

PEER REVIEW REPORT

Review of: Ontologies relevant to behaviour change interventions: a method for their development [version 1; peer review: 1 not approved]

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1. Introduction

In “[Ontologies Relevant to BCIs: A Method for their Development](#)” Wright, et al. outline a step by step process for building ontologies of behaviour modification – what the authors call the Refined Ontology Developmental Method (RODM) – and demonstrate its use in the development of the Behaviour Change Intervention Ontology (BCIO). RODM is based on the principles of good ontology building used by the Open Biomedical Ontology (OBO) Foundry in addition to those outlined in (Arp, Smith, and Spear 2015). BCIO uses as its top-level ontology Basic Formal Ontology (BFO). The methods outlined in Wright, et al. are a valuable contribution to the field, especially the use of formal mechanisms for literature annotation and expert stakeholder review, and the BCIO will certainly play an important role in the extension of OBO Foundry ontologies into the behavioural domain.

1.1 Realist Methodology

We shall concentrate here, however, on problems with the paper as it now stands, problems which arise primarily from a lack of emphasis on the realist methodology underlying BFO and the OBO Foundry. By ‘realist methodology’ we mean that terms in an ontology should refer to real entities and not (leaving aside ontologies of psychology) ideas or concepts in the minds of individuals (Smith and Ceusters 2010). For example, the term ‘disease’ should refer to whatever it is in the world that a disease *is* (in a specific patient) rather than referring to, for example, the *idea* of a disease in the mind of a clinician. The reason for this approach is that it promotes the interoperability and scalability of the ontologies developed – in much the way that a realist approach used in the sciences generally (which are not about the concepts in scientists’ minds) promotes the development of scientific theories. The underlying assumption is that there are no contradictions in reality, and thus, if we carefully build ontologies in such a way that their terms refer to real entities, then the results will be consistent, and thus interoperable, and the whole approach will be scalable to ever new areas or to ever more detailed levels of granularity. This approach has proved successful in the OBO Foundry (Kamdar, Tudorache, and Musen 2017).

1.1.1 Unification

The realist approach is in the interest of *unification*. By ‘unification’ we mean, at least a shared vocabulary that

allows discussants to avoid merely verbal disputes, even if there is disagreement on what the world is like. That is, unification is approached when the building blocks used to assemble theories about reality are shared, even if experts assemble those blocks in different ways. As such, unification does not require absence of disagreement. It requires only that, when disagreement occurs, it is a disagreement over the nature of some phenomenon – of reality as it is – rather than over what some phenomenon is rightly called – for example, should we call it a ‘mallard’ or a ‘duck’? An example of such a verbal dispute is provided by William James:

The corpus of the dispute was a squirrel—a live squirrel supposed to be clinging to one side of a tree-trunk; while over against the tree’s opposite side a human being was imagined to stand. This human witness tries to get sight of the squirrel by moving rapidly round the tree, but no matter how fast he goes, the squirrel moves as fast in the opposite direction, and always keeps the tree between himself and the man, so that never a glimpse of him is caught. The resultant metaphysical problem now is this: Does the man go round the squirrel or not? (James 1907, 34)

The answer is, of course, it depends on what type of activity is properly referred to by ‘go around’, and were all of the senses of ‘go around’ distinguished and given appropriate labels and definitions, then all that would be left is a dispute about which sense of ‘go around’ is the right one to use in this instance: the discussants would have achieved unification.

Unification is accomplished (at least) through having a shared vocabulary through which to express disagreement. For example, if one person claims that addiction is a disease while another claims that it is not, then to avoid merely verbal disputes it is important that ‘addiction’ and ‘disease’ mean the same thing to each person. Agreement of this sort is most readily achieved through the principle of low hanging fruit: start with vocabulary that reflects real entities unproblematically, and build up from there definitions of more complicated phenomena.

1.1.2 Scientifically Sound

Now, while the authors never use the term ‘realist’ when they describe their methodologies, they do mention the need for ontological vocabularies to be *scientifically sound*. What the authors mean by ‘scientifically sound’ is unclear but seems to be:

- 1) terms are understandable by experts, and
- 2) terms are expressive enough to refer to all relevant entities in a field.

While these conditions are important, they are not enough on their own to ensure that an ontology is realist, and thus not enough to build a good ontology. This is because, though experts in a field are generally extremely good at describing, to other experts in their field, entities relevant to their domain, they are not always good at describing them in a way that promotes the development of clear, organized, scalable, and interoperable vocabularies that can be understood also by experts in neighboring fields.

The data-driven approach outlined by the authors to building and revising ontologies should, then, be paired with a process of carefully examining how terms are used by experts in order to understand the reality being referred to, and then adjusting and adding terms so that the ontology is both understandable and usable by experts and such as to follow the structure of reality.

2 Specific Criticisms

2.1 Definitions of Key Terms

Table 1 in Wright, et al. provides a glossary of key terms used in their article (as contrasted with terms in the BCIO). There are problems with some of the definitions of these terms, however, and in the spirit of complying with realist methods of ontology building and the goal of unification, it is useful if all relevant terms are treated as

if they are or will be included in an ontology.

Artificial Intelligence: The theory and practice of building computer programs to perform tasks that a human would reasonably regard as requiring intelligence.

According to the authors, ‘Artificial Intelligence’ is defined as a concept or piece of knowledge (“theory”), which is a continuant, and as a process (“practice”), which is an occurrent. Nothing can be both a continuant and an occurrent. By the authors’ own lights, this is a bad definition because it traverses the two most fundamental categories of reality and thereby invites ambiguity when used in the article. However, to make matters worse, the authors then go on to use ‘artificial intelligence’ in what seems to be yet another sense: “*Artificial Intelligence (AI)* within the knowledge system will make predictions based on the evidence in response to users’ queries about the most effective interventions in a wide variety of situations (e.g. type of behaviour, mode of delivery, population, setting),” which seems to suggest that AI is to be understood as an algorithm (p. 13).

Interoperability: Ontology developers should collaborate with others wherever possible to re-use entities and limit duplication of work. Interoperability of ontologies sits within the OBO Foundry principle of Commitment to Collaboration.

Unfortunately, this definition (or elucidation) does not correspond to the way ‘interoperability’ is predominantly used, according to which (in the simplest version): two systems are interoperable if data coming from each system can be used by the other system.

What the authors provide, however, is not a definition of ‘interoperability’ but rather a prescriptive statement (“ontology developers *should...*”). Furthermore, it misunderstands the OBO Foundry principle of Commitment to Collaboration, which sites collaboration as having interoperability as one of its benefits, not as something that would be part of the definition of ‘interoperability’. What the authors seem to be gesturing towards is a practice of making an ontology interoperable (in the standard sense) by using pre-existing terms and definitions where applicable. Thus, they are doing little more, here, than repeating the OBO Foundry’s Commitment to Collaboration:

An expectation that Foundry ontologies will collaborate with other Foundry ontologies, particularly in ensuring orthogonality of distinct ontologies, in re-using content from other ontologies in cross-product definitions where appropriate, and in establishing and evolving Foundry principles to advance the Foundry suite of ontologies to better serve the joint users (<http://www.obofoundry.org/principles/fp-010-collaboration.html>).

2.2 Ontologies as Knowledge Graphs

The authors sometimes describe ontologies as representing knowledge. This is, of course, true in the sense that ontologies do indeed provide proxies (for instance, in the form of definitions, and of is-a and other links in the ontology graph) for items of knowledge. If ‘representing’ is understood as meaning ‘stand-in proxy for’, then ‘to represent knowledge’ comes close to capturing the goal of realist ontology development. Unfortunately, however, there is another use of ‘represent’ and this yields a reading according to which terms in an ontology should *be about* or *refer to* knowledge, and this is antithetical to the realist methodology (just as ‘ontologies represent concepts in people’s minds’ is antithetical to the realist methodology). More generally: terms like ‘knowledge representation’ should only ever be used with caution, because they run the risk of encouraging bad ontology development. Examples of Wright, et al.’s use of such terms are as follows (emphasis added): “Ontologies are *knowledge structures ...*” (abstract) or “ontologies *encapsulate knowledge...*” (p. 3).

The same issue occurs in another paper developing the lower-level Mode of Delivery (MoD) Ontology that extends the BCIO (Marques, et al., “Delivering Behaviour Change Interventions: Development of a Mode of Delivery Ontology” [version 1]), and which shared a number of the same authors, where it is asserted that, “An

ontology is a more expressive structure *for organizing knowledge,*” (p. 3, emphasis added) and that, “The research team developed relationships between ontology entities to formally capture the *types of knowledge that are present in the ontology*” (p. 6, emphasis added).

2.3 Lack of Conformance with Basic Formal Ontology

Dispositions. Wright et al. define ‘BCI scenario’ as being both a **disposition**, which is a **specifically dependent continuant** in BFO, and a **process**, which is an **occurrent**. In line with the realist approach and principles of BFO and the OBO Foundry, no continuant is an occurrent and no occurrent is a continuant.

- a. **‘BCI scenario’**: said to be the disposition (SDC) had by multiple entity types, but it is defined as a sub-type of **planned process** (occurrent).
 - i. **BCI scenario** subclass_of **planned process**
 - ii. **BCI scenario plan** realizes **BCI scenario**

The screenshot displays an ontology editor interface. On the left, a hierarchical tree view shows the structure of the ontology. The 'Behaviour change intervention scenario' is highlighted in blue. The right-hand panel shows the 'Annotations' and 'Description' for this class. The 'Annotations' section includes a label 'Behaviour change intervention scenario', a definition 'A process in which a BCI is applied in a given context, including BCI engagement and outcome behaviour.', and an alternative term 'BCI scenario'. The 'Description' section lists several sub-classes and axioms, including 'located in' relationships with 'Behaviour change intervention', 'Behaviour change intervention engagement', 'Behaviour change intervention mechanism', and 'Outcome behaviour', as well as 'planned process' and 'realized in' relationships with 'Behaviour change intervention scenario plan' and 'Behaviour change intervention context'.

- iii. **BCI scenario report** has_disposition **BCI scenario**

The screenshot shows a class hierarchy on the left and a detailed view of the 'Behaviour change intervention scenario report' class on the right. The hierarchy includes classes like 'data item', 'Evaluation finding', 'Behaviour change intervention evaluation finding', 'Behaviour change intervention effect estimate', 'Behaviour change intervention outcome estimate', 'directive information entity', 'plan specification', 'Behaviour change intervention evaluation study plan', 'Behaviour change intervention scenario plan', 'document', 'report', 'Behaviour change intervention evaluation report', and 'Behaviour change intervention scenario report'. The right panel shows annotations for the selected class, including a label, definition, and alternative term.

Annotations: Behaviour change intervention scenario report

Annotations +

label [type: xsd:string]
Behaviour change intervention scenario report

definition [type: xsd:string]
A report that describes a BCI scenario.

'alternative term' [type: xsd:string]
BCI scenario report

Description: Behaviour change intervention scenario report

Equivalent To +

SubClass Of +

- 'has disposition' some 'Behaviour change intervention scenario'
- report

General class axioms +

SubClass Of (Anonymous Ancestor)

- iv. **BCI scenario plan** realizes **BCI scenario** (see image above, under (ii)), and **BCI scenario plan** subclass_of **information content entity**

The screenshot shows a class hierarchy on the left and a detailed view of the 'Behaviour change intervention scenario plan' class on the right. The hierarchy includes classes like 'owl:Thing', 'entity', 'continuant', 'generically dependent continuant', 'information content entity', 'Behaviour change intervention evaluation study risk of bias or error', 'data item', 'Evaluation finding', 'Behaviour change intervention evaluation finding', 'Behaviour change intervention effect estimate', 'Behaviour change intervention outcome estimate', 'directive information entity', 'plan specification', 'Behaviour change intervention evaluation study plan', 'Behaviour change intervention scenario plan', 'document', 'report', 'Behaviour change intervention evaluation report', 'Behaviour change intervention scenario report', 'independent continuant', 'immaterial entity', 'site', 'environmental zone', 'populated place', and 'dense settlement'. The right panel shows annotations for the selected class, including a label, definition, and alternative term.

Annotations: Behaviour change intervention scenario plan

Annotations +

label [type: xsd:string]
Behaviour change intervention scenario plan

definition [type: xsd:string]
A plan specification that represents an intended or hypothetical BCI scenario.

'alternative term' [type: xsd:string]
BCI scenario plan

Description: Behaviour change intervention scenario plan

Equivalent To +

SubClass Of +

- 'plan specification'

General class axioms +

SubClass Of (Anonymous Ancestor)

- b. **'outcome behaviour'**: said to be the **disposition** (SDC) had by some entity types, but it is defined as a sub-type of **planned process** (occurrent).
- BCI outcome estimate** has_disposition **outcome behaviour**
 - BCI outcome estimate** realizes **BCI evaluation study**, and **BCI outcome estimate** subclass_of **information content entity** (not a realizing entity)

The screenshot shows an ontology browser interface. On the left, a class hierarchy is displayed, with 'Behaviour change intervention outcome estimate' highlighted. The right pane shows the 'Annotations' for this class, including a definition: 'A BCI evaluation finding that is about an outcome behaviour.' Below this, there are sections for 'Description' and 'SubClass Of', listing relationships such as 'Behaviour change intervention evaluation finding' and 'has disposition some Outcome behaviour'.

iii. **BCI outcome estimate** realizes **BCI evaluation study** (image directly above), but **BCI evaluation study** realized_by **BCI evaluation study plan** (again, a non-realizing ICE, per image directly above)

The screenshot shows an ontology browser interface. On the left, a class hierarchy is displayed, with 'Behaviour change intervention evaluation study' highlighted. The right pane shows the 'Annotations' for this class, including a definition: 'An intervention evaluation study of a BCI scenario.' Below this, there are sections for 'Description' and 'SubClass Of', listing relationships such as 'comparatively evaluates some Behaviour change intervention scenario' and 'has BCI source some Behaviour change intervention study investigator'.

iv. **outcome behaviour** (said to be disposition) subclass_of **process**

- c. **'BCI evaluation study'**: said to be the disposition (SDC) had by some entity types, but it is defined as a sub-type of **planned process** (occurrent).
 - i. **BCI evaluation study risk of bias or error** and **BCI evaluation report** has_disposition **BCI evaluation study**

ii. **BCI evaluation study** subclass_of **planned process**

The screenshot shows an ontology editor interface. On the left is a class hierarchy tree. The class 'Behaviour change intervention evaluation study' is highlighted in blue. A tooltip for this class is visible, showing its URI: 'Behaviour change intervention evaluation study' (BCIO:018000) with the URL http://humanbehaviourchange.org/ontology/BCIO_018000. On the right, the 'Annotations' panel for this class is displayed, showing a label 'Behaviour change intervention evaluation study', a definition 'An intervention evaluation study of a BCI scenario.', and an alternative term 'BCI evaluation study'. Below the annotations, the 'Description' panel shows 'Behaviour change intervention evaluation study'. The 'Equivalent To' and 'SubClass Of' sections are empty. The 'General class axioms' section lists several axioms: 'comparatively evaluates' some 'Behaviour change intervention scenario', 'has BCI source' some 'Behaviour change intervention study investigator', 'has study investigator' some 'Behaviour change intervention study sample', 'intervention evaluation study', and 'realized in' some 'Behaviour change intervention evaluation study plan'.

d. **'BCI comparison evaluation study'**: said to be realized in (realizable entities are SDCs in BFO) some entity types, but it is defined as a sub-type of **planned process** (occurrent).

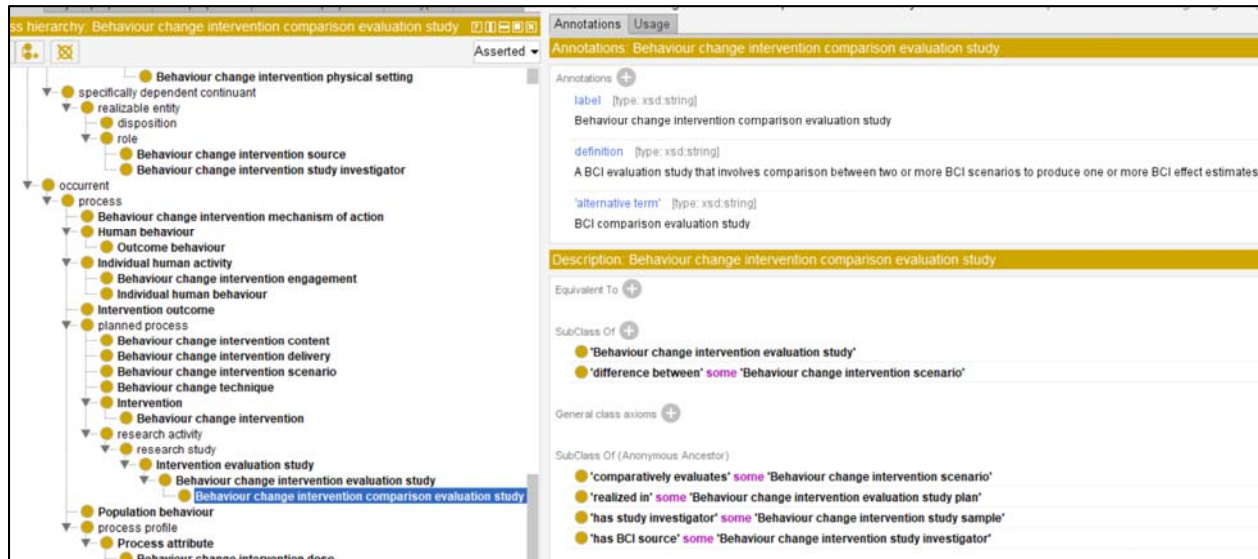
i. **BCI effect estimate** (a non-realizing ICE) realizes **BCI comparison evaluation study** (a process) and **BCI evaluation study** (a process)

The screenshot shows an ontology editor interface. On the left is a class hierarchy tree. The class 'Behaviour change intervention effect estimate' is highlighted in blue. On the right, the 'Annotations' panel for this class is displayed, showing a label 'Behaviour change intervention effect estimate', a definition 'A BCI evaluation finding that characterises the difference between BCI outcome estimates of two BCI scenarios.', and an alternative term 'BCI effect estimate'. Below the annotations, the 'Description' panel shows 'Behaviour change intervention effect estimate'. The 'Equivalent To' and 'SubClass Of' sections are empty. The 'General class axioms' section lists several axioms: 'Behaviour change intervention evaluation finding' and 'realizes some 'Behaviour change intervention comparison evaluation study''. The 'SubClass Of (Anonymous Ancestor)' section lists 'realizes some 'Behaviour change intervention evaluation study''. The 'Instances' section is empty.

ii. **BCI comparison evaluation study** subclass_of **planned process**, and also realized_in **BCI evaluation study plan** (another non-realizing ICE)

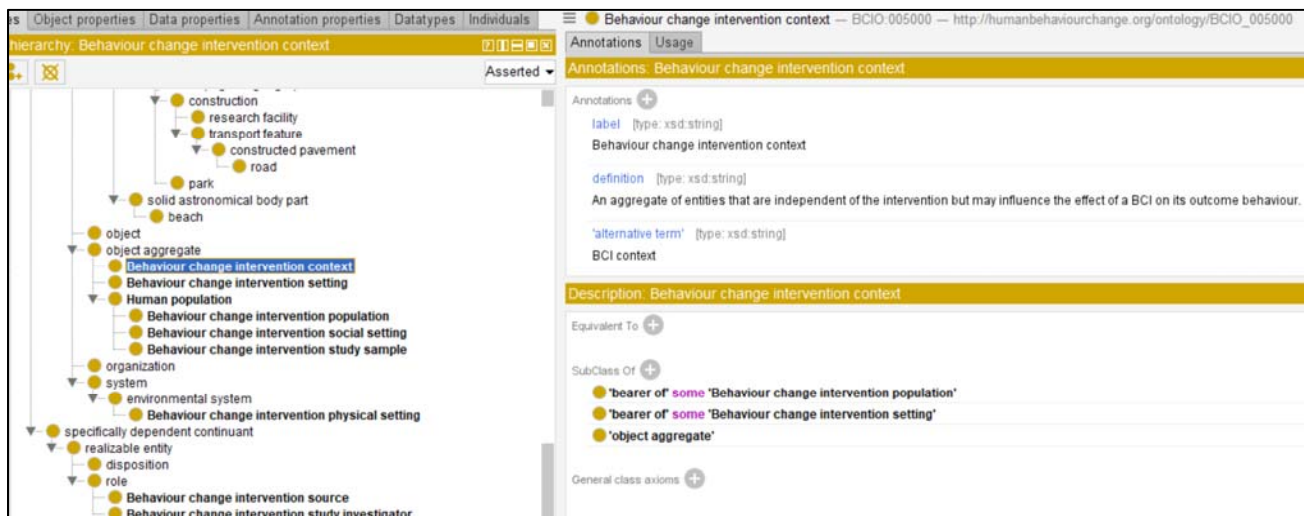
iii. **BCI comparison evaluation study** has_study_investigator **BCI study sample**, making the study sample the same as the study investigator

iv. **BCI comparison evaluation study** difference_between **BCI scenario**, which confuses the comparison of difference (process) and the difference itself (a quality)



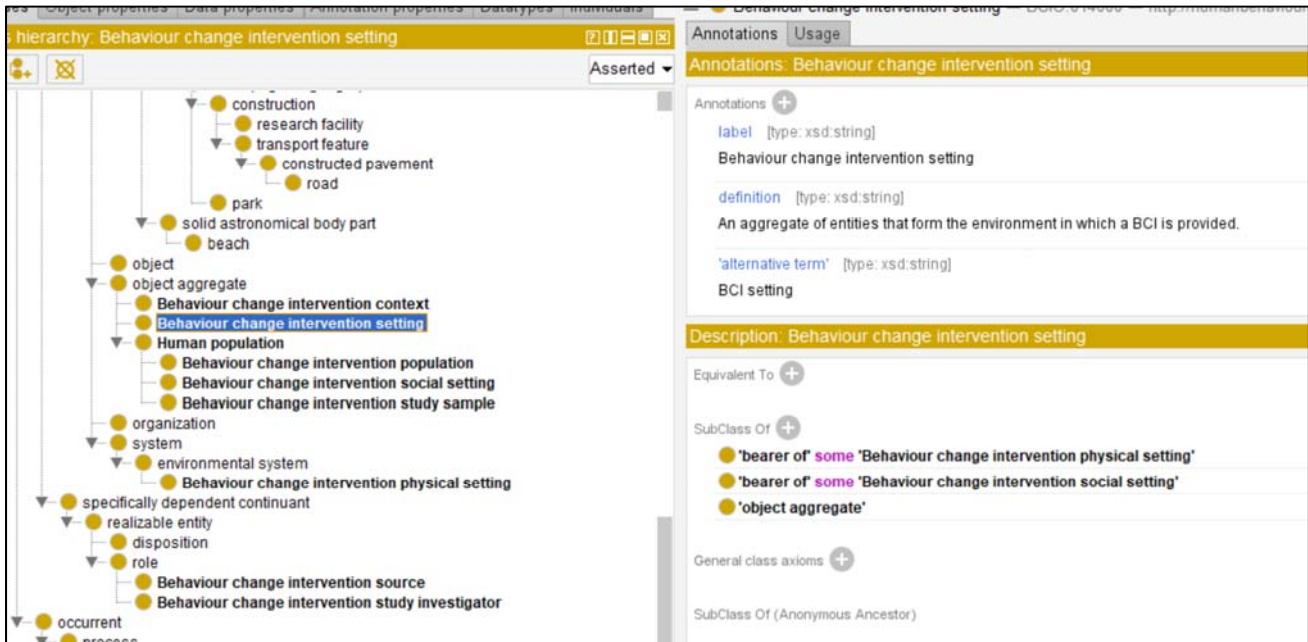
B. **Bearer_of Relation used incorrectly.** Wright et al. use the bearer_of relation in their ontology in a way that is inconsistent with the realist principles of BFO and the OBO Foundry. They allow that some entities can be bearers of material entities (ICs) like object aggregates and systems.

- a. **'BCI context':** said to be bearer_of **BCI setting** and **BCI population**, which are defined as object aggregate and human population, respectively. This entails that an object aggregate (e.g. a context) can bear a human population (an object aggregate).
 - i. **BCI context** bearer_of **BCI setting** and **BCI population**
 - ii. **BCI context** subclass_of **object aggregate**
 - iii. **BCI population** subclass_of **object aggregate**
 - iv. **BCI setting** subclass_of **object aggregate**

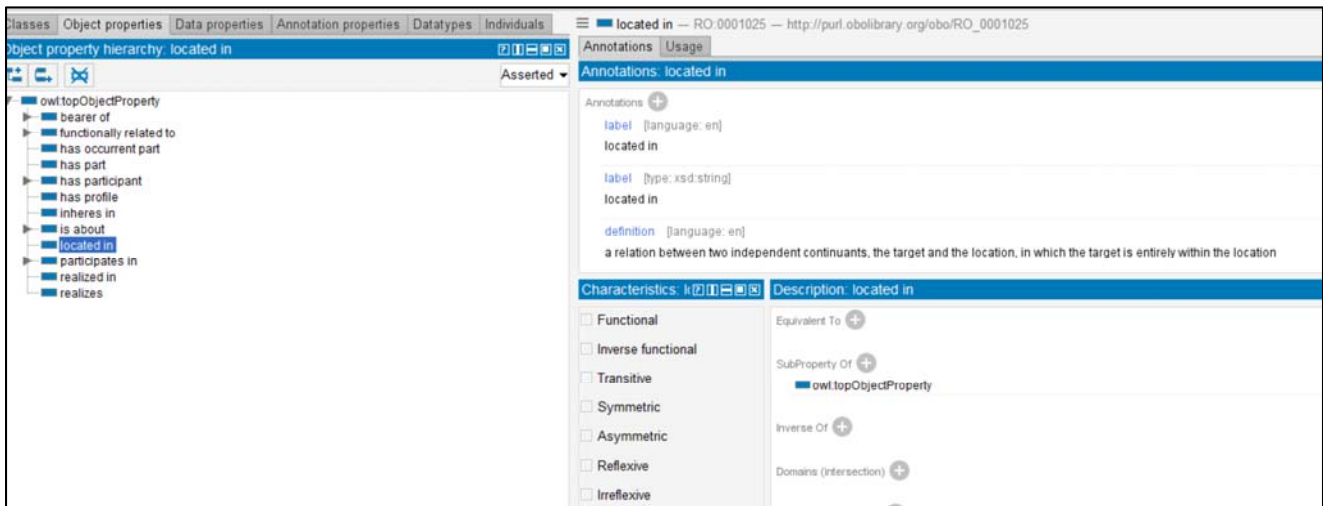


- b. **'BCI setting':** said to be bearer_of **BCI physical setting** and **BCI social setting**, which are defined as **environmental system** and **human population**, respectively. This entails that an object aggregate (e.g. a setting) can bear a human population (object aggregate) or a system (material entity/IC)
 - i. **BCI setting** bearer_of **BCI physical setting** and **BCI social setting**
 - ii. **BCI setting** subclass_of **object aggregate**

- iii. **BCI physical setting subclass_of environmental system**
- iv. **BCI social setting subclass_of human population (object aggregate)**



- C. **Location of BCI Scenario:** Wright et al. define **BCI scenario** as being located_in other occurrent entities in their ontology, some of which may be distinct, and even non-overlapping occurrent entities. Given the definition for the located_in relation, this is inconsistent since the “target” must be “entirely within” the location.
 - a. **Entirely Within:** The located_in relation is defined as requiring the “target” to be “entirely within” the location.



- b. **BCI scenario located_in BCI**
- c. **BCI scenario located_in BCI engagement**
- d. **BCI scenario located_in BCI mechanism of action**
- e. **BCI scenario located_in outcome behaviour** (defined as a disposition and a process). This implies a process (BCI scenario) is located_in a disposition.

The screenshot displays the Protégé ontology editor interface. On the left, a class hierarchy tree is visible, with 'Behaviour change intervention scenario' highlighted. The right pane shows the details for this class, including its label, definition, and sub-classes.

Class hierarchy: Behaviour change intervention scenario

- environmental system
 - Behaviour change intervention physical setting
- specifically dependent continuant
 - realizable entity
 - disposition
 - role
 - Behaviour change intervention source
 - Behaviour change intervention study investigator
- occurrent
 - process
 - Behaviour change intervention mechanism of action
 - Human behaviour
 - Outcome behaviour
 - Individual human activity
 - Behaviour change intervention engagement
 - Individual human behaviour
 - Intervention outcome
 - planned process
 - Behaviour change intervention content
 - Behaviour change intervention delivery
 - Behaviour change intervention scenario
 - Behaviour change technique
 - Intervention
 - Behaviour change intervention
 - research activity
 - research study
 - Intervention evaluation study
 - Behaviour change intervention evaluation study
 - Behaviour change intervention comparison evaluation study
 - Population behaviour
 - process profile
 - Process attribute
 - Behaviour change intervention dose
 - Behaviour change intervention mode of delivery
 - Behaviour change intervention schedule of delivery
 - Behaviour change intervention style of delivery

Annotations: Behaviour change intervention scenario

Annotations: +

label [type: xsd:string]
Behaviour change intervention scenario

definition [type: xsd:string]
A process in which a BCI is applied in a given context, including BCI engagement and outcome behaviour.

'alternative term' [type: xsd:string]
BCI scenario

Description: Behaviour change intervention scenario

Equivalent To +

SubClass Of +

- 'located in' some 'Behaviour change intervention'
- 'located in' some 'Behaviour change intervention engagement'
- 'located in' some 'Behaviour change intervention mechanism of action'
- 'located in' some 'Outcome behaviour'
- 'planned process'
- 'realized in' some 'Behaviour change intervention scenario plan'
- evaluates some 'Behaviour change intervention context'

General class axioms +

SubClass Of (Anonymous Ancestor)

Instances +

3. Conclusion

In our view, Wright, et al.'s work developing the BCIO, as well as their RODM/SELAR3 method, constitutes a valuable and timely contribution to the field. As the authors point out, changing behaviors (whether at the individual, group, or organizational level) is required to improve public health and well-being, and to facilitate environmental sustainability (p. 3). Insofar as these things are valuable, so will be the need to study BCIs, their efficacy, how various factors like environment or technique influence their implementation or outcomes, and so forth. Hence, given the complexity of the phenomena surrounding BCIs, the volume of research and data on BCIs, and the heterogeneity of this data, we agree with Wright, et al. that development of the BCIO is an extremely important project to undertake.

Importantly, the authors are committed to developing an ontology that is compliant with BFO and follows the principles of good ontology building used by the OBO Foundry. Indeed, Wright et al.'s RODM method outlined in the paper is strikingly analogous to the basic steps of building an ontology outlined in (Arp, Smith, & Spear 2015). For instance, Wright et al.'s method starts with defining the scope and identifying key entities, moves through a process of ensuring understandability and usability, and ends with specifying relations and making the ontology machine readable for dissemination, access, and maintenance. Arp and colleagues start with "demarcating the subject matter" and "gathering information," and then move to "regimenting the result to ensure" coherence, compatibility, and understandability, and end with "formalizing the regimented representational artifact" (Arp, Smith, and Spear 2015, p. 50). Moreover, in addition to the steps of development, Wright, et al. seem to subscribe to many of the core principles of good ontology design, like *perspectivalism*, *fallibilism*, *re-use*, and *open-endedness*.

Despite the importance of the authors' contribution, and without any intention of undermining that value, our review concentrated on the shortcomings of the ontology as it stands at present. In particular, we found that the BCIO is at present not fully compliant with BFO, nor does it yet fully adhere to the realist methodology underlying BFO and the OBO Foundry. It is this methodology that facilitates achieving unification in a discipline, and promotes the interoperability and scalability of the ontologies developed. This motivates our recommendation that the authors' data-driven approach be paired with a process of

carefully examining how terms are used by experts in order to understand the reality being referred to, and then adjusting and adding terms so that the ontology is both understandable to and usable by experts and such as to follow the structure of reality.

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Abstract

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Prepared for Wellcome Open Research, July 6, 2020

<https://wellcomeopenresearch.org/articles/5-126/v1#referee-response-39004>

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1.1.1 Unification

The realist approach is in the interest of *unification*. By ‘unification’ we mean, at least a shared vocabulary that allows discussants to avoid merely verbal disputes, even if there is disagreement on what the world is like. That is, unification is approached when the building blocks used to assemble theories about reality are shared, even if experts assemble those blocks in different ways. As such, unification does not require absence of disagreement. It requires only that, when disagreement occurs, it is a disagreement over the nature of some phenomenon – of reality as it is – rather than over what some phenomenon is rightly called – for example, should we call it a ‘mallard’ or a ‘duck’? An example of such a verbal dispute is provided by William James:

The corpus of the dispute was a squirrel—a live squirrel supposed to be clinging to one side of a tree-trunk; while over against the tree’s opposite side a human being was imagined to stand. This human witness tries to get sight of the squirrel by moving rapidly round the tree, but no matter how fast he goes, the squirrel moves as fast in the opposite direction, and always keeps the tree between himself and the man, so that never a glimpse of him is caught. The resultant metaphysical problem now is this: Does the man go round the squirrel or not? (James 1907, 34)

The answer is, of course, it depends on what type of activity is properly referred to by ‘go around’, and were all of the senses of ‘go around’ distinguished and given appropriate labels and definitions, then all that would be left is a dispute about which sense of ‘go around’ is the right one to use in this instance: the discussants would have achieved unification.

Unification is accomplished (at least) through having a shared vocabulary through which to express disagreement. For example, if one person claims that addiction is a disease while another claims that it is not, then to avoid merely verbal disputes it is important that ‘addiction’ and ‘disease’ mean the same thing to each person. Agreement of this sort is most readily achieved through the principle of low hanging fruit: start with vocabulary that reflects real entities unproblematically, and build up from there definitions of more complicated phenomena.

1.1.2 Scientifically Sound

Now, while the authors never use the term ‘realist’ when they describe their methodologies, they do mention the need for ontological vocabularies to be *scientifically sound*. What the authors mean by ‘scientifically sound’ is unclear but seems to be:

- 1) terms are understandable by experts, and
- 2) terms are expressive enough to refer to all relevant entities in a field.

While these conditions are important, they are not enough on their own to ensure that an ontology is realist, and thus not enough to build a good ontology. This is because, though experts in a field are generally extremely good at describing, to other experts in their field, entities relevant to their domain, they are not always good at describing them in a way that promotes the development of clear, organized, scalable, and interoperable vocabularies that can be understood also by experts in neighboring fields.

The data-driven approach outlined by the authors to building and revising ontologies should, then, be paired with a process of carefully examining how terms are used by experts in order to understand the reality being referred to, and then adjusting and adding terms so that the ontology is both understandable to and usable by experts and such as to follow the structure of reality.

2 Specific Criticisms

2.1 Definitions of Key Terms

Table 1 in Wright, et al. provides a glossary of key terms used in their article (as contrasted with terms in the BCIO). There are problems with some of the definitions of these terms, however, and in the spirit of complying with realist methods of ontology building and the goal of unification, it is useful if all relevant terms are treated as if they are or will be included in an ontology.

Artificial Intelligence: The theory and practice of building computer programs to perform tasks that a human would reasonably regard as requiring intelligence.

According to the authors, ‘Artificial Intelligence’ is defined as a concept or piece of knowledge (“theory”), which is a continuant, and as a process (“practice”), which is an occurrent. Nothing can be both a continuant and an occurrent. By the authors’ own lights, this is a bad definition because it traverses the two most fundamental categories of reality and thereby invites ambiguity when used in the article. However, to make matters worse, the authors then go on to use ‘artificial intelligence’ in what seems to be yet another sense: “*Artificial Intelligence* (AI) within the knowledge system will make predictions based on the evidence in response to users’ queries about the most effective interventions in a wide variety of situations (e.g. type of behaviour, mode of delivery, population, setting),” which seems to suggest that AI is to be understood as an algorithm (p. 13).

Interoperability: Ontology developers should collaborate with others wherever possible to re-use entities and limit duplication of work. Interoperability of ontologies sits within the OBO Foundry principle of Commitment to Collaboration.

Unfortunately, this definition (or elucidation) does not correspond to the way ‘interoperability’ is predominantly used, according to which (in the simplest version): two systems are interoperable if data coming from each system can be used by the other system.

What the authors provide, however, is not a definition of ‘interoperability’ but rather a prescriptive statement (“ontology developers *should...*”). Furthermore, it misunderstands the OBO Foundry principle of Commitment to Collaboration, which sites collaboration as having interoperability as one of its benefits, not as something that would be part of the definition of ‘interoperability’. What the authors seem to be gesturing towards is a practice of making an ontology interoperable (in the standard sense) by using pre-existing terms and definitions where applicable. Thus, they are doing little more, here, than repeating the OBO Foundry’s Commitment to Collaboration:

An expectation that Foundry ontologies will collaborate with other Foundry ontologies, particularly in ensuring orthogonality of distinct ontologies, in re-using content from other ontologies in cross-product definitions where appropriate, and in establishing and evolving Foundry principles to advance the Foundry suite of ontologies to better serve the joint users (<http://www.obofoundry.org/principles/fp-010-collaboration.html>).

2.3 Ontologies as Knowledge Graphs

The authors sometimes describe ontologies as representing knowledge. This is, of course, true in the sense that ontologies do indeed provide proxies (for instance, in the form of definitions, and of is-a and other links in the ontology graph) for items of knowledge. If ‘representing’ is understood as meaning ‘stand-in proxy for’, then ‘to represent knowledge’ comes close to capturing the goal of realist ontology development. Unfortunately, however, there is another use of ‘represent’ and this yields a reading according to which terms in an ontology should *be about* or *refer to* knowledge, and this is antithetical to the realist methodology (just as ‘ontologies represent concepts in people’s minds’ is antithetical to the realist methodology). More generally: terms like ‘knowledge representation’ should only ever be used with caution, because they run the risk of encouraging bad ontology development. Examples of Wright, et al.’s use of such terms are as follows (emphasis added): “Ontologies are *knowledge structures ...*” (abstract) or “ontologies *encapsulate knowledge...*” (p. 3).

The same issue occurs in another paper developing the lower-level Mode of Delivery (MoD) Ontology that extends the BCIO (Marques, et al., “Delivering Behaviour Change Interventions: Development of a Mode of Delivery Ontology” [version 1]), and which shared a number of the same authors, where it is asserted that, “An ontology is a more expressive structure *for organizing knowledge,*” (p. 3, emphasis added) and that, “The research team developed relationships between ontology entities to formally capture the *types of knowledge that are present in the ontology*” (p. 6, emphasis added).

2.3 Lack of Conformance with Basic Formal Ontology

Dispositions. Wright et al. define ‘BCI scenario’ as being both a **disposition**, which is a **specifically dependent continuant** in BFO, and a **process**, which is an **occurrent**. In line with the realist approach and principles of BFO and the OBO Foundry, no continuant is an occurrent and no occurrent is a continuant.

- f. **‘BCI scenario’:** said to be the disposition (SDC) had by multiple entity types, but it is defined as a sub-type of **planned process** (occurrent).
 - i. **BCI scenario subclass_of planned process**
 - ii. **BCI scenario plan realizes BCI scenario**

The screenshot shows a class hierarchy on the left and a details panel on the right for the class 'Behaviour change intervention scenario'. The hierarchy includes classes like 'specifically dependent continuant', 'realizable entity', 'disposition', 'role', 'Behaviour change intervention source', 'Behaviour change intervention study investigator', 'occurrent', 'process', 'Behaviour change intervention mechanism of action', 'Human behaviour', 'Outcome behaviour', 'Individual human activity', 'Behaviour change intervention engagement', 'Individual human behaviour', 'Intervention outcome', 'planned process', 'Behaviour change intervention content', 'Behaviour change intervention delivery', 'Behaviour change intervention scenario', 'Behaviour change technique', 'Intervention', 'Behaviour change intervention', 'research activity', 'research study', 'Intervention evaluation study', 'Behaviour change intervention evaluation study', 'Behaviour change intervention comparison evaluation study', 'Population behaviour', 'process profile', and 'Process attribute'. The details panel shows annotations for 'label' (Behaviour change intervention scenario), 'definition' (A process in which a BCI is applied in a given context, including BCI engagement and outcome behaviour.), and 'alternative term' (BCI scenario). It also lists 'Equivalent To' and 'SubClass Of' relationships.

iii. **BCI scenario report** has_disposition **BCI scenario**

The screenshot shows a class hierarchy on the left and a details panel on the right for the class 'Behaviour change intervention scenario report'. The hierarchy includes classes like 'data item', 'Evaluation finding', 'Behaviour change intervention evaluation finding', 'Behaviour change intervention effect estimate', 'Behaviour change intervention outcome estimate', 'directive information entity', 'plan specification', 'Behaviour change intervention evaluation study plan', 'Behaviour change intervention scenario plan', 'document', 'report', 'Behaviour change intervention evaluation report', 'Behaviour change intervention scenario report', 'independent continuant', 'immaterial entity', 'site', 'environmental zone', 'populated place', 'dense settlement', 'city', 'terrestrial environmental zone', 'anthropised terrestrial environmental zone', 'rural area', 'vegetated area', 'grassland area', and 'woodland area'. The details panel shows annotations for 'label' (Behaviour change intervention scenario report), 'definition' (A report that describes a BCI scenario.), and 'alternative term' (BCI scenario report). It also lists 'Equivalent To' and 'SubClass Of' relationships, including 'has disposition' some 'Behaviour change intervention scenario' and 'report'.

iv. **BCI scenario plan** realizes **BCI scenario** (see image above, under (ii)), and **BCI scenario plan** subclass_of **information content entity**

The screenshot displays the Protégé ontology editor interface. On the left, a class hierarchy tree is shown, with 'Behaviour change intervention scenario plan' selected and highlighted in blue. The right-hand pane shows the 'Annotations' tab for this class, containing the following information:

- label** [type: xsd:string]: Behaviour change intervention scenario plan
- definition** [type: xsd:string]: A plan specification that represents an intended or hypothetical BCI scenario.
- 'alternative term'** [type: xsd:string]: BCI scenario plan
- Description**: Behaviour change intervention scenario plan
- Equivalent To**: (empty)
- SubClass Of**: 'plan specification'
- General class axioms**: (empty)
- SubClass Of (Anonymous Ancestor)**: (empty)

- g. **'outcome behaviour'**: said to be the **disposition** (SDC) had by some entity types, but it is defined as a sub-type of **planned process** (occurrent).
- i. **BCI outcome estimate** has_disposition **outcome behaviour**
 - ii. **BCI outcome estimate** realizes **BCI evaluation study**, and **BCI outcome estimate** subclass_of **information content entity** (not a realizing entity)

The screenshot displays the Protégé ontology editor interface. On the left, a class hierarchy tree is shown, with 'Behaviour change intervention outcome estimate' selected and highlighted in blue. The right-hand pane shows the 'Annotations' tab for this class, containing the following information:

- definition** [type: xsd:string]: A BCI evaluation finding that is about an outcome behaviour.
- 'alternative term'** [type: xsd:string]: BCI outcome estimate
- 'example of usage'** [type: xsd:string]: This includes as subclasses 1) type of outcome estimate , 2) value of outcome estimate , 3)
- Description**: Behaviour change intervention outcome estimate
- Equivalent To**: (empty)
- SubClass Of**:
 - 'Behaviour change intervention evaluation finding'
 - 'has disposition' some 'Outcome behaviour'
- General class axioms**: (empty)
- SubClass Of (Anonymous Ancestor)**:
 - realizes some 'Behaviour change intervention evaluation study'

- iii. **BCI outcome estimate** realizes **BCI evaluation study** (image directly above), but **BCI evaluation study** realized_by **BCI evaluation study plan** (again, a non-realizing ICE, per image directly above)

The screenshot shows a class hierarchy on the left and a details pane on the right. The class 'Behaviour change intervention evaluation study' is selected. The details pane shows:

- label** [type: xsd:string]: Behaviour change intervention evaluation study
- definition** [type: xsd:string]: An intervention evaluation study of a BCI scenario.
- 'alternative term'** [type: xsd:string]: BCI evaluation study
- Description**: Behaviour change intervention evaluation study
- SubClass Of**:
 - 'comparatively evaluates' some 'Behaviour change intervention scenario'
 - 'has BCI source' some 'Behaviour change intervention study investigator'
 - 'has study investigator' some 'Behaviour change intervention study sample'
 - 'intervention evaluation study'
 - 'realized in' some 'Behaviour change intervention evaluation study plan'

iv. **outcome behaviour** (said to be disposition) subclass_of **process**

The screenshot shows a class hierarchy on the left and a details pane on the right. The class 'Outcome behaviour' is selected. The details pane shows:

- label** [type: xsd:string]: Outcome behaviour
- definition** [type: xsd:string]: Human behavior that is an intervention outcome.
- Description**: Outcome behaviour
- SubClass Of**:
 - 'Human behaviour'

- h. **'BCI evaluation study'**: said to be the disposition (SDC) had by some entity types, but it is defined as a sub-type of **planned process** (occurent).
 - i. **BCI evaluation study risk of bias or error** and **BCI evaluation report** has_disposition **BCI evaluation study**

This screenshot shows the ontology editor interface. On the left, a class hierarchy is displayed, with 'Behaviour change intervention evaluation study risk of bias or error' selected. The right-hand pane shows the class's annotations and properties:

- Annotations:** Behaviour change intervention evaluation study risk of bias or error
- label** [type: xsd:string]: Behaviour change intervention evaluation study risk of bias or error
- definition** [type: xsd:string]: An information content entity that is about the likelihood of the BCI evaluation finding misrepresenting the outcome behaviour.
- 'alternative term'** [type: xsd:string]: BCI study risk of bias or error
- Description:** Behaviour change intervention evaluation study risk of bias or error
- Equivalent To:** (empty)
- SubClass Of:**
 - 'has disposition' some 'Behaviour change intervention evaluation study'
 - 'information content entity'

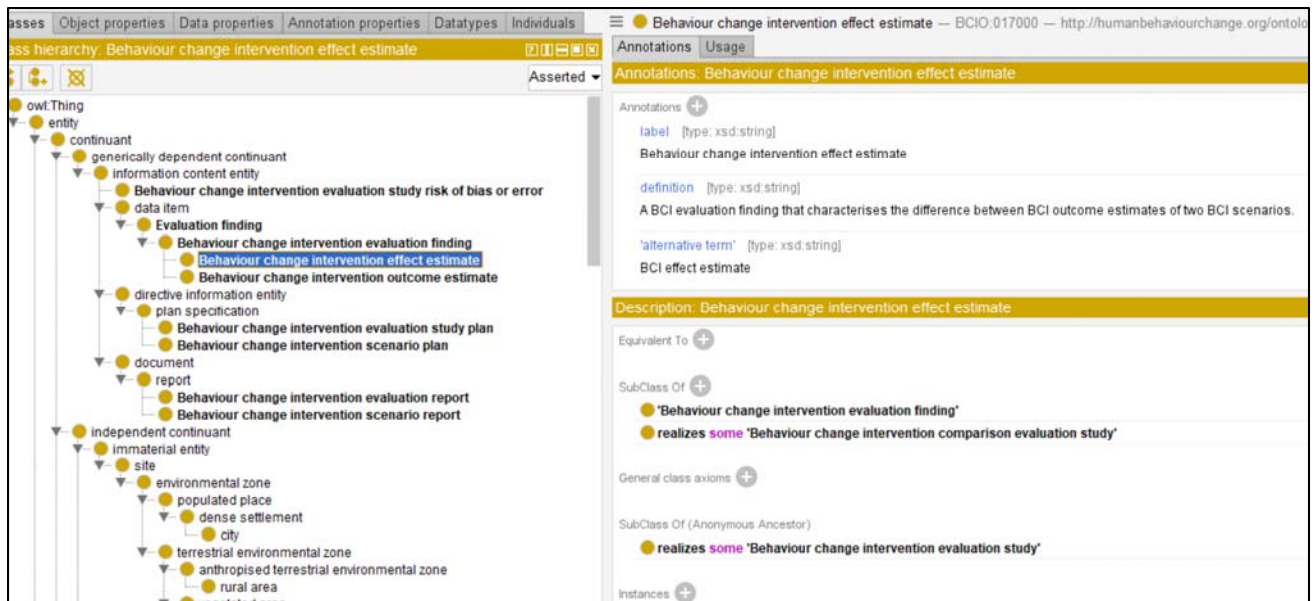
This screenshot is identical to the one above, showing the same ontology editor view for the class 'Behaviour change intervention evaluation study risk of bias or error'.

ii. BCI evaluation study subclass_of planned process

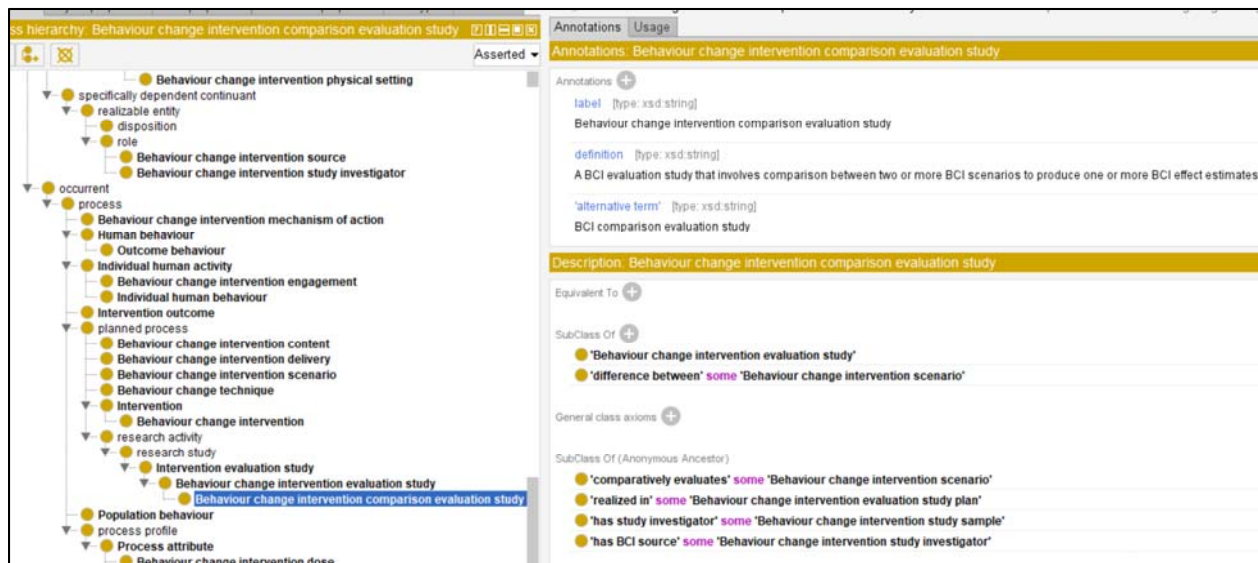
This screenshot shows the ontology editor interface for the class 'Behaviour change intervention evaluation study'. The left pane shows a detailed class hierarchy, and the right pane shows the class's annotations and properties:

- Annotations:** Behaviour change intervention evaluation study
- label** [type: xsd:string]: Behaviour change intervention evaluation study
- definition** [type: xsd:string]: An intervention evaluation study of a BCI scenario.
- 'alternative term'** [type: xsd:string]: BCI evaluation study
- Description:** Behaviour change intervention evaluation study
- Equivalent To:** (empty)
- SubClass Of:**
 - 'comparatively evaluates' some 'Behaviour change intervention scenario'
 - 'has BCI source' some 'Behaviour change intervention study investigator'
 - 'has study investigator' some 'Behaviour change intervention study sample'
 - 'intervention evaluation study'
 - 'realized in' some 'Behaviour change intervention evaluation study plan'
- General class axioms:**
 - 'Behaviour change intervention evaluation study'
 - BCIO:018000
 - http://humanbehaviourchange.org/ontology/BCIO_018000

- i. **'BCI comparison evaluation study'**: said to be realized in (realizable entities are SDCs in BFO) some entity types, but it is defined as a sub-type of **planned process** (occurrent).
 - i. **BCI effect estimate** (a non-realizing ICE) realizes **BCI comparison evaluation study** (a process) and **BCI evaluation study** (a process)



- ii. **BCI comparison evaluation study** subclass_of **planned process**, and also realized_in **BCI evaluation study plan** (another non-realizing ICE)
- iii. **BCI comparison evaluation study** has_study_investigator **BCI study sample**, making the study sample the same as the study investigator
- iv. **BCI comparison evaluation study** difference_between **BCI scenario**, which confuses the comparison of difference (process) and the difference itself (a quality)



D. **Bearer_of Relation used incorrectly.** Wright et al. use the bearer_of relation in their ontology in a way that is inconsistent with the realist principles of BFO and the OBO Foundry. They allow that some entities can be bearers of material entities (ICs) like object aggregates and systems.

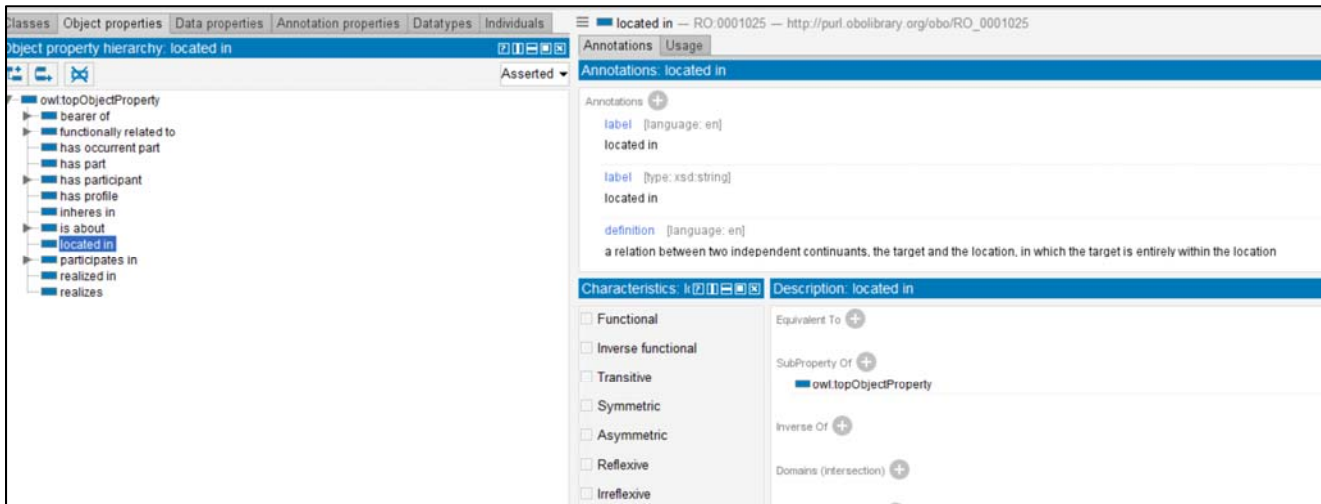
- a. **'BCI context'**: said to be bearer_of **BCI setting** and **BCI population**, which are defined as object aggregate and human population, respectively. This entails that an object aggregate (e.g. a context) can bear a human population (an object aggregate).
- i. **BCI context** bearer_of **BCI setting** and **BCI population**
 - ii. **BCI context** subclass_of **object aggregate**
 - iii. **BCI population** subclass_of **object aggregate**
 - iv. **BCI setting** subclass_of **object aggregate**

The screenshot displays the Protégé ontology editor interface. On the left, a class hierarchy tree shows 'Behaviour change intervention context' as a subclass of 'object aggregate'. The right-hand pane shows the 'Annotations' for this class, including a label, a definition: 'An aggregate of entities that are independent of the intervention but may influence the effect of a BCI on its outcome behaviour.', and an alternative term 'BCI context'. Below the annotations, the 'SubClass Of' section lists 'bearer of some Behaviour change intervention population', 'bearer of some Behaviour change intervention setting', and 'object aggregate'.

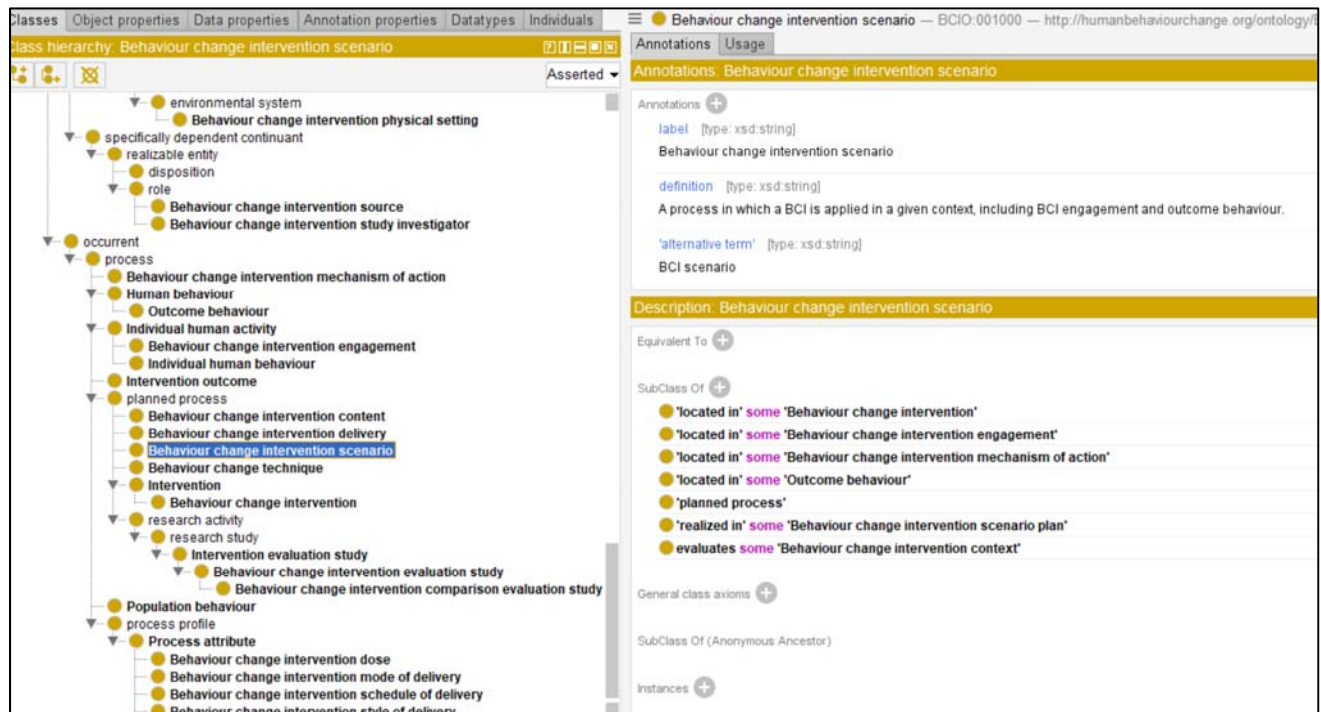
- b. **'BCI setting'**: said to be bearer_of **BCI physical setting** and **BCI social setting**, which are defined as **environmental system** and **human population**, respectively. This entails that an object aggregate (e.g. a setting) can bear a human population (object aggregate) or a system (material entity/IC)
- i. **BCI setting** bearer_of **BCI physical setting** and **BCI social setting**
 - ii. **BCI setting** subclass_of **object aggregate**
 - iii. **BCI physical setting** subclass_of **environmental system**
 - iv. **BCI social setting** subclass_of **human population** (object aggregate)

The screenshot displays the Protégé ontology editor interface for 'Behaviour change intervention setting'. The left-hand class hierarchy tree shows 'Behaviour change intervention setting' as a subclass of 'object aggregate'. The right-hand pane shows the 'Annotations' for this class, including a label, a definition: 'An aggregate of entities that form the environment in which a BCI is provided.', and an alternative term 'BCI setting'. Below the annotations, the 'SubClass Of' section lists 'bearer of some Behaviour change intervention physical setting', 'bearer of some Behaviour change intervention social setting', and 'object aggregate'.

- E. **Location of BCI Scenario:** Wright et al. define **BCI scenario** as being located_in other occurrent entities in their ontology, some of which may be distinct, and even non-overlapping occurrent entities. Given the definition for the located_in relation, this is inconsistent since the “target” must be “entirely within” the location.
- Entirely Within:** The located_in relation is defined as requiring the “target” to be “entirely within” the location.



- BCI scenario located_in BCI**
- BCI scenario located_in BCI engagement**
- BCI scenario located_in BCI mechanism of action**
- BCI scenario located_in outcome behaviour** (defined as a disposition and a process). This implies a process (BCI scenario) is located_in a disposition.



3. Conclusion

In our view, Wright, et al.'s work developing the BCIO, as well as their RODM/SELAR3 method, constitutes a valuable and timely contribution to the field. As the authors point out, changing behaviors (whether at the individual, group, or organizational level) is required to improve public health and well-being, and to facilitate environmental sustainability (p. 3). Insofar as these things are valuable, so will be the need to study BCIs, their efficacy, how various factors like environment or technique influence their implementation or outcomes, and so forth. Hence, given the complexity of the phenomena surrounding BCIs, the volume of research and data on BCIs, and the heterogeneity of this data, we agree with Wright, et al. that development of the BCIO is an extremely important project to undertake.

Importantly, the authors are committed to developing an ontology that is compliant with BFO and follows the principles of good ontology building used by the OBO Foundry. Indeed, Wright et al.'s RODM method outlined in the paper is strikingly analogous to the basic steps of building an ontology outlined in (Arp, Smith, & Spear 2015). For instance, Wright et al.'s method starts with defining the scope and identifying key entities, moves through a process of ensuring understandability and usability, and ends with specifying relations and making the ontology machine readable for dissemination, access, and maintenance. Arp and colleagues start with "demarcating the subject matter" and "gathering information," and then move to "regimenting the result to ensure" coherence, compatibility, and understandability, and end with "formalizing the regimented representational artifact" (Arp, Smith, and Spear 2015, p. 50). Moreover, in addition to the steps of development, Wright, et al. seem to subscribe to many of the core principles of good ontology design, like *perspectivalism*, *fallibilism*, *re-use*, and *open-endedness*.

Despite the importance of the authors' contribution, and without any intention of undermining that value, our review concentrated on the shortcomings of the ontology as it stands at present. In particular, we found that the BCIO is at present not fully compliant with BFO, nor does it yet fully adhere to the realist methodology underlying BFO and the OBO Foundry. It is this methodology that facilitates achieving unification in a discipline, and promotes the interoperability and scalability of the ontologies developed. This motivates our recommendation that the authors' data-driven approach be paired with a process of carefully examining how terms are used by experts in order to understand the reality being referred to, and then adjusting and adding terms so that the ontology is both understandable to and usable by experts and such as to follow the structure of reality.

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Is the rationale for developing the new method (or application) clearly explained?

Yes

Is the description of the method technically sound?

Partly

Are sufficient details provided to allow replication of the method development and its use by others?

Partly

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Robert Kelly: Bioethics, Applied Ontology Barry Smith: Ontology, Biomedical Informatics, and David Limbaugh's: Applied Ontology, Biomedical Ethics

We confirm that we have read this submission and believe that we have an appropriate level of expertise to state that we do not consider it to be of an acceptable scientific standard, for reasons outlined above.
