Association for Psychological Science

Current Directions in Psychological Science
1–9

DOI: 10.1177/09637214231183917
www.psychologicalscience.org/CDPS
Sage

The Use of Ontologies to Accelerate the Behavioral Sciences: Promises and Challenges

Carla Sharp[1], Robert M. Kaplan[2], and Timothy J. Strauman[3]
[1]Department of Psychology, University of Houston; [2]Clinical Excellence Research Center, Stanford University School of Medicine; and [3]Department of Psychology and Neuroscience, Duke University

Abstract
Behavioral scientists produce a vast amount of research every year yet struggle to produce cumulative knowledge that is easily translated in applied settings. This article summarizes a National Academies of Sciences, Engineering, and Medicine consensus report on the development and use of ontologies to accelerate the behavioral sciences. The report examines key challenges in the behavioral and psychological sciences motivating an evaluation of ontology use and development in the behavioral sciences. The advantages of ontologies, including enhanced organization and retrieval of research evidence, improved scientific communication, reduction of duplication, and enhanced scientific replicability, are highlighted. Challenges that may impede the development and use of ontologies in the behavioral sciences are also considered. The article concludes with future directions for fulfilling the promise of ontologies to accelerate the behavioral and psychological sciences.

Keywords
ontology, behavioral sciences

The behavioral sciences include a broad array of disciplines concerned with describing, understanding, predicting, and changing human behavior. Included are disciplines such as psychology, anthropology, sociology, economics, law, psychiatry, political science, and the behavioral aspects of biology. Behavioral scientists produce a vast amount of research every year yet struggle to produce cumulative knowledge that is easily translated for implementation in applied settings. Key challenges to accelerating behavioral sciences have been identified that may benefit from the development and use of ontologies.

The overall goal of this article is to communicate the findings of a consensus report commissioned by the National Academies of Sciences, Engineering, and Medicine (NASEM). The sponsors of the report include the American Psychological Association, Association for Psychological Science, Federation of Associations in Behavioral and Brain Sciences, National Cancer Institute, National Institute on Aging, National Library of Medicine, National Science Foundation, and the National Institutes of Health Office of Behavioral and Social Sciences Research. The purpose of the report was to study ways to improve the development and use of ontologies to accelerate the behavioral sciences. The complete findings of the consensus study report are publicly available (Kaplan & Beatty, 2022; https://www.nationalacademies.org/our-work/accelerating-social-and-behavioral-science-through-ontology-development-and-use).

Our goal here is to provide an abbreviated, more targeted summary of the report for investigators and practitioners in the psychological sciences. We begin by defining "ontology" and suggest its promise to accelerate the behavioral sciences. We then describe key challenges in the behavioral and psychological sciences for which ontologies may offer one type of solution. Next, we discuss the promise of ontologies for accelerating the behavioral sciences. This section is followed by an analysis of challenges impeding the development

Corresponding Author:
Carla Sharp, Department of Psychology, University of Houston
Email: csharp2@uh.edu

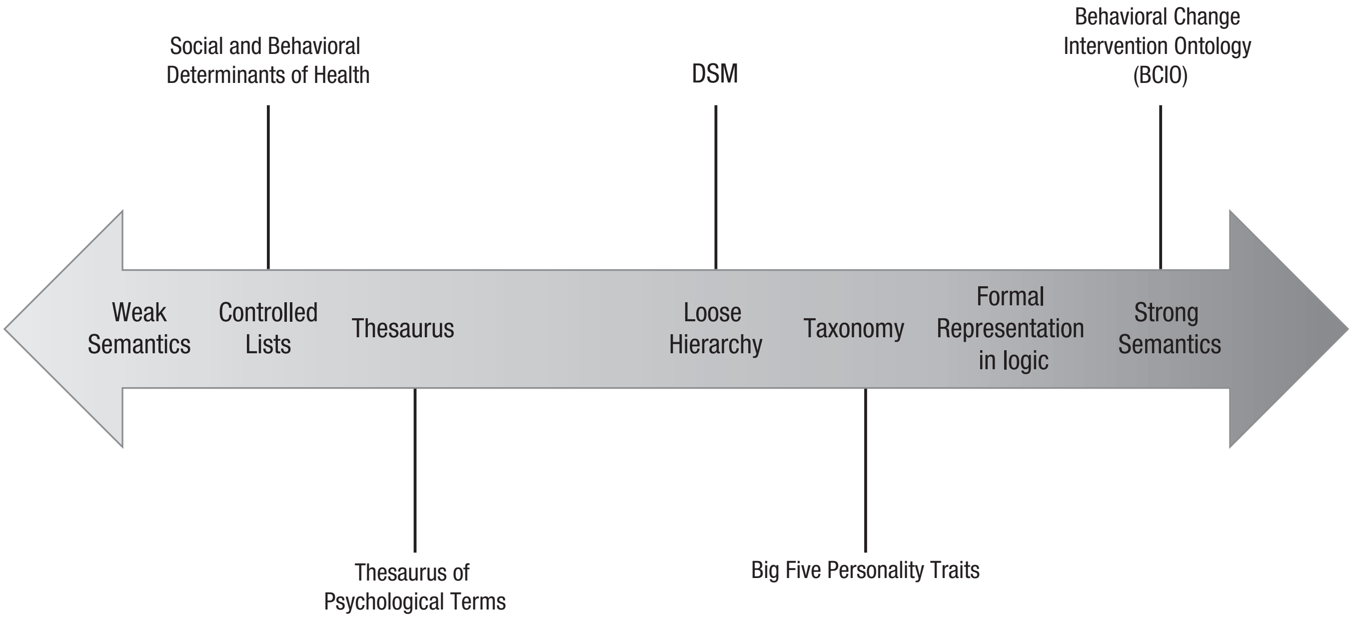

Fig. 1. Continuum of representations for ontological systems, with examples from the behavioral sciences.

and use of ontologies in the behavioral sciences. We conclude with a brief discussion of future directions for fulfilling the promise of ontologies to accelerate the behavioral and psychological sciences.

The Definition and Promise of Ontologies

Philosophers use the term *ontology* (literally, "discourse on being") to describe efforts to classify or group ideas, particularly those related to the nature of existence. Scientists use the word to refer to efforts to organize knowledge in particular domains. As such, an ontology may define and categorize a variety of constructs and terms, ranging from ice cream products (distinguishing those served in vessels, sticks, or cones) to the Gene Ontology (Gene Ontology Consortium, 2019).

Given the wide range of classification systems that may be considered under "ontology," a useful working definition of *ontology* is "an explicit, formal specification of a shared conceptualization"—a systematic set of shared terms and an explication of their interrelationships (Gruber, 1993, 1995; Staab & Studer, 2016). This particular definition originated in computer science and therefore naturally lends itself to leveraging the advantages of artificial intelligence to support ontology use and development. In this definition, "explicit" refers to the manner in which a developer carefully enumerates the types of concepts used and the constraints on their uses; "conceptualization" refers to an abstract view of the world consisting of the relevant concepts and the relationships among them that exist within a specific domain. "Formal" refers to specifications that are machine readable with well-defined semantics, and "shared" refers to the conceptualization being agreed upon and accepted by those working in a discipline. Based on this definition, an ontology's primary purpose is to represent the entities in a domain by providing sets of machine-readable statements that reflect scientists' shared understanding of phenomena and link the descriptions and classifications of the terms and relationships among them.

Ontologies may be specified in various ways, such as lists of controlled terms, thesauri, taxonomies, and formal representations in logic, as all of these can represent formal, explicit specifications of shared conceptualizations—although with different degrees of formality. Thus, classification systems designed for ontological purposes (the specification of definitions and relationships) may include "weak" semantics (such as a simple taxonomy that specifies only class-subclass relationships) or "strong" semantics (such as formal representation in a logic that allows developers to specify machine-readable properties of entities and constraints on those properties). Figure 1 illustrates the spectrum of semantic specification used in the context of the behavioral sciences, showing where controlled lists, thesauri, loose hierarchies, and taxonomies fit. Table 1 elaborates on the placement of these systems with reference to their level of sematic specification. Note that the descriptors "strong" and "weak" are intended not as evaluative but merely as reflecting a continuum of formal semantic properties.

Table 1. Examples of Ontological Systems Varying in Level of Specification

Ontology	Brief description
Social and behavioral determinants of health	A controlled list of defined terms related to behavioral, social, economic, environmental, and occupational factors. The list helps organize information and provides terminology for the factors that might influence morbidity, mortality, and future well-being.
Thesaurus of Psychological Index Terms	A controlled list of standardized terms and definitions of psychological concepts with a loose hierarchy showing relationships to other terms. The controlled vocabulary allows for indexing, cataloging, and searching of psychological concepts.
Diagnostic and Statistical Manual of Mental Disorders (*DSM*)	A loose hierarchy of the behavioral phenotypic manifestation of mental disorders using a common language and standard criteria based on consensus. The *DSM* features descriptions of mental health conditions and use categories to offer a diagnostic tool for clinical practice and research.
Big Five personality traits	A suggested grouping (taxonomy) of personality traits. The grouping provides a model of the primary dimensions of individual differences in personality and personality-trait facets that form part of a primary dimension.
Behavioral Change Intervention Ontology (BCIO)	A formally specified set of entities and their relationships that establishes a common language. BCIO is used to organize information in a form that enables efficient accumulation of knowledge and enables links to other knowledge systems.

A nonexhaustive scoping review (Falzon, 2021) included in the online supplementary material lists 49 well-known ontologies in the behavioral sciences (Supplementary Table 1). This, along with other published reviews (Blanch et al., 2017; Hastings & Schultz, 2012; Larsen et al., 2017; Norris et al., 2019; Poldrack & Yarkoni, 2016), indicates numerous valuable efforts but comparatively few well-developed behavioral ontologies that meet Gruber's (1993, 1995) definition of strong semantics. Ontologies with weaker semantics are of course equally valuable in the behavioral sciences but will not be machine readable in the same way than those with strong semantics, rendering them less beneficial for the acceleration of science specifically through artificial intelligence.

For examples of important efforts in ontology development, we suggest consideration of the Behavioral Change Intervention Ontology (BCIO; Michie et al., 2017) or Cognitive Atlas (Poldrack & Yarkoni, 2016). The BCIO is a good example of a successful ontology in the behavioral sciences characterized by strong semantics. To illustrate (see Fig. 2), the final upper-level BCIO specifies entities central and common to all behavioral interventions, such as "content," "delivery," "outcome behavior," "mechanism of action," "context," "population," and "settings," that are linked to other entities through relationship types, for example, "is about," "has process part," "has process attribute," and "realizes" (Michie et al., 2020). In this way, entities are formally and logically linked to one another using machine-readable terms, thereby offering efficiency in synthesizing and organizing behavioral change interventions, their contexts, and their evaluations. The BCIO was created by, and continues to be maintained and updated by, intervention scientists with experience in behavioral intervention development and validation.

The committee regarded the *Diagnostic and Statistical Manual for Mental Disorders* (5th ed.; *DSM-5*; American Psychological Association, 2013) as an example of a relatively looser and also more problematic hierarchy. In contrast to the type of entities specified in the BCIO, the *DSM-5* includes catch-all entities, such as "not otherwise specified," that in ontological terms are meaningless. In addition, although a diagnostic system like the *DSM* offers a taxonomy, it does not offer semantic implementations. Put differently, relationships between entities (even when they are meaningful) are not articulated in ontological language that is amenable to automated classification. More recent suggestions for nosological reform, such as the National Institute of Mental Health Research Domain Criteria (Insel et al., 2010) and the Hierarchical Taxonomy of Psychopathology (HiTOP; Kotov et al., 2021), address some problems of the *DSM* system (e.g., common co-occurrence of psychiatric disorders and heterogeneity within disorders) by offering underlying dimensions that may better represent the structure of psychopathology; however, these systems vary in the extent to which they offer strong enough semantics for an ontology to be formally specified. HiTOP may come closest as it provides a clear framework for how psychopathologies may be organized in a hierarchical structure.

Regardless of the semantic strength, ontologies organized at any point on the illustrated continuum have important benefits. They clarify the phenomena being studied, they aid in classification and communication, and if semantically strong and enumerated, they can facilitate data integration, data sharing, bibliographic retrieval, and comparison and analysis of data. The

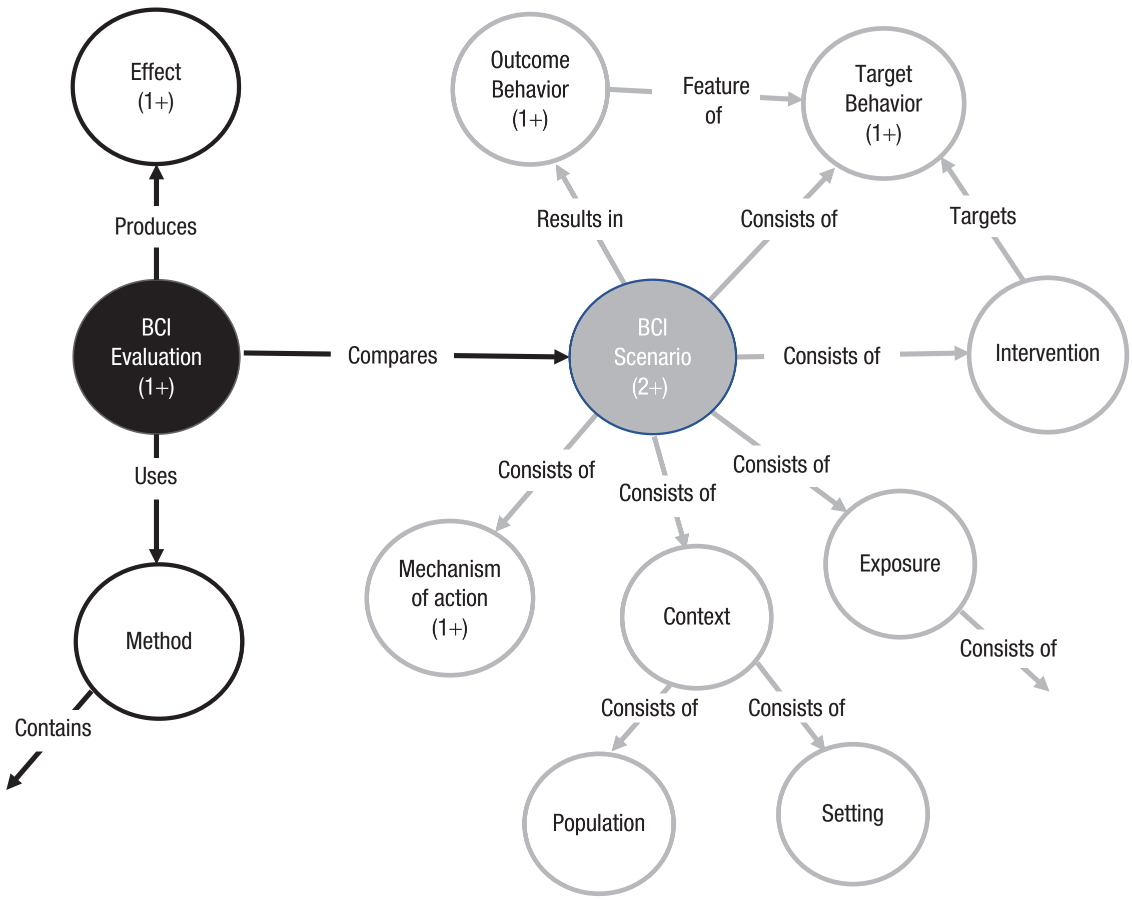

Fig. 2. A snapshot of key upper-level entities and examples of relationships in the Behavioral Change Intervention Ontology (Michie et al., 2020).

promise of such benefits is apparent when considering the Gene Ontology. Created in 1998, the Gene Ontology encompasses a logical structure that describes biological functions, molecular pathways, and cellular locations for the biological functions as well as relationships among classes and a body of annotations that trace evidence-based statements about links between specific genes and their biological roles. The Gene Ontology currently references more than 150,000 published papers as justification for the terms and relationships that it models (du Plessis et al., 2011; Gene Ontology Consortium, 2019). We believe that ontology development and use in the behavioral sciences hold significant promise to address several key challenges, discussed next, that may be slowing down progress in the behavioral sciences.

Key Challenges in Accelerating the Behavioral Sciences

Lack of clear definitions and/or their inconsistent use

A basic function of science is to label and classify observed phenomena and organize them for study in a particular domain. Scientific classifications are the basis for the organization of knowledge through the formation of hypotheses, the design of experiments, the modeling and interpretation of data, and the integration of findings. Clear labeling is the basis for systems of classification, yet the constructs and classifications that have been established in the behavioral sciences have not been systematized (see, e.g., Barrett, 2009; Davis et al., 2015; Lawson & Robins, 2021; Lilienfeld et al., 2015) and often fall prey to jingle-jangle fallacies. The jingle fallacy occurs when one makes the assumption that two things described by the same name are indeed the same (Thorndike, 1904). The jangle fallacy occurs when constructs that are identical or almost identical are assumed to be different because they are described with different labels (Kelley, 1927). These fallacies are surprisingly common in the behavioral sciences and occur at both the construct and measurement levels (Lawson & Robins, 2021). For example, there are literally hundreds of instruments used to measure quality of life, and yet these measures are often poorly correlated with one another. Nevertheless, it is assumed that they are measuring the same construct because they are labeled quality-of-life instruments (jingle fallacy). An example of the jangle fallacy comes from evaluations of two highly correlated psychological states: anxiety and depression. In practice, measures such as the Hamilton Anxiety and Depression scales (HAM-A and HAM-D) are highly correlated (Mountjoy & Roth, 1982). But, because they are labeled as measures of two distinct psychological states, it is assumed that two different constructs are being evaluated. Matters are further complicated by constructs that are overlapping but still distinct from each other (so-called sibling constructs; Lawson & Robins, 2021).

Lack of clear definitions and their consistent use is typical of the often empirically and conceptually siloed psychological sciences, where it is not uncommon for investigators to evaluate a research question without sufficient recognition that others had used different terminology for the same (or highly similar) constructs. Such inefficiencies inhibit scientific progress and lead to imprecision in the constructs and measures we employ. They also stifle retrievability and actionability, thereby widening the gap between knowledge and the ability to act upon that knowledge.

Lack of clarity that measures are not constructs

In their seminal work, Cronbach and Meehl (1955) suggest that psychological scientists often do not study directly observable phenomena but instead study unobserved (and perhaps unobservable) phenomena for which we create a theoretical construct, which is then operationalized in one or more measures. It is therefore critical to draw a distinction between a phenomenon (which exists in theory only) and the measures used to observe or assess its features. Put differently, the acceleration of the behavioral sciences depends on careful attention to measures and their assumed (theoretical) relationship to the constructs for which they are measured indicators. In this sense, construct validation is a form of theory testing that is dynamic, prospective, and seeking both confirmatory and discriminatory evidence.

In addition, constructs are logically and empirically related to one another, and their relation should be understood. A nomological network (or nomological net; Cronbach & Meehl, 1955) is a representation of the concepts (constructs) of interest in an area of study, their observable manifestations, and the interrelationships between these. The term “nomological” derives from the Greek word meaning “lawful” or, in philosophy-of-science terms, “law-like.” Without intentionally operationalized measures associated with clear definitions and their consistent use, the nomological net is not clearly defined, slowing down the acceleration of science.

Information (publication) overload

Lack of clear definitions and an appreciation of a construct’s location in the nomological net can lead to information (and publication) overload. There are 23,000 scientific journals that collectively publish more than 2 million peer-reviewed scientific articles each year (National Science Board, National Science Foundation, 2021). The proliferation of scientific publication, also in the psychological sciences, is partly explained by incentives to innovate, ultimately resulting in a proliferation of theories, constructs, and measures. For example, over the past 50 years, more than 500 psychosocial treatments for youth have been developed (Chorpita et al., 2011; Weisz et al., 2017). For disruptive behavior alone, 131 treatment protocols have been tested in 149 randomized control trials. Yet, effect sizes in treatment effectiveness have not increased. Closer examination reveals that there are 48 practice elements common to these treatment approaches (Okamura et al., 2020), which, if more thoughtfully synthesized and applied through ontology use and development, could improve overall treatment effectiveness. Imprecision in construct definition and use therefore has not only scientific implications but also real-world clinical implications.

Generalizability of findings

There are additional serious problems with the uncritical use of methods and measures to evaluate constructs. Without careful documentation of the relation between the measures and the constructs being measured, it is challenging to generalize findings across populations. Not surprisingly, the psychological sciences struggle to replicate findings under different conditions, necessitating the articulation of a common framework for accurately describing and comparing conclusions, describing how measures are related to conclusions, identifying moderating variables, and distinguishing conditions under which relationships can be replicated.

Summary

The pace of scientific discovery is unprecedented, with new clinical trials and experimental and correlational psychological research being published every day. Despite these advances, the behavioral and psychological sciences face substantial challenges. Inconsistent use of terms and classification systems makes it challenging to integrate findings from individual studies and, in turn, to cumulatively build bodies of knowledge even in domains that are consistently studied. Furthermore, knowledge generated by behavioral science research is not efficiently translated for the consumers who will apply it to benefit individuals and society. The gap between what is known and the capacity to act on that knowledge has never been larger, and it continues to grow.

Challenges for the Development and Use of Ontologies in the Behavioral Sciences

Development and deployment of ontologies for the behavioral sciences face a variety of challenges. First, the notion of "shared conceptualization" has been a challenge for many sciences. For example, the concept of species is a fundamental unit of comparison in biological sciences, yet scholars have been debating about the definition of species for decades (Saikia et al., 2008). Despite the ubiquity of definitional problems in science, the behavioral sciences may face unique challenges (Blanch et al., 2017). Constructs such as rationality, self-regulation, emotion, and personality are complex and may not be directly observable. Ontology development and construct validation therefore stand in reciprocal relation to each other, with the latter a critical precondition especially if considering that semantic standardization and integration are the logical consequence of ontology development and use. Semantic standardization and integration within and across ontologies are important to enable researchers to use a wide range of computational tools to advance their scientific work more rapidly, but they rely on strong construct validity of units.

Second, the knowledge structures (i.e., the nomological net) around many constructs in the behavioral sciences are most often logically or statistically inferred rather than observed through the senses. Ontologies and their content must be viewed as dynamic, nonstatic structures that continuously respond to new knowledge. As such, ontologies can be particularly valuable when they identify not only areas of agreement among researchers but also areas of disagreement, such as differing definitions of concepts and constructs, differing operationalizations of those constructs, and differing interpretations of the meaning of experimental tasks and manipulations. An optimal ontology within the behavioral sciences would be designed to facilitate and refine communication and precise use of terms rather than reification of constructs or top-down enforcement of ideas. Ontologies help us, as researchers, to take a dispassionate perspective on the state of our sciences (and even more so, the state of the science in our specific areas of research). Nonetheless, many behavioral scientists remain skeptical of the usefulness of ontologies despite these potential benefits. Skeptics argue that ontologies may have the unintended consequence of stifling research creativity or that the imposition of a common ontology hinders originality and punishes some of the unorthodox thinking that has led to major scientific advances (Niiniluoto, 2002). And many of us in the behavioral sciences were socialized over the course of our training to prioritize novelty (particularly in terminology) rather than to develop a comfort level working within existing nomological structures.

Third, ontologies are not well suited for areas of studies that do not allow for meta-analytic reviews that facilitate the distillment of core concepts and patterns. Thus, ontology development and use are better suited for mature areas in the behavioral sciences where stakeholders have a relatively clear idea of their needs for an ontology.

Fourth, because ontologies are dynamic, institutional support is necessary not only for their creation but also for continued editing, dissemination, adoption, evaluation, and revision. Guidelines such as the MIRO (Minimum Information for Reporting an Ontology; Matentzoglu et al., 2018) recommend the articulation of a sustainability plan, which includes a strategy for how the ontology will be kept up-to-date on the basis of evolving knowledge in the field. To illustrate, the BCIO upper level is made available in an open-access repository, which includes an "issue tracker portal," allowing feedback with open replies and discussion on the ontology. Built-in mechanisms in the software allow for tracking and "versioning" as the ontology is revised and updated in response to feedback and scientific advances in the field (Michie et al., 2020). To ensure continued monitoring of completeness, accuracy, consistency, computational efficiency, and clarity, substantial resources are needed (Amith et al., 2018; Gruber, 1995; Rensselaer Polytechnic Institute, 2013), including resources for computational and engineering tools for data reduction, organization, and visualization. Ontology dissemination requires application programing interfaces that allow programs to access and use information from others (e.g., BioPortal at Stanford University, which allows the upload of ontologies for distribution; Noy et al., 2010). Tools and technologies are furthermore needed to evaluate and debug ontologies (e.g., ROBOT; Jackson et al., 2021).

All of this requires institutional support and funding and may even be beyond the scope of what individual institutions can accomplish. At present, there are no existing cross-institutional structures or incentives in place to directly promote the development and use of ontologies in the behavioral sciences. Neither is ontology use formally encouraged by journals, conferences, academic societies, federal grant–funding agencies, or scientific practices, such as the open-science movement. If ontologies are to be routinely applied to accelerate the behavioral sciences, we need more discussion of the advantages and disadvantages and more institutional legitimization.

Finally, ontology development and use will not accelerate if their value is not communicated as part of training in the behavioral sciences. As yet, even the term "ontology" is not widely known or used in behavioral science academic settings, despite centuries-old use of ontologies of all kinds in the humanities and social sciences. As suggested earlier, the informal and formal aspects of training in the behavioral sciences may be creating barriers to better sharing and standardization of ideas, constructs, measures, and findings.

What Is Needed to Bring Ontology Development to the Next Level?

The NASEM report articulates several recommendations to realize the potential of ontologies for accelerating behavioral science research and practice. First, more research is needed to identify best practices for developing, disseminating, teaching, and implementing ontologies in the behavioral sciences. Other disciplines have identified their own best practices that have clearly benefited the research community. For example, ontology development in engineering benefits from experience and from some oversight by the engineering research community. Similar exercises in the behavioral sciences would be valuable. Organizations such as the Association for Psychological Sciences and the American Psychological Association could play a crucial role, but getting to the next level will require resources that are not currently available.

In addition to funding, greater capacity needs to be developed. For example, professional organizations may expand awareness of the importance of ontologies and encourage, if not initially mandate, participation in this broader enterprise of knowledge development. Journal editors might contribute by devoting greater space to ontology development and by encouraging more consistent use of terminology and conceptualizations. Scholarly conferences could devote more attention to the need for establishing formal shared conceptualizations. PhD programs and accrediting agencies might encourage inclusion of ontology development in core curricula.

Finally, open science depends on the development and utilization of ontologies to allow data sharing and comparison between data sets. Organization and retrieval of scientific information depends on the establishment of meaningful ontologies. All of these efforts should be supported by federal and private research agencies. Our academic communities must play a central role in this.

Conclusion and Future Directions

Decades of research have created an impressive archive of information on human and animal behavior. Yet the explosion of new research has created a crisis in the way information is organized, understood, and used. In the behavioral and social sciences, inconsistent use of language and variable methods for describing, measuring, and reporting constructs have contributed to poor replicability and reproducibility of research findings.

A new report from NASEM describes these problems and offers suggestions for how systematic ontology development might reinvigorate behavioral sciences research. The report offers specific recommendations for how government, funding agencies, professional societies, academic journals, and training institutions might use ontologies to accelerate scientific progress and the application of research findings, and readers are encouraged to peruse those recommendations. Ultimately, we hope the report will stimulate better methods for defining and categorizing behavioral phenomena. This will require collaboration between behavioral scientists who understand the content, philosophers with an understanding of the nature of knowledge, and computer scientists with expertise in the organization and retrieval of information. The collaboration has the potential to democratize knowledge about human behavior by making actionable research findings easily retrievable by the wide diversity of stakeholders.

Recommended Reading

Gruber, T. R. (1995). (See References). The classic introduction to ontologies from a computer science perspective.

Larsen, K. R., Michie, S., Hekler, E. B., Gibson, B., Spruijt-Metz, D., Ahern, D., Cole-Lewis, H., Bartlett Ellis, R. J., Hesse, B., Moser, R. P., & Yi, J. (2017). (See References). An accessible article building the rationale for the importance of ontologies in advancing clinical psychological sciences.

Norris, E., Finnerty, A. N., Hastings, J., Stokes, G., & Michie, S. (2019). (See References). A good review on existing ontologies focused on clinical interventions.

Poldrack, R. A., & Yarkoni, T. (2016). (See References). An accessible article building the rationale for the importance of ontologies in advancing cognitive psychological sciences.

Staab, S., & Studer, R. (2016). (See References). A comprehensive, highly accessible overview of ontology development and use

Transparency

Action Editor: Robert L. Goldstone
Editor: Robert L. Goldstone

Declaration of Conflicting Interests

The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

ORCID iDs

Carla Sharp https://orcid.org/0000-0001-8349-4701
Timothy J. Strauman https://orcid.org/0000-0002-0310-4505

Acknowledgments

The authors recognize the many significant contributions of Alexandra Beatty, who served as study director. Ms. Beatty was centrally involved in all aspects of the project, including coordination of the investigation and drafting of the report. The quality of the report reflects her myriad efforts and insights. The authors also wish to thank all members of the NASEM Committee on Accelerating Behavioral Science Through Ontology Development and Use who contributed to the consensus report from which this article draws its content.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual for mental disorders* (5th ed.).

Amith, M., He, Z., Bian, J., Lossio-Ventura, J. A., & Tao, C. (2018). Assessing the practice of biomedical ontology evaluation: Gaps and opportunities. *Journal of Biomedical Informatics*, *80*, 1–13. https://doi.org/10.1016/j.jbi.2018.02.010

Barrett, L. F. (2009). The future of psychology: Connecting mind to brain. *Perspectives on Psychological Science*, *4*(4), 326–339. https://doi.org/10.1111/j.1745-6924.2009.01134.x

Blanch, A., Garcia, R., Planes, J., Gil, R., Balada, F., Blanco, E., & Aluja, A. (2017). Ontologies about human behavior: A review of knowledge modeling systems. *European Psychologist*, *22*(3), 180–197. https://doi.org/10.1027/1016-9040/a000295

Chorpita, B. F., Daleiden, E. L., Ebesutani, C., Young, J., Becker, K. D., Nakamura, B. J., Phillips, L., Ward, A., Lynch, R., Trent, L., Smith, R. L., Okamura, K., & Starace, N. (2011). Evidence-based treatments for children and adolescents: An updated review of indicators of efficacy and effectiveness. *Clinical Psychology: Science and Practice*, *18*(2), 154–172. https://doi.org/10.1111/j.1468-2850.2011.01247.x

Cronbach, L. J., & Meehl, P. E. (1955). Construct validity in psychological tests. *Psychological Bulletin*, *52*(4), 281–302. https://doi.org/10.1037/h0040957

Davis, R., Campbell, R., Hildon, Z., Hobbs, L., & Michie, S. (2015). Theories of behaviour and behaviour change across the social and behavioural sciences: A scoping review. *Health Psychology Review*, *9*(3), 323–344. https://doi.org/10.1080/17437199.2014.941722

du Plessis, L., Skunca, N., & Dessimoz, C. (2011). The what, where, how and why of gene ontology-a primer for bioinformaticians. *Briefings in Bioinformatics*, *12*(6), 723–735. https://doi.org/10.1093/bib/bbr002

Falzon, L. (2021). *Scoping review of ontologies in the behavioral sciences*. Paper prepared for the Committee on Accelerating Behavioral Science Through Ontology Development and Use.

Gene Ontology Consortium. (2019). The Gene Ontology resource: 20 years and still going strong. *Nucleic Acids Research*, *47*(D1), D330–D338. https://doi.org/10.1093/nar/gky1055

Gruber, T. R. (1993). A translation approach to portable ontology specifications. *Knowledge Acquisition*, *5*(2), 199–220. https://doi.org/10.1006/knac.1993.1008

Gruber, T. R. (1995). Toward principles for the design of ontologies used for knowledge sharing. *International Journal of Human-Computer Studies*, *43*(5–6), 907–928. https://doi.org/10.1006/ijhc.1995.1081

Hastings, J., & Schultz, S. (2012). Ontologies for human behavior analysis and their application to clinical data. In E. J. Chesler & M. A. Haendel (Eds.), *Bioinformatics of behavior: Part 1* (pp. 89–107). Elsevier.

Insel, T., Cuthbert, B., Garvey, M., Heinssen, R., Pine, D. S., Quinn, K., Sanislow, C., & Wang, P. (2010). Research domain criteria (RDoC): Toward a new classification framework for research on mental disorders. *American Journal of Psychiatry*, *167*(7), 748–751. https://doi.org/10.1176/appi.ajp.2010.09091379

Jackson, R., Matentzoglu, N., Overton, J. A., Vita, R., Balhoff, J. P., Buttigieg, P. L., Carbon, S., Courtot, M., Diehl, A. D., Dooley, D. M., Duncan, W. D., Harris, N. L., Haendel, M. A., Lewis, S. E., Natale, D. A., Osumi-Sutherland, D., Ruttenbert, A., Schriml, L. M., Smith, B., . . . Peters, B. (2021). OBO foundry in 2021: Operationalizing open data principles to evaluate ontologies. *Database*, *2021*. https://doi.org/10.1093/database/baab069

Kaplan, R. M., & Beatty, A. S. (2022). *Ontologies in the behavioral sciences: Accelerating research and the spread of knowledge*. National Academies of Sciences, Engineering, and Medicine (NASEM).

Kelley, T. L. (1927). *Interpretation of educational measurements*. World Book Co.

Kotov, R., Krueger, R. F., Watson, D., Cicero, D. C., Conway, C. C., DeYoung, C. G., Eaton, N. R., Forbes, M. K., Hallquist, M. N., Latzman, R. D., Mullins-Sweatt, S. N., Ruggero, C. J., Simms, L. J., Waldman, I. D., Waszczuk, M. A., & Wright, A. G. C. (2021). The Hierarchical Taxonomy of Psychopathology (HiTOP): A quantitative nosology based on consensus of evidence. *Annual Review of Clinical Psychology*, *17*, 83–108. https://doi.org/10.1146/annurev-clinpsy-081219-093304

Larsen, K. R., Michie, S., Hekler, E. B., Gibson, B., Spruijt-Metz, D., Ahern, D., Cole-Lewis, H., Bartlett Ellis, R. J., Hesse, B., Moser, R. P., & Yi, J. (2017). Behavior change interventions: The potential of ontologies for advancing science and practice. *Journal of Behavioral Medicine*, *40*(1), 6–22. https://doi.org/10.1007/s10865-016-9768-0

Lawson, K. M., & Robins, R. W. (2021). Sibling constructs: What are they, why do they matter, and how should you handle them? *Personality and Social Psychology Review*, *25*(4), 344–366. https://doi.org/10.1177/10888683211047101

Lilienfeld, S. O., Sauvigne, K. C., Lynn, S. J., Cautin, R. L., Latzman, R. D., & Waldman, I. D. (2015). Fifty psychological and psychiatric terms to avoid: A list of inaccurate, misleading, misused, ambiguous, and logically confused words and phrases. *Frontiers in Psychology*, *6*, Article 1100. https://doi.org/10.3389/fpsyg.2015.01100

Matentzoglu, N., Malone, J., Mungall, C., & Stevens, R. (2018). MIRO: Guidelines for minimum information for the reporting of an ontology. *Journal of Biomedical Semantics*, *9*(1), Article 6. https://doi.org/10.1186/s13326-017-0172-7

Michie, S., Thomas, J., Johnston, M., Aonghusa, P. M., Shawe-Taylor, J., Kelly, M. P., Deleris, L. A., Finnerty, A. N., Marques, M. M., Norris, E., O'Mara-Eves, A., & West, R. (2017). The Human Behaviour-Change Project: Harnessing the power of artificial intelligence and machine learning for evidence synthesis and interpretation. *Implementation Science*, *12*(1), Article 121. https://doi.org/10.1186/s13012-017-0641-5

Michie, S., West, R., Finnerty, A. N., Norris, E., Wright, A. J., Marques, M. M., Johnston, M., Kelly, M. P., Thomas, J., & Hastings, J. (2020). Representation of behaviour change interventions and their evaluation: Development of the upper level of the Behaviour Change Intervention Ontology. *Wellcome Open Research*, *5*, Article 123. https://doi.org/10.12688/wellcomeopen res.15902.2

Mountjoy, C. Q., & Roth, M. (1982). Studies in the relationship between depressive disorders and anxiety states. Part 1. Rating scales. *Journal of Affective Disorders*, *4*(2), 127–147. https://doi.org/10.1016/0165-0327(82)90043-x

National Science Board, National Science Foundation. (2021). *Publications output: U.S. trends and international comparisons*. *Science and engineering indicators 2022*. https://ncses.nsf.gov/pubs/nsb20214

Niiniluoto, I. (2002). *Critical scientific realism*. Oxford Academic. https://doi.org/10.1093/0199251614.003.0002

Norris, E., Finnerty, A. N., Hastings, J., Stokes, G., & Michie, S. (2019). A scoping review of ontologies related to human behaviour change. *Nature Human Behaviour*, *3*(2), 164–172. https://doi.org/10.1038/s41562-018-0511-4

Noy, N., Tudorache, T., Nyulas, C., & Musen, M. (2010). The ontology life cycle: Integrated tools for editing, publishing, peer review, and evolution of ontologies. *AMIA Annual Symposium Proceedings*, *2010*, 552–556.

Okamura, K. H., Orimoto, T. E., Nakamura, B. J., Chang, B., Chorpita, B. F., & Beidas, R. S. (2020). A history of child and adolescent treatment through a distillation lens: Looking back to move forward. *Journal of Behavioral Health Services & Research*, *47*(1), 70–85.

Poldrack, R. A., & Yarkoni, T. (2016). From brain maps to cognitive ontologies: Informatics and the search for mental structure. *Annual Review of Psychology*, *67*, 587–612. https://doi.org/10.1146/annurev-psych-122414-033729

Rensselaer Polytechnic Institute. (2013). *The general ontology evaluation framework (GOEF): A proposed infrastructure for the ontology development lifecycle*. http://ontolog.cim3.net/file/work/OntologySummit2013/2013-03

Saikia, U., Sharma, N., & Das, A. (2008). What is a species? An endless debate. *Resonance: Journal of Science Education*, *13*(11), 1049–1064.

Staab, S., & Studer, R. (2016). *Handbook on ontologies*. Springer.

Thorndike, E. L. (1904). *An Introduction to the theory of mental and social measurements*. Science Press.

Weisz, J. R., Kuppens, S., Ng, M. Y., Eckshtain, D., Ugueto, A. M., Vaughn-Coaxum, R., Jensen-Doss, A., Hawley, K. M., Krumholz Marchette, L. S., Chu, B. C., Weersing, V. R., & Fordwood, S. R. (2017). What five decades of research tells us about the effects of youth psychological therapy: A multilevel meta-analysis and implications for science and practice. *American Psychologist*, *72*(2), 79–117. https://doi.org/10.1037/a0040360