

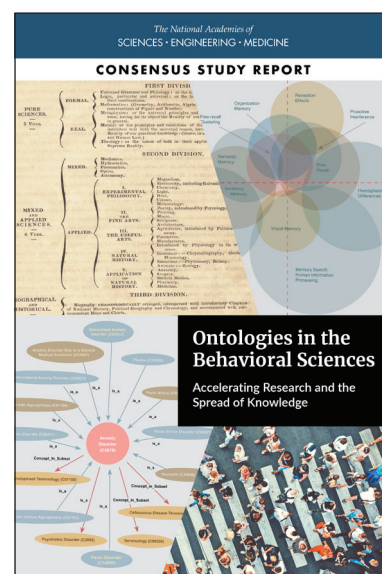


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Ontologies in the Behavioral Sciences Accelerating Research and the Spread of Knowledge

New research in psychology, neuroscience, cognitive science, and other fields is published every day. But the gap between what is known and the capacity to act on that knowledge has never been larger. Inconsistent use of terms and classification systems makes it challenging to integrate findings from individual studies and to cumulatively build bodies of knowledge, even in domains that are consistently studied. Scholars, like all learners, face the problem of how to organize knowledge and to integrate new observations with what is already known. By providing formal, explicit specifications of the meaning of the concepts and entities that scientists study, ontologies help to address these and other challenges.

The National Institutes of Health, the National Science Foundation, the American Psychological Association, the Association for Psychological Science, and the Federation of Associations in Behavioral & Brain Sciences asked the National Academies of Sciences, Engineering, and Medicine to appoint a committee to study ways of accelerating the behavioral sciences by improving the development and use of ontologies. The committee, which had expertise in medicine, population health, psychology, psychiatry, biobehavioral science, biomedical informatics, neural and cognitive science, library and information science, the history and philosophy of science, computer science, and bioengineering, offered conclusions and recommendations for advancing behavioral ontologies.



THE NEED FOR ONTOLOGIES IN THE BEHAVIORAL SCIENCES

Ontologies spell out the nature of the ideas that are studied in a particular domain and connections among those ideas. They are a means of reliably classifying behavioral phenomena and providing a shared vocabulary for discussing them. Ontologies help researchers identify the inconsistent use of definitions, labels, and measures. They provide the basis for sharing knowledge across diverse approaches and methodologies. Although ontologies are an ancient idea, modern researchers rely on them to facilitate the generation, dissemination, and retrieval of knowledge. They make it possible to codify research findings in computer-readable formats, which is essential for research that relies on large datasets and computer-based analytic techniques. Thus, ontologies can address challenges with research itself and with its application to real-world problems.

A wide variety of stakeholders rely on the knowledge created by the behavioral sciences, including, just in the domain of mental health, scientists who study behavior, social science, psychology, development, and cognition; clinicians who provide educational, behavioral, social, and psychological interventions; as well as educators, health care practitioners, policy makers, and patients. The overwhelming cascade of new research makes it difficult to synthesize results, and ontologies offer an infrastructure for systematically organizing and sorting research findings in particular domains so that key developments can easily be discerned by those who rely on them. Ontological specifications that are interoperable—useful across applications because they provide formal consistent, computable, and readily re-purposed specifications—can yield cost savings, efficiencies, and opportunities across research needs and applications.

A lack of ontological rigor can hinder scientific progress. Existing ontological systems in the behavioral sciences offer varying degrees of formal semantic specification. Valuable ontological systems and related tools exist and are supporting research in the behavioral sciences. However, many of these efforts have been isolated, their adoption has been constrained, and resources to support them (including training and education) have been limited. The developers of ontological systems are largely on their own to identify or develop the models, tools, and approaches that might best advance research and practice. Many of the systems that have been developed to support research do not have formal semantics, and therefore do not readily provide opportunities to support automated reasoning and other artificial intelligence applications. Even the systems that have been most explicitly designed with ontological goals in mind are not widely used.

STRENGTHENING ONTOLOGY USE IN THE BEHAVIORAL SCIENCES

To provide the intended benefits, an ontology should be logically sound (containing no contradictions, technically correct, and concisely expressed in formal terms), valid (accurately reflecting the domain), and usable by a diverse range of stakeholders, including scientists, practitioners, and others. The development and maintenance of ontologies are expensive because they are painstaking efforts. The socio-cognitive practices involved in creating and editing an ontology and adapting it over time require intensive human community engagement and iteration.

Computer tools—including software that supports collaboration and brainstorming, makes it easier to visualize complex relationships, and facilitates sharing and disseminating ontologies—can bring extremely valuable efficiency to the development, maintenance, and editing of ontologies. Statistical methods that identify common factors and hierarchical organizations among correlated behavioral measures can also support ontology development. But these tools can never stand in for the human understanding, ingenuity, establishment of consensus, and leadership that go into the development and use of ontologies.

For ontology engineering to progress in the behavioral sciences, sustained resources are needed to foster:

- *Discovery*, both foundational and translational research that are needed to develop and improve effective practices and the next generation of computational tools for ontology engineering in the behavioral sciences.
- *Capacity* to address shortfalls in implementation and to take advantage of the cases when novel research is not required—that is, when what needs to be done is clear, but there is currently no capacity to do it.
- *Promotion of practices and processes* that could support the wider use of ontologies in the behavioral sciences, and for which the capacity is already in place, but have not been widely deployed, such as institutional incentives, open data and code, and community-level efforts to bring consensus about ontologies in the behavioral sciences through collaboration.

SUPPORTING AND SUSTAINING BEHAVIORAL ONTOLOGIES

Pursuing greater ontological rigor in the behavioral sciences may require complicated tradeoffs. Increased use of ontologies would involve a commitment to continual evaluation and modification and openness to the existence of multiple, sometimes parallel ontologies. Nevertheless, ontology development and use have the potential to move behavioral science forward from a domain in which research is generally siloed and data and results are often incompatible to one in which the evidence is searchable and more easily integrated and in which computer technology is leveraged in the discovery of new relationships, the development of novel hypotheses, and the identification of knowledge gaps.

Because there is no substitute for the needed intellectual work, ontology development is quite expensive. Although ontologies are central to the advancement of science, there are no existing funding mechanisms for the development and maintenance of such systems and for the tools that support them. Sustained public and private support for the long-term development, dissemination, and maintenance of ontologies in the behavioral sciences and related tools is needed.

An infrastructure is also needed to expand available resources and incentives, to stimulate grassroots ontology development, and to coordinate efforts, with the aim of pushing for ontologies to be a higher priority in behavioral science research. Federal agencies are best positioned to provide the coordination and resources needed for this kind of activity. The committee recommends that the National Institutes of Health (NIH) and the National Science Foundation (NSF) take the lead in supporting and encouraging the development and use of ontologies in the behavioral sciences. Activities to further these goals include:

Development of formal agendas for accelerating behavioral science research through the development and use of semantically formal ontologies.

- Engage experts to develop a plan for ontology development across NIH institutes and centers.
- Develop an ontology for classifying intramural and extramural behavioral research at NIH.
- Coordinate ontology development efforts with the NSF Computer, Information Science, and Engineering Directorate.
- Collaborate in providing transition grants to allow ontology centers to develop business plans and distribution models that could put them on a sustainable footing.
- Bolster the training to strengthen the capacity of the people who will lead the development of the next generation of scientific ontologies.
- Coordinate ontology-related efforts.

Funding research that will support continuing progress in the development and use of ontologies in the behavioral sciences.

Development of a report on how an explicit formal specification of a shared conceptualization for behavioral science can be implemented across federal science agencies, based on the review of ontologies developed by other agencies.

Professional organizations and publishers also have a role to play, by,

- coordinating ontology development across academic and professional organizations;
- developing policies to improve the use of common vocabularies and data-reporting standards in behavioral science journals; and
- creating strategies to integrate ontology development into graduate-level teaching and practical training.

These ideas build on what has been accomplished through centuries of attempts to synthesize what is known, as well as decades of research on human and animal behavior. Better communications within the scientific community and between scientists and knowledge consumers will improve the science of behavior, the way it is disseminated, and its capacity to benefit society.

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