND evaluat*) NOT ti(protocol)"*. The results were limited to those written in the English language and published between 2018 and April 2021, under the assumption that more recent reports would include better descriptions of engagement. Two researchers (EH & CM) screened the retrieved 394 reports until they identified 25 that mentioned intervention engagement measures.

The details of the 76 papers can be found on https://osf.io/mreyj.

To ensure consistency in annotation, the researchers developed and followed an ***annotation guidance manual*** (https://osf.io/abg9k). The researchers annotated batches of ~10 papers at a time, revising the ontology and annotation manual after each batch. They refined the ontology through regular comparisons of annotations, resolution of discrepancies through discussion, and consulting experts when needed. Adjustments were made to the labels, definitions, structure, and annotation guidelines of the ontology as deemed necessary. The process continued until no new classes were identified and there were no further significant discrepancies between the two researchers.

Step 4: Expert stakeholder review

To ensure that the ontology is reflective of wider perspectives about engagement, we sought feedback on the ontology's comprehensiveness and clarity from stakeholders from a range of countries and professional backgrounds relating to psychology, technology and public health. We used an online platform using Qualtrics software (https://www.qualtrics.com/uk/).

Sample and recruitment strategy. We recruited participants through invitations posted through the UCL Centre for Behaviour Change and Human Behaviour-Change Project's (HBCP) social media accounts, calls at advisory board meetings and conferences, and invitations sent to professionals who had expressed interest in providing feedback for the HBCP. Altogether, 100 people were randomly selected and invited from a panel of 351 experts, using research randomiser (https://www.randomizer.org/).

Procedure. In a survey, feedback was requested on whether:

i. any characteristics of engagement were missing from the ontology, and therefore new classes needed to be added,

ii. any changes needed to be made to improve the clarity of class definitions,

iii. any class belonged to a different section of the ontology, and so the ontology's structure needed to be updated.

An option to provide additional comments was given. The expert review exercise consisted of six multiple-choice and open-ended questions each divided into three parts, taking approximately 45 minutes (see https://osf.io/5szcb).

Analysis. The proportion of characteristics and terms reported to be missing or needing changes and proposed changes to the ontology were summarised. Each participant comment was logged and discussed by the ontology development team to decide how to address it (e.g., by changing classes in the ontology). The final decisions or rationale for not addressing a proposed change or other comment were recorded, and the ontology was updated accordingly.

Step 5: Testing inter-rater reliability and making revisions

To test whether the classes in the ontology could be reliably applied, we evaluated the inter-rater reliability of researchers' annotations of engagement in two rounds using EPPI-Reviewer software (Thomas *et al.*, 2020). First, two researchers (MC, PS) involved in developing the ontology independently applied the ontology to annotate aspects of intervention engagement in 50 research reports selected from Cochrane reviews (30 on smoking cessation and 20 on physical activity). During these annotations, the researchers used the annotation manual for guidance to apply the ontology. After annotating all reports, the researchers discussed disagreements and uncertainties with applying the ontology, which informed updates to the annotation manual. In the second round, two researchers (EH, LZ) unfamiliar with the ontology and with Masters' degrees relevant to behaviour change, applied it to another batch of 50 reports from Cochrane reviews (30 on smoking cessation and 20 on physical activity). The papers used in each annotation round can be found on https://osf.io/mreyj.

Fifty reports were used in each round, as they given an acceptable 10–15% margin of error around the estimated percentage agreement for inter-rater reliability calculations (Gwet, 2014). Inter-rater reliability was evaluated with Krippendorff´s alpha (Hayes & Krippendorff, 2007), which was calculated with the Automation Inter-Rater Reliability script developed for the HBCP and available at ***GitHub*** (Finnerty & Moore, 2020). Alpha values higher than .67 were considered acceptable (Gwet, 2014; Krippendorff, 2009; Krippendorff, 2011). If alpha values fell below .67 in an annotation round, disagreements were systematically reviewed and discussed to inform changes to the ontology.

Step 6: Specifying relationships between classes in the ontology

Relationships from the Relation Ontology (Smith *et al.*, 2005) and the ***Basic Formal Ontology*** (Arp *et al.*, 2015) were selected to specify relations between classes. For example, the hierarchical relationship 'is_a' was used to specify relations between classes and their parent classes, e.g., 'BCI emotional engagement' *is_a* 'BCI engagement'. Where necessary, new classes and relationships were added to logically structure the ontology and cover all aspects of engagement. The Intervention Engagement Ontology was aligned with other lower-level ontologies of the BCIO, as the work proceeded.

Step 7: Disseminating and maintaining the ontology

The ontology was documented in a spreadsheet file summarising the ontology with classes as rows and columns of primary label, parent class, ontological definition and informal definition. Once the ontology reached a stable level of development, it was converted to a ***Web Ontology Language (OWL)*** file by using the tool ***ROBOT*** (Jackson *et al.*, 2019), an automated library and command line tool for ontology workflows. The OWL file was made available in the HBCP GitHub repository, allowing users of the ontology to provide feedback on it through its ***issue tracker*** and assist developers in keeping track of subsequent versions of the ontology as updates are made.

Results

Step 1: Specifying the scope of the ontology

The starting point for specifying the ontology's scope was a definition proposed in a systematic review of behaviour change intervention engagement (Perski *et al.*, 2017). This definition read as: "*(1) the extent (e.g. amount, frequency, duration, depth) of usage and (2) a subjective experience characterised by attention, interest and affect*" (p. 258, Perski *et al.*, 2017).

Through iterative updates, intervention engagement was labelled as 'participant engagement with intervention' and defined as "*An individual human activity of an intervention participant within one or more parts of the intervention*" (see Step 6 for details on the class's creation). The term 'activity' helped capture behaviours but also any other human activity, such as cognitive processes and emotions. The final class to capture behaviour change intervention engagement was formally labelled as 'participant engagement with behaviour change intervention' and defined as *"Participant engagement with intervention, where the intervention focuses on changing behaviour.*"

Step 2: Identifying key classes and developing their preliminary definitions

Three researchers (AFM, KA, EN) extracted information from 125 full text reports related to how engagement was reported. The first draft of the ontology had 33 classes organised within or related to three upper-level classes: 1) 'behavioural engagement', 2) 'cognitive engagement' and 3) 'emotional engagement'. Other upper-level classes included 'behaviour change intervention temporal part', 'increased engagement', 'decreased engagement' and 'same engagement'. The first draft ontology version can be found on https://osf.io/m642s.

Step 3: Refining the ontology through an iterative process of literature annotation, discussion and revision

The researchers identified aspects and measures of engagement (e.g., 'attrition', 'number of posts written and read', 'task completion' and 'looking at the time') that led to several classes being changed or removed. Since defining specific engagement measures was beyond the scope of this study, the researchers instead used them to create or refine classes about the engagement aspects they tap into.

Many of the classes were kept the same but minor edits were made to the word ordering in their labels, e.g., 'duration of BCI engagement events' became 'BCI engagement event duration'. Additions to the ontology included the class 'BCI engagement event' and other classes, such as 'emotion process' and 'cognitive process', which would help structure the ontology in later steps (e.g., specifying a relationship between 'engagement through emotion process' and 'emotion process'). The following classes were removed: 'BCI temporal part', 'increased engagement', 'decreased engagement' and 'same engagement', along with the lower-level classes for 'average', 'minimum' and 'maximum' values of the number, frequency and duration of BCI engagement events. The updated ontology had 28 classes, with 'BCI engagement event', 'behavioural engagement', 'cognitive engagement' and 'emotional engagement' as top-level classes. The resulting version of the ontology can be accessed here: https://osf.io/9yg5a.

Step 4: Expert stakeholder review

Of the 100 experts contacted, 43 agreed to participate in the survey, with 27 completing it in full. Of these, the majority were from the well-represented countries within our stakeholder group (UK, USA, Canada, Australia and Netherlands) and six were from under-represented countries (France, UAE, Switzerland, Spain and Singapore). The primary areas of expertise included psychology (behavioural and health) and public health, with others having expertise in sustainability, mathematics, computer science and implementation science.

The comments from the experts related to behavioural, cognitive and emotional engagement. Of the 27 participants, 21 reported that at least one engagement characteristic was missing from the ontology, 18 indicated that at least one label or definition of a class needed changing, and nine indicated a need to change the structure of one or more classes. The full data received from participants regarding the Intervention Engagement Ontology can be found at: https://osf.io/5jmwx

Team discussion of stakeholders' comments led to the responses that can be found on https://osf.io/r7jby. The changes made to the ontology included:

- Adding 25 classes, including five to capture various aspect of engagement (e.g., emotional engagement relating to mistrust) and 20 as subclasses to capture the mean, median, maximum and minimum data associated with classes, such as 'behavioural BCI engagement duration'
- Removing 5 top-level classes from the Basic Formal Ontology (not specific to engagement), such as 'process', from being explicitly presented as part of the Intervention Engagement Ontology
- Changing 13 class labels (e.g., 'behavioural engagement' became 'behavioural behaviour change intervention engagement') and 10 classes' definitions
- Updating the parent classes of two classes (e.g., the parent class of 'behavioural BCI engagement frequency' was updated to 'BCI attribute')
- Adding or updating the informal definitions of seven classes, examples of three classes and elaborations of eight classes.

The updated version of the ontology had 48 classes and can be found on https://osf.io/tvebq. Of the 48 classes, 10 were not applied in the next step to annotate engagement in behaviour change intervention reports. This was because these classes (e.g., 'emotional process') supported the understanding of classes specific to engagement (e.g., 'emotional BCI engagement through emotional process') but did not capture engagement itself. The class 'behaviour change intervention engagement' was considered too broad for annotation, leaving 37 classes that were included for testing inter-rater reliability.

Step 5: Testing inter-rater reliability and making revisions

Two researchers familiar with the Intervention Engagement Ontology had 'acceptable' inter-rater reliability ($\alpha = 0.71$) when applying this ontology to annotate references to engagement in published intervention reports. The ***inter-rater reliability*** for each annotated class across the 50 reports can be found here: https://osf.io/za4jb. Following minor updates to the annotation manual, the two researchers unfamiliar with the ontology also had an 'acceptable' inter-rater reliability ($\alpha = 0.78$) when applying the Intervention Engagement Ontology in annotations. For each class, the inter-rater reliability for annotated classes across the 50 reports in this second round can be found here: https://osf.io/bzpgc.

Step 6: Specifying relationships between classes in the ontology

Key relationships drawn from the Basic Formal Ontology and the Relation Ontology (Smith *et al.*, 2005) were specified between classes. For example, to specify parent class-subclass relationships, the relationship *'is_a'* was used, e.g., 'behavioural BCI engagement' *is_a* 'BCI engagement'. In addition, drawing on the Information Artifact Ontology (Ceusters, 2012), we used the relationship, '*is_about*' [IAO:0000136] to represent one class presenting information about another class (e.g., 'minimum behavioural BCI engagement frequency' *is_about* 'behavioural BCI engagement'). Where needed, new relationships were developed for the BCIO. For example, the relationship 'has_process_part' was developed to link processes, such as 'appraisal process', to the relevant engagement process (e.g., 'cognitive BCI engagement through appraisal process').

To align the Intervention Engagement Ontology with the BCIO Schedule Ontology (Marques *et al.*, 2024a), five classes were added, and minor changes were made to the labels or definitions of 22 classes. Most changes related to classes about statistical data: The five new classes captured general statistical data for specific aspects of engagement (e.g., 'behavioural BCI engagement number statistic [BCIO:050525] and 'behavioural BCI engagement frequency statistic' [BCIO:050524]), under which the 20 classes to capture the minimum, maximum, mean and median data were organised. Accordingly, the changes to 20 classes related to this reorganisation (e.g., changes in their definitions to reflect their new parent classes). Two of the remaining updated classes were 'number of behavioural BCI engagements' [BCIO:013015] and 'behavioural BCI engagement frequency' [BCIO:013020]. For both, their parent classes were changed from 'BCI attribute' to 'data item' [IAO:0000027] and their definitions were updated accordingly. The class 'appraisal process' was also replaced with the class 'judging' [MF: 0000006], due to changes to the class 'appraisal process' (label changed to 'emotional relevance appraisal process' [MFOEM:000002]) in the Emotion Ontology (Hastings *et al.*, 2011). The corresponding engagement class 'cognitive BCI engagement through appraisal process' was changed to 'cognitive BCI engagement through judging' [BCIO: 013055] and its definition was updated accordingly.

A change was also made to the definition of 'mistrust' [MFOEM:000225] based on the comments of the Emotion Ontology (Hastings *et al.*, 2011) developers, and to the definition of 'attending' [MF:0000018] from the Mental Functioning Ontology in line with updates to this class (Hastings *et al.*, 2012).

To align with the Mental Health Ontology (Schenk *et al.*, 2024a), one broad engagement class was added 'participant engagement with intervention' [BCIO:050916] (definition: "*An individual human activity of an intervention participant within one or more parts of the intervention*"), capturing engagement with any intervention. Based on this change, the label and definition of 'behaviour change intervention engagement' [BCIO:013000] were also updated to reflect this broader class as its new parent class. The updated label and definition read as "participant engagement with behaviour change intervention**:** *Participant engagement with intervention, where the intervention focuses on changing behaviour*". At the end of this step, the Intervention Engagement Ontology included 54 classes.

Step 7: Disseminating and maintaining the ontology

The first published version of the Intervention Engagement Ontology comprises 54 classes, with 44 classes specific to engagement and 10 classes supporting the definitions of engagement classes (e.g., 'cognitive process'). Of the 44 classes specific to engagement, 21 represent unique aspects of intervention engagement (e.g., cognitive BCI engagement through attention, emotional BCI engagement through emotion, behavioural BCI engagement), while 25 are aggregate data items (e.g., statistic, minimum, maximum, mean, median). The classes were organised across three hierarchical levels with seven upper-level classes for engagement. The ontology's simplified version, with the 21 classes representing unique aspects of engagement, can be found in Table 2, while the ontology's complete version at time of publication (with its 54 classes) can be found on: https://osf.io/tvw9r.

Table 2. The simplified version of the Intervention Engagement Ontology, with 20 classes capturing unique aspects of intervention engagement, and their labels, alphanumeric identifiers, definitions, informal definitions, examples and elaborations.

Level 1	Level 2	Level 3	Level 4	Definition	Examples
participant engagement with intervention *BCIO:050916*				An individual human activity of an intervention participant within one or more parts of the intervention.	
	participant engagement with behaviour change intervention *BCIO:013000*			Participant engagement with intervention, where the intervention focuses on changing behaviour.	
		cognitive BCI engagement *BCIO:013040*		Participant engagement with behaviour change intervention in which the engagement activity is a cognitive process.	
			cognitive BCI engagement through attention *BCIO:013045*	A cognitive BCI engagement that involves attending.	Paying attention to certain images or information within the intervention

Level 1	Level 2	Level 3	Level 4	Definition	Examples
			cognitive BCI engagement through comprehension *BCIO:013050*	A cognitive BCI engagement that involves comprehension.	Comprehension of meaning, requirements or importance. Formal testing, providing feedback
			cognitive BCI engagement through judging *BCIO:013055*	A cognitive BCI engagement that involves a judging process.	
		emotional BCI engagement *BCIO:013060*		Participant engagement with behaviour change intervention in which the engagement activity is an emotion process.	Enjoying or liking the intervention
			emotional BCI engagement through enjoyment *BCIO:013065*	Emotional BCI engagement that involves enjoyment.	
			emotional BCI engagement through fear *BCIO:050526*	Emotional BCI engagement that involves fear.	
			emotional BCI engagement through interest *BCIO:013075*	Emotional BCI engagement that involves interest.	
			emotional BCI engagement through satisfaction *BCIO:013070*	Emotional BCI engagement that involves satisfaction.	
			emotional BCI engagement through mistrust *BCIO:050527*	Emotional BCI engagement that involves mistrust.	
		behavioural BCI engagement *BCIO:013010*		Participant engagement with behaviour change intervention in which the engagement activity is a behaviour..	Eye movements, body movements, meditation, attending an intervention session, using nicotine patches in a smoking cessation intervention, or online activity: attending, logging in, posting on a discussion board, reading content, mouse clicks, viewing, using tools, journaling

Level 1	Level 2	Level 3	Level 4	Definition	Examples
			number of behavioural BCI engagements* *BCIO:013015*	A data item that is about the number of times behavioural BCI engagement occurs.	Number of: sessions attended, worksheets initiated, log ins, online posts, online responses. The amount of content viewed or the number of non-consecutive days an intervention was engaged with (e.g., the app was used on 20 days out of a possible 60 days).
			behavioural BCI engagement frequency* *BCIO:013020*	A data item that is about the number of times behavioural BCI engagement occurs within a unit of time.	Hourly, daily, weekly or monthly encounters.
			behavioural BCI engagement duration* *BCIO:013025*	A temporal interval between the start and end of a behavioural BCI engagement.	A 30-minute session, 1 hour spent 'logged in'
	aggregate behavioural BCI engagement duration* *BCIO:013030*			A temporal interval that is the sum of the duration of behavioural BCI engagements for a BCI.	90 minutes total app usage, 12 hours of counselling sessions
	BCI engagement period* *BCIO:013035*			A temporal interval between the start of the first behavioural BCI engagement and the end of the last behavioural BCI engagement.	The video content was accessed for 6 weeks, the classes were attended for 12 months.
	temporal reference point associated with behavioural BCI engagement *BCIO:050549*			A time point against which behavioural BCI engagement is referenced.	First engagement with an app (e.g., 2 weeks after app launch)

*These classes have associated classes capturing statistical information about them (i.e., their minimum, maximum, median and mean values).

The Intervention Engagement Ontology is available in a downloadable Excel spreadsheet format, "BCIO_Engagement.xlsx", and in its owl format, labelled "bcio_engagement.owl", from GitHub (https://github.com/HumanBehaviourChangeProject/ontologies/tree/master/Engagement; see view of relevant pages in Figure 2 and Figure 3). As GitHub allows for ***versioning***, each version of the ontology can be found in this repository. An issue tracker on GitHub (https://github.com/HumanBehaviourChangeProject/ontologies/issues) allows users to provide comments and feedback on the ontology. This feedback can be submitted by creating a "New issue" on the issue tracker. Updates to the ontology will be regularly published if any changes are required based on feedback or continued development.

Additional detail on the development of the ontology and how it can be used to annotate behaviour change intervention reports (https://osf.io/abg9k) can be found on the HBCP Open Science Framework folder: https://osf.io/h4sdy/. Classes in the

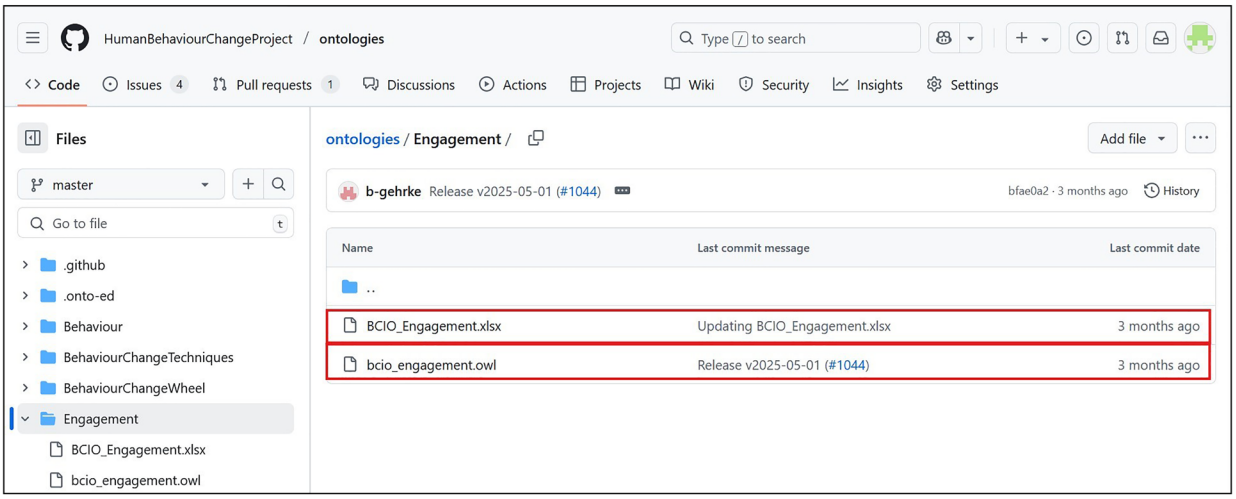

Figure 2. Screenshot of Intervention Engagement Ontology files on GitHub.

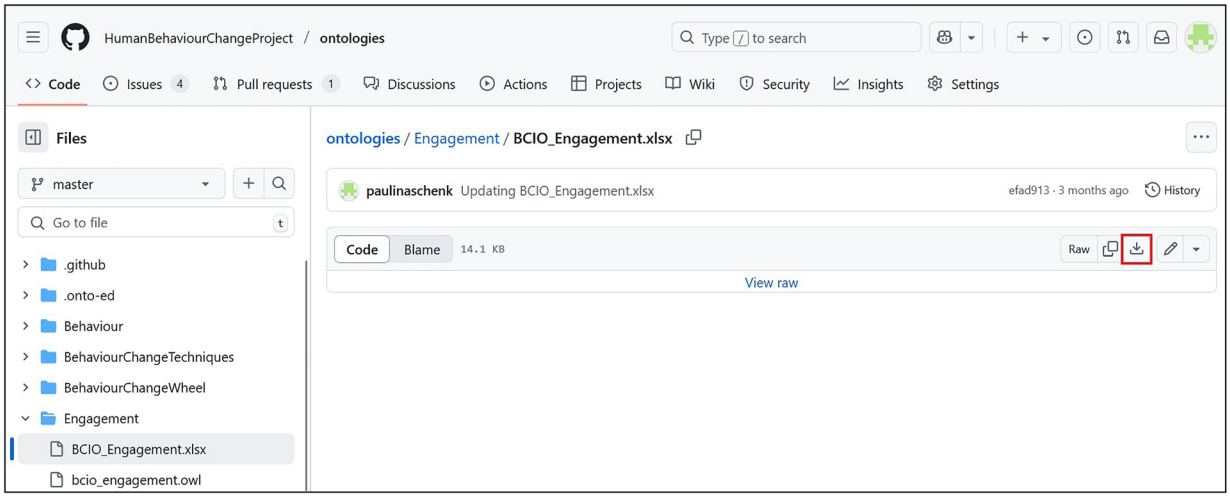

Figure 3. Screenshot of where to download the Intervention Engagement Ontology as xlsx spreadsheet on GitHub.

Intervention Engagement Ontology can also be searched through BCIO Search (https://www.bciosearch.org) and visualised through BCIOVisualise (https://bciovis.hbcptools.org/).

Discussion

This study developed the Intervention Engagement Ontology as part of the BCIO to enable precise reporting of how people engage with interventions. It has 54 classes across three hierarchical levels, covering behavioural, cognitive (e.g., attention, judging and comprehension) and emotional (e.g., enjoyment, satisfaction and fear) engagement. It also enables precise reporting of temporal aspects of engagement, including the number, frequency, duration and period of participants' engagement with an intervention. It therefore provides an extensive and reliable formal structure to specify characteristics of engagement with behaviour change interventions, as well as a basis to improve assessment of engagement in the evaluation of interventions. Inter-rater reliability for annotating research reports using the Intervention Engagement Ontology was found to be acceptable for those familiar ($\alpha = 0.71$) and unfamiliar ($\alpha = 0.78$) with the ontology.

The complexity and variation in how 'engagement' is defined in the literature (Doherty & Doherty, 2018) meant that we needed to refer to a wide range of sources to develop an ontological definition for 'participant engagement with behaviour change intervention' and thereby specify the ontology's scope. The subjective and behavioural dimensions of engagement (Bijkerk *et al.*, 2023; Perski *et al.*, 2017; Walton *et al.*, 2017) were formally captured through the ontology's upper-level classes for cognitive, emotional and behavioural engagement. Consistent with previous findings (Bauermeister *et al.*, 2017; Nelson *et al.*, 2016;

Rookes *et al.*, 2022; Walton *et al.*, 2017), when applying this ontology to annotate references to engagement, researchers found that engagement was under- or partially reported in the literature, suggesting the need for clearer and more detailed reporting about engagement.

The Intervention Engagement Ontology is linked to and ***interoperable*** with the other lower-level ontologies within the BCIO, including the Behaviour Change Technique (Marques *et al.*, 2024b), Intervention Source (Norris *et al.*, 2021b), Mode of Delivery (Marques *et al.*, 2021), Schedule (Marques *et al.*, 2024a), Setting (Norris *et al.*, 2020), Population (Wright *et al.*, 2025), Mechanism of Action (Schenk *et al.*, 2024c) and Human Behaviour Ontologies (Schenk *et al.*, 2024b). As the Intervention Engagement Ontology includes classes about the temporal aspects of engagement (e.g., frequency of engagement with an intervention), its structure is closely aligned with the Schedule Ontology (Marques *et al.*, 2024a), which more broadly characterise temporal aspects of interventions. Conceptually the Intervention Engagement Ontology is closely related with the Fidelity Ontology (Wright *et al.*, in prep), with the Fidelity Ontology capturing the adherence of those providing an intervention and the Intervention Engagement Ontology capturing participants' responses to an intervention. These two ontologies enable the precise reporting of how the intervention is implemented and received in context.

Engagement is influenced by various aspects of the intervention (e.g., its content, delivery and sources) and its context (e.g., target population characteristics and the setting) (Perski *et al.*, 2017). By drawing on the classes in the Intervention Engagement Ontology and the wider BCIO, researchers can formally represent detailed and complex information about engagement with interventions. This means that the BCIO can be used to support clear and transparent hypothesising, testing, reporting and synthesising of evidence about engagement, including how engagement is influenced by an intervention, and how engagement influences intervention outcomes. Evidence structured with the BCIO can also be used to further develop automated or semi-automated extraction and prediction tools (Hastings *et al.*, 2023; West *et al.*, 2024)

Strengths and limitations

The current study broadly followed the method for ontology development used in the HBCP (Wright *et al.*, 2020), adapting these steps to fit the requirements of the current scope for engagement. A strength of this method was the integration of stakeholder feedback to improve the ontology's classes and structure (Norris *et al.*, 2021a). We also iteratively updated the Intervention Engagement Ontology to align with other BCIO lower-level ontologies and external ontologies, such as the Mental Health Ontology (Schenk *et al.*, 2024a). This alignment allows users to easily apply these ontologies together and integrate data annotated with these ontologies (He *et al.*, 2018; Wright *et al.*, 2020).

An important step in developing ontologies is drawing on and annotating reports of engagement in the literature. However, as engagement is often underreported, there were challenges in identifying relevant articles. Some of these challenges were addressed by selectively identifying studies reporting engagement (e.g., through systematic reviews). However, our identified articles may have focused more on specific types of interventions (e.g., digital interventions) and only a subset of behavioural domains. Based on these articles, the ontology content (e.g., class examples) may reflect engagement in these areas better than in other domains and potentially underrepresent examples of engagement in domains where it is reported less. Future iterations of the ontology can be updated to reflect more examples and classes from a broader range of domains (see Future directions; Arp *et al.*, 2015; Hastings *et al.*, 2024; He *et al.*, 2018; Matentzoglu *et al.*, 2022).

Another key challenge when developing the Intervention Engagement Ontology was deciding on the level of detail for its classes. For example, there are numerous behaviours that could be included as potential subclasses for behavioural engagement (e.g., clicking behaviours, viewing intervention content, attending sessions, signing up to sessions). For the current ontology, we kept the classes at a very broad level (e.g., only including an upper-level class for behavioural engagement, rather than its subclasses) and recorded various granular aspects of engagement as examples of relevant classes. This provides an overview of intervention engagement, allowing users to familiarise themselves with the ontology's structure before adding more detail to it. Due to the flexible structure of ontologies (He *et al.*, 2018), new classes can be added to represent specific types of engagement in greater detail as and when needed (see Future directions).

Future directions

Many reviewed articles included reports of measures for engagement (e.g., attendance level, activity log, recall etc). These were organised and categorised as part of the early steps of ontology development but specifying these in detail was beyond the current version's scope. Future work is needed to organise measurements of engagement and link them to relevant classes. Such links can provide ontology users with guidance on how to operationalise and evaluate aspects of intervention engagement.

Intervention engagement is a not a linear process but can change over time (Domian *et al.*, 2010; Lin *et al.*, 2015; Scherer *et al.*, 2017). For example, there may be peaks in app usage and people may attend intervention sessions less over time. Accordingly, the Intervention Engagement Ontology classes do not intend to capture engagement statically. Ontology users need to apply these broad engagement classes flexibly, capturing levels of engagement at various timepoints that are relevant for their use case. For example, the broad class for timepoints associated within intervention engagement ("temporal reference point associated with behavioural BCI engagement" [BCIO:050549]) can be used in annotations. However, to make their annotations meaningful, ontology users need to further specify detail on timings relevant to their use case (e.g., 1 month following intervention start). The Schedule Ontology (Marques *et al.*, 2024a) could be used in combination with the Intervention Engagement Ontology for such annotations.

To support users in applying and contributing to the development of the BCIO and its lower-level ontologies, there are

systematic efforts to provide more detailed guidance on using the ontology and updating it based on feedback from users. For example, there are training sessions on a bespoke HBCP YouTube channel https://www.youtube.com/@humanbehaviourchange-project.

A new project to carry this work forward has been funded 2024–2029: the Advancing Prevention Research in Cancer through Ontology Tools (APRICOT) Project (Michie *et al.*, 2024). This will develop a variety of tools, resources, including user manuals for the BCIO, based on community feedback. Tools and resources will be shared as they are developed on the joint HBCP/APRICOT website, www.humanbehaviourchange.org. A Community of Practice platform will also be developed and serve as a space for users to discuss applications of ontologies; the details about this platform will be shared on the project website.

Conclusion

The Intervention Engagement Ontology provides a classification system for specifying and precisely describing aspects of participants' engagement with a behaviour change intervention, using a shared language that is computer readable. This enables precise reporting, hypothesis generation, data and knowledge syntheses and complex data analyses about intervention engagement. This first version of the ontology broadly represents and logically organises aspects of engagement, which can be elaborated through wider application and collaboration, thereby contributing to a strong evolving knowledge base.

Please also note that while several of these classes are not subclasses of 'behavioural BCI engagement', they capture data items about behavioural engagement (e.g., its frequency) and so have been presented underneath the relevant class.

Ethics and consent

Ethical approval was granted by University College London's Research Ethics Committee (CEHP/2020/579) in February 2020. Participants provided informed written consent via an online Qualtrics survey before starting the review.

Data availability

Underlying data

Open Science Framework: Human Behaviour-Change Project. https://doi.org/10.17605/OSF.IO/EFP4X (West *et al.*, 2020): The relevant data can be accessed under the Behavioural Science Component of the registration

This project contains the following underlying data:

- Expert stakeholder feedback on Intervention Engagement Ontology; Raw feedback received from behavioural science and ontology experts; https://osf.io/5jmwx

Extended data

Open Science Framework: Human Behaviour-Change Project. https://doi.org/10.17605/OSF.IO/EFP4X (West *et al.*, 2020): The relevant data can be accessed under the Behavioural Science Component of the registration

This project contains the following extended data:

- Papers used in the development and refinement of ontology classes (Steps 2 and 3) and testing of the application of these classes (Step 5): https://osf.io/mreyj
- Expert stakeholder survey; Full survey provided to behaviour science experts in the review in Step 4; https://osf.io/5szcb
- The classes hierarchically organised in the Intervention Engagement Ontology at the end of Step 2; https://osf.io/m642s
- The classes hierarchically organised in the Intervention Engagement Ontology at the end of Step 3; https://osf.io/9yg5a
- Log of responses for stakeholder feedback in Step 4, including decisions on changing aspects of the ontology or rationale for not making changes; https://osf.io/r7jby
- The classes hierarchically organised in the Intervention Engagement Ontology at the end of Step 4; https://osf.io/tvebq
- Inter-rater reliability testing for annotations by researchers familiar with the Intervention Engagement Ontology in Step 5; https://osf.io/za4jb
- Inter-rater reliability testing for annotations by researchers unfamiliar with the Intervention Engagement Ontology in Step 5; https://osf.io/bzpgc
- Annotation guidelines; Manual for coding using the Intervention Engagement Ontology; https://osf.io/abg9k
- The first published version of the Intervention Engagement Ontology; https://osf.io/tvw9r.

OSF page for the Human Behaviour-Change Project; Homepage for all outputs across the project; https://osf.io/h4sdy/

Zenodo: HumanBehaviourChangeProject/ontologies: https://doi.org/10.5281/zenodo.14882463 (Hastings *et al.*, 2025)

Software availability

Source code used to calculate alpha for IRR available from: https://github.com/HumanBehaviourChangeProject/Automation-InterRater-Reliability.

Archived code at time of publication: https://doi.org/10.5281/zenodo.3833816 (Finnerty & Moore, 2020)

License: GNU General Public License v3.0 only

Acknowledgements

We are grateful to Ella Howes for annotating papers during the inter-rater reliability testing stage, and Kristina Pfeffer for supporting work in organising annotation data to review for potential refinements to the ontology.

References

Alrashidi O, Phan HP, Ngu BH: **Academic engagement: an overview of its definitions, dimensions, and major conceptualisations.** *Int Educ Stud.* 2016; **9**(12): 41–52.
Publisher Full Text

Arp R, Smith B, Spear AD: **Building ontologies with basic formal ontology**. Mit Press, 2015.
Publisher Full Text

Bauermeister JA, Golinkoff JM, Muessig KE, *et al.*: **Addressing engagement in technology-based behavioural HIV interventions through paradata metrics.** *Curr Opin HIV AIDS.* 2017; **12**(5): 442–446.
PubMed Abstract | Publisher Full Text | Free Full Text

Ben-Eliyahu A, Moore D, Dorph R, *et al.*: **Investigating the multidimensionality of engagement: affective, behavioral, and cognitive engagement across science activities and contexts.** *Contemp Educ Psychol.* 2018; **53**: 87–105.
Publisher Full Text

Bijkerk LE, Oenema A, Geschwind N, *et al.*: **Measuring engagement with mental health and behavior change interventions: an integrative review of methods and instruments.** *Int J Behav Med.* 2023; **30**(2): 155–166.
PubMed Abstract | Publisher Full Text | Free Full Text

Bond M, Finnerty A, O'Mara-Eves A, *et al.*: **Digital evidence synthesis tool evaluations**. EPPI Visualiser Database, 2024.
Reference Source

Bright FA, Kayes NM, Worrall L, *et al.*: **A conceptual review of engagement in healthcare and rehabilitation.** *Disabil Rehabil.* 2015; **37**(8): 643–654.
PubMed Abstract | Publisher Full Text

Carey RN, Connell LE, Johnston M, *et al.*: **Behavior change techniques and their mechanisms of action: a synthesis of links described in published intervention literature.** *Ann Behav Med.* 2019; **53**(8): 693–707.
PubMed Abstract | Publisher Full Text | Free Full Text

Ceusters W: **An information artifact ontology perspective on data collections and associated representational artifacts.** *Stud Health Technol Inform.* IOS Press, 2012; **180**: 68–72.
PubMed Abstract | Publisher Full Text

Doherty K, Doherty G: **Engagement in HCI: conception, theory and measurement.** *ACM Computing Surveys (CSUR).* 2018; **51**(5): 1–39.
Publisher Full Text

Domian EW, Baggett KM, Carta JJ, *et al.*: **Factors influencing mothers' abilities to engage in a comprehensive parenting intervention program.** *Public Health Nurs.* 2010; **27**(5): 399–407.
PubMed Abstract | Publisher Full Text | Free Full Text

Dusseldorp E, van Genugten L, van Buuren S, *et al.*: **Combinations of techniques that effectively change health behavior: evidence from Meta-CART analysis.** *Health Psychol.* 2014; **33**(12): 1530–1540.
PubMed Abstract | Publisher Full Text

Ellis ML, Lindsey MA, Barker ED, *et al.*: **Predictors of engagement in a school-based family preventive intervention for youth experiencing behavioral difficulties.** *Prev Sci.* 2013; **14**(5): 457–467.
PubMed Abstract | Publisher Full Text | Free Full Text

European Bioinformatics Institute: **Ontology lookup service**. 2019.
Reference Source

Finnerty A, Moore C: **Humanbehaviourchangeproject/automation-interrater-reliability: release of HBCP inter-rater reliability code v1. 0.0 (Version v1. 0.0).** *Zenodo.* 2020.
https://doi.org/10.5281/zenodo.3833816

Gene Ontology Consortium: **The gene ontology resource: 20 years and still GOing strong.** *Nucleic Acids Res.* 2019; **47**(D1): D330–D338.
PubMed Abstract | Publisher Full Text | Free Full Text

Glasgow RE, Harden SM, Gaglio B, *et al.*: **RE-AIM planning and evaluation framework: adapting to new science and practice with a 20-year review.** *Front Public Health.* 2019; **7**: 64.
PubMed Abstract | Publisher Full Text | Free Full Text

Gwet KL: **Handbook of inter-rater reliability: the definitive guide to measuring the extent of agreement among raters**. Advanced Analytics, LLC, 2014.
Reference Source

Hankonen N: **Participants' enactment of behavior change techniques: a call for increased focus on what people do to manage their motivation and behavior.** *Health Psychol Rev.* 2021; **15**(2): 185–194.
PubMed Abstract | Publisher Full Text

Harris RV, Lowers V, Van Der Zande M, *et al.*: **Designing complex interventions: a description of the development of an intervention to reduce inequalities in planned dental visiting.** *Community Dent Oral Epidemiol.* 2023; **51**(6): 1118–1129.
PubMed Abstract | Publisher Full Text

Hastings J, Ceusters W, Jensen M, *et al.*: **Representing mental functioning: ontologies for mental health and disease**. 2012.
Reference Source

Hastings J, Ceusters W, Smith B, *et al.*: **Dispositions and processes in the emotion ontology**. 2011.
Reference Source

Hastings J, Glauer M, West R, *et al.*: **Predicting outcomes of smoking cessation interventions in novel scenarios using ontology-informed, interpretable machine learning [version 1; peer review: 1 approved, 1 approved with reservations].** *Wellcome Open Res.* 2023; **8**: 503.
Publisher Full Text

Hastings J, Norris E, Finnerty AN, *et al.*: **Human Behaviour Change Project/ ontologies: Behaviour Change Technique Ontology, Mechanism of Action Ontology.** (Version v2024.12). *Zenodo*. 2025.

Hastings J, Zhang L, Schenk P, *et al.*: **The BSSO foundry: a community of practice for ontologies in the behavioural and social sciences [version 1; peer review: 1 approved, 3 approved with reservations].** *Wellcome Open Res.* 2024; **9**: 656.
PubMed Abstract | Publisher Full Text | Free Full Text

Hawkes RE, Miles LM, Ainsworth B, *et al.*: **Engagement with a nationally-implemented digital behaviour change intervention: usage patterns over the 9-month duration of the National Health Service Digital Diabetes Prevention Programme.** *Internet Interv.* 2023; **33**: 100647.
PubMed Abstract | Publisher Full Text | Free Full Text

Hayes AF, Krippendorff K: **Answering the call for a standard reliability measure for coding data.** *Commun Methods Meas.* 2007; **1**(1): 77–89.
Publisher Full Text

He Y, Xiang Z, Zheng J, *et al.*: **The eXtensible Ontology Development (XOD) principles and tool implementation to support ontology interoperability.** *J Biomed Semantics.* 2018; **9**(1): 3.
PubMed Abstract | Publisher Full Text | Free Full Text

Hightow-Weidman LB, Bauermeister JA: **Engagement in mHealth behavioral interventions for HIV prevention and care: making sense of the metrics.** *Mhealth.* 2020; **6**: 7.
PubMed Abstract | Publisher Full Text | Free Full Text

Holdsworth E, Bowen E, Brown S, *et al.*: **Client engagement in psychotherapeutic treatment and associations with client characteristics, therapist characteristics, and treatment factors.** *Clin Psychol Rev.* 2014; **34**(5): 428–450.
PubMed Abstract | Publisher Full Text

Jackson RC, Balhoff JP, Douglass E, *et al.*: **ROBOT: a tool for automating ontology workflows.** *BMC Bioinformatics.* 2019; **20**(1): 407.
PubMed Abstract | Publisher Full Text | Free Full Text

Karekla M, Kasinopoulos O, Neto DD, *et al.*: **Best practices and recommendations for digital interventions to improve engagement and adherence in chronic illness sufferers.** *Eur Psychol.* 2019.
Publisher Full Text

Kreyenbuhl J, Nossel IR, Dixon LB: **Disengagement from mental health treatment among individuals with schizophrenia and strategies for facilitating connections to care: a review of the literature.** *Schizophr Bull.* 2009; **35**(4): 696–703.
PubMed Abstract | Publisher Full Text | Free Full Text

Krippendorff K: **The content analysis reader**. Sage, 2009.
Reference Source

Krippendorff K: **Agreement and information in the reliability of coding.** *Commun Methods Meas.* 2011; **5**(2): 93–112.
Publisher Full Text

Lakind D, Bradley WJ, Patel A, *et al.*: **A Multidimensional examination of the measurement of treatment engagement: implications for children's mental health services and research.** *J Clin Child Adolesc Psychol.* 2022; **51**(4): 453–468.
PubMed Abstract | Publisher Full Text | Free Full Text

Lin PH, Intille S, Bennett G, *et al.*: **Adaptive intervention design in mobile health: intervention design and development in the Cell Phone Intervention for You trial.** *Clin Trials.* 2015; **12**(6): 634–645.
PubMed Abstract | Publisher Full Text | Free Full Text

Lorencatto F, West R, Stavri Z, *et al.*: **How well is intervention content described in published reports of smoking cessation interventions?** *Nicotine Tob Res.* 2013; **15**(7): 1273–1282.
PubMed Abstract | Publisher Full Text

Marques MM, Carey RN, Norris E, *et al.*: **Delivering Behaviour Change Interventions: development of a mode of delivery ontology [version 2; peer review: 2 approved].** *Wellcome Open Res.* 2021; **5**: 125.
PubMed Abstract | Publisher Full Text | Free Full Text

Marques MM, West R, Moore C, *et al.*: **Specifying the schedule of delivery of interventions within the Behaviour Change Intervention Ontology [version 1; peer review: 4 approved with reservations, 1 not approved].** *Wellcome Open Res.* 2024a; **9**: 721.
Publisher Full Text

Marques M, Wright A, Corker E, *et al.*: **The Behaviour Change Technique Ontology: transforming the Behaviour Change Technique Taxonomy v1 [version 2; peer review: 4 approved].** *Wellcome Open Res.* 2024b; **8**: 308.
PubMed Abstract | Publisher Full Text | Free Full Text

Matentzoglu N, Goutte-Gattat D, Tan SZK, *et al.*: **Ontology Development Kit: a toolkit for building, maintaining and standardizing biomedical ontologies.** *Database (Oxford).* 2022; **2022**: baac087.
PubMed Abstract | Publisher Full Text | Free Full Text

Matentzoglu N, Malone J, Mungall C, *et al.*: **MIRO: guidelines for Minimum Information for the Reporting of an Ontology.** *J Biomed Semantics.* 2018; **9**(1): 1–13.
PubMed Abstract | Publisher Full Text | Free Full Text

Mavergames C, Everett J, Becker L, *et al.*: **Cochrane PICO Ontology**. 2019.
Reference Source

Michie S, Thomas J, Johnston M, *et al.*: **The Human Behaviour-Change Project: harnessing the power of artificial intelligence and machine learning for evidence synthesis and interpretation.** *Implement Sci.* 2017a; **12**(1): 121.
PubMed Abstract | Publisher Full Text | Free Full Text

Michie S, West R, Finnerty AN, *et al.*: **Representation of Behaviour Change Interventions and their evaluation: development of the upper level of the Behaviour Change Intervention Ontology [version 2; peer review: 2 approved].** *Wellcome Open Res.* 2020; **5**: 123.
PubMed Abstract | Publisher Full Text | Free Full Text

Michie S, West R, Hastings J: **Creating ontological definitions for use in science.** *Qeios.* 2019.
Publisher Full Text

Michie S, West R, Hastings J, *et al.*: **The Human Behaviour-Change Project phase 2: advancing behavioural and social sciences through ontology tools [version 1; peer review: not peer reviewed].** *Wellcome Open Res.* 2024; **9**: 730.
Publisher Full Text

Michie S, Yardley L, West R, *et al.*: **Developing and evaluating digital interventions to promote behavior change in health and health care: recommendations resulting from an international workshop.** *J Med Internet Res.* 2017b; **19**(6): e232.
PubMed Abstract | Publisher Full Text | Free Full Text

Moher D, Hopewell S, Schulz KF, *et al.*: **CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials.** *BMJ.* 2010; **340**: c869.
PubMed Abstract | Publisher Full Text | Free Full Text

Morawska A, Sanders M: **A review of parental engagement in parenting interventions and strategies to promote it.** *J Child Serv.* 2006; **1**(1): 29–40.
Publisher Full Text

Morrison L, Moss-Morris R, Michie S, *et al.*: **Optimizing engagement with Internet-based health behaviour change interventions: comparison of self-assessment with and without tailored feedback using a mixed methods approach.** *Br J Health Psychol.* 2014; **19**(4): 839–855.
PubMed Abstract | Publisher Full Text | Free Full Text

Murray JM, Brennan SF, French DP, *et al.*: **Mediators of behavior change maintenance in physical activity interventions for young and middle-aged adults: a systematic review.** *Ann Behav Med.* 2018; **52**(6): 513–529.
PubMed Abstract | Publisher Full Text

Nahum-Shani I, Shaw SD, Carpenter SM, *et al.*: **Engagement in digital interventions.** *Am Psychol.* 2022; **77**(7): 836–852.
PubMed Abstract | Publisher Full Text | Free Full Text

Nelson LA, Coston TD, Cherrington AL, *et al.*: **Patterns of user engagement with mobile- and web-delivered self-care interventions for adults with T2DM: a review of the literature.** *Curr Diab Rep.* 2016; **16**(7): 66.
PubMed Abstract | Publisher Full Text | Free Full Text

Noar SM, Benac CN, Harris MS: **Does tailoring matter? Meta-analytic review of tailored print health behavior change interventions.** *Psychol Bull.* 2007; **133**(4): 673–93.
PubMed Abstract | Publisher Full Text

Norris E, Hastings J, Marques MM, *et al.*: **Why and how to engage expert stakeholders in ontology development: insights from social and behavioural sciences.** *J Biomed Semantics.* 2021a; **12**(1): 4.
PubMed Abstract | Publisher Full Text | Free Full Text

Norris E, Marques MM, Finnerty AN, *et al.*: **Development of an intervention setting ontology for behaviour change: specifying where interventions take place [version 1; peer review: 2 approved].** *Wellcome Open Res.* 2020; **5**: 124.
PubMed Abstract | Publisher Full Text | Free Full Text

Norris E, Wright AJ, Hastings J, *et al.*: **Specifying who delivers behaviour change interventions: development of an intervention source ontology [version 1; peer review: 2 approved, 1 approved with reservations].** *Wellcome Open Res.* 2021b; **6**: 77.
PubMed Abstract | Publisher Full Text | Free Full Text

Palsola M, Renko E, Kostamo K, *et al.*: **Thematic analysis of acceptability and fidelity of engagement for behaviour change interventions: the let's move it intervention interview study.** *Br J Health Psychol.* 2020; **25**(3): 772–789.
PubMed Abstract | Publisher Full Text

Perski O, Baretta D, Blandford A, *et al.*: **Engagement features judged by excessive drinkers as most important to include in smartphone applications for alcohol reduction: a mixed-methods study.** *Digit Health.* 2018; **4**: 2055207618785841.
PubMed Abstract | Publisher Full Text | Free Full Text

Perski O, Blandford A, West R, *et al.*: **Conceptualising engagement with digital behaviour change interventions: a systematic review using principles from critical interpretive synthesis.** *Transl Behav Med.* 2017; **7**(2): 254–267.
PubMed Abstract | Publisher Full Text | Free Full Text

Rookes TA, Schrag A, Walters K, *et al.*: **Measures of fidelity of delivery and engagement in self-management interventions: a systematic review of measures.** *Clin Trials.* 2022; **19**(6): 665–672.
PubMed Abstract | Publisher Full Text | Free Full Text

Saleem M, Kühne L, De Santis K, *et al.*: **Navigating the complexity of user engagement: need for normative evaluations in digital interventions.** *Eur J Public Health.* 2024; **34**(Supplement_ 3): ckae144–132.
Publisher Full Text

Schenk PM, Hastings J, Santilli M, *et al.*: **Towards an ontology of mental health: protocol for developing an ontology to structure and integrate evidence regarding anxiety, depression and psychosis [version 2; peer review: 1 approved, 3 approved with reservations].** *Wellcome Open Res.* Open Access Publishing Platform, 2024a; **9**: 40.
PubMed Abstract | Publisher Full Text | Free Full Text

Schenk PM, West R, Castro O, *et al.*: **An ontological framework for organising and describing behaviours: the human behaviour ontology [version 2; peer review: 3 approved with reservations].** *Wellcome Open Res.* 2024b; **9**(237): 237.
Publisher Full Text

Schenk PM, Wright AJ, West R, *et al.*: **An ontology of mechanisms of action in behaviour change interventions [version 2; peer review: 3 approved].** *Wellcome Open Res.* 2024c; **8**: 337.
PubMed Abstract | Publisher Full Text | Free Full Text

Scherer EA, Ben-Zeev D, Li Z, *et al.*: **Analyzing mHealth engagement: joint models for intensively collected user engagement data.** *JMIR Mhealth Uhealth.* 2017; **5**(1): e1.
PubMed Abstract | Publisher Full Text | Free Full Text

Schubart JR, Stuckey HL, Ganeshamoorthy A, *et al.*: **Chronic health conditions and internet behavioral interventions: a review of factors to enhance user engagement.** *Comput Inform Nurs.* 2011; **29**(2): 81–92.
PubMed Abstract | Publisher Full Text | Free Full Text

Short CE, DeSmet A, Woods C, *et al.*: **Measuring engagement in eHealth and mHealth behavior change interventions: viewpoint of methodologies.** *J Med Internet Res.* 2018; **20**(11): e292.
PubMed Abstract | Publisher Full Text | Free Full Text

Smith B, Ashburner M, Rosse C, *et al.*: **The OBO foundry: coordinated evolution of ontologies to support biomedical data integration.** *Nat Biotechnol.* 2007; **25**(11): 1251–1255.
PubMed Abstract | Publisher Full Text | Free Full Text

Smith B, Ceusters W, Klagges B, *et al.*: **Relations in biomedical ontologies.** *Genome Biol.* 2005; **6**(5): R46.
PubMed Abstract | Publisher Full Text | Free Full Text

Thomas J, Brunton J, Graziosi S: **EPPI-Reviewer 4.0: software for research synthesis**. EPPI-Centre Software. London: Social Science Research Unit, Institute of Education, 2010.
Reference Source

Thomas J, Graziosi S, Brunton J, *et al.*: **EPPI-Reviewer: advanced software for systematic reviews, maps and evidence synthesis**. EPPI-Centre Software. London: UCL Social Research Institute, 2020.

Walton H, Spector A, Tombor I, *et al.*: **Measures of fidelity of delivery of, and engagement with, complex, face-to-face health behaviour change interventions: a systematic review of measure quality.** *Br J Health Psychol.* 2017; **22**(4): 872–903.
PubMed Abstract | Publisher Full Text | Free Full Text

Walton H, Spector A, Williamson M, *et al.*: **Developing quality fidelity and engagement measures for complex health interventions.** *Br J Health Psychol.* 2020; **25**(1): 39–60.
PubMed Abstract | Publisher Full Text | Free Full Text

West R, Bonin F, Thomas J, *et al.*: **Using machine learning to extract information and predict outcomes from reports of randomised trials of smoking cessation interventions in the human behaviour-change project [version 2; peer review: 3 approved, 1 approved with reservations].** *Wellcome Open Res.* 2024; **8**: 452.
PubMed Abstract | Publisher Full Text | Free Full Text

West R, Michie S, Shawe-Taylor J: **Human Behaviour-Change Project.** [Dataset]. 2020.
http://www.doi.org/10.17605/OSF.IO/UXWDB

Weston L, Rybczynska-Bunt S, Quinn C, *et al.*: **Interrogating intervention delivery and participants' emotional states to improve engagement and implementation: a realist informed multiple case study evaluation of Engager.** *PLoS One.* 2022; **17**(7): e0270691.
PubMed Abstract | Publisher Full Text | Free Full Text

Wijaya BS: **The development of hierarchy of effects model in advertising.** *Int Res J Bus Stud.* 2012; **5**(01): 73–85.
Publisher Full Text

Wright AJ, Finnerty Mutlu AN, Norris E, *et al.*: **Development of an intervention population ontology for specifying the characteristics of intervention participants [version 1; peer review: 2 not approved].** *Wellcome Open Res.* 2025; **10**: 122.
Publisher Full Text

Wright AJ, Norris E, Finnerty AN, *et al.*: **Ontologies relevant to behaviour change interventions: a method for their development [version 3; peer review: 2 approved, 1 approved with reservations].** *Wellcome Open Res.* 2020; **5**: 126.
PubMed Abstract | Publisher Full Text | Free Full Text

Yardley L, Morrison L, Muller I, *et al.*: **Maximizing user engagement with behavior change interventions**. In: *The handbook of behavior change*. Cambridge University Press, 2020; 361–371.
Publisher Full Text

Yardley L, Spring BJ, Riper H, *et al.*: **Understanding and promoting effective engagement with digital behavior change interventions.** *Am J Prev Med.* 2016; **51**(5): 833–842.
PubMed Abstract | Publisher Full Text