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An ontology for unifying behavior-change literature

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ABSTRACT

Changing the behavior of human operators is an underutilized approach to reduce the resource consumption of manufacturing. We created an ontology to make more accessible the existing work on behavior change, and categorized current knowledge under the headings: Problem Types, Barriers, Principles, Strategies, Mechanisms, Applications and Authors. Constructed using a web ontology language, the structure allows free navigation from any of the above category headings, and enables design practitioners better access to the strategies most relevant to their problem. We provide an example of how researchers can identify useful strategies for a specific problem in manufacturing.

1. Introduction

1.1. Resource-efficient manufacturing and behavior change

Resource scarcity and harmful environmental effects of industrial development have motivated research on resource-efficient manufacturing [1]. Any effort to reduce the resource consumption of industrial processes must begin with improved ways of determining how much energy and other resources such processes consume. To that end, research has focused on measuring: the energy requirements of different operating states of individual machines [1,2] as well as groups of machines and factories [3], and the life-cycle impacts of materials and equipment used in manufacturing processes [4]. Such results can then be used to design more efficient machines and automation schemes that adjust resource usage [5]. In addition to better automation and efficiency of industrial machines, we suggest it is also worthwhile to influence the behavior of machine operators toward actions that reduce resource usage. There is a large body of literature on changing human behavior, and specifically on facilitating pro-environmental behaviors that can be consulted for this purpose. We present a knowledge framework that organizes the results from this body of literature, to better support its application to modify human behavior in manufacturing settings. We will refer to humans/machine operators as *operators* below.

1.2. Behavior-change literature

Most research on behavior change has been carried out outside the realm of manufacturing and may seem inaccessible to manufacturing researchers. Additionally, due to differing aims, vocabularies and domain conventions, extant research is difficult to unify and analyze. First, the aims of various authors in the area of behavior change vary by discipline. At one extreme, behavioral psychologists and behavioral economists are interested in the motivations, whether rational or emotional, that lead to behaviors. Thus, they tend to postulate descriptive models of how behavior change occurs [6]. At the other extreme, some design researchers perform case studies of behavior-change interventions and inductively determine design principles for behavior change [7–12]. Other design researchers fall in between these extremes and try to find principles for change while also creating a model of behavior change. The different goals of researchers in different domains, along with domain-specific terminology used to describe results make it difficult to compare findings from different groups. Insights from these studies are also presented in a way that makes them difficult for engineers and designers to apply. The strategies or principles for behavior change usually provide direction in terms of where and how they should be applied. On the other hand, research that presents models of behavior change usually does not prescribe strategies that are specific enough for application. As a result, current behavior-change research, while containing very useful insights related to different aspects of behavior change, is difficult to use.

1.3. Ontologies and the semantic web

Semantic web technologies such as ontologies present a useful way of clarifying and organizing the information present in current behavior-change research. An ontology is a unifying framework that defines terms as well as the relationships between them using formal logic [13]. Ontologies have been used to store knowledge in a myriad of domains, including life-cycle management in manufacturing settings [4,14] and user requirements during the conceptual phase of design [15]. Ontologies have also been used to unify concepts in ecology [16] and genetics [17], and are well suited to uniting the concepts in behavior-change research.

2. Creating the Behavior-Change Ontology (BCO)

2.1. Structure of the ontology

We have designed an ontology with the aims of making it easy to understand, use and modify. It is constructed using the Web

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Ontology Language (OWL). Almost any concept or relationship can be described in OWL using the *Class/Property* structure. A concept is described as an individual member of a *class.* For example, a plastic extruder is a member of the class *extruders.* Individuals can be members of multiple classes. For example, a plastic extruder is also a member of the class *thermoplastic forming machines.* Classes can have subclasses and superclasses. For example, the *extruders* class can have the subclass *single-screw extruders* and the superclass *industrial equipment.* A relationship between two classes can be described as a *property*. For example, any member of the *single-screw extruders* class can be described by the property *has_screws* that links to *one* (which is a member of the *cardinal numbers* class). This type of linkage is called a *triple* because it consists of three parts, two individuals or classes connected by one or more properties (*single-screw extruders* → *has_screws* → *one*). This structure is robust enough to describe all manner of concepts and relationships in a way that can be parsed by a software algorithm.

2.2. Source material for the ontology

We consulted a variety of sources to create the ontology and each provided insights on different aspects of behavior change. We organized the insights under seven main categories and created classes for each of these. Behavioral psychology and behavioral economics theories such as the Trans-Theoretical Behavior Model and the Theory of Reasoned Action [6] provided insights related to the *types* of behavior-change *problems* that exist. A review of behavior-change interventions [18] identified *barriers* that users or operators face when they try to change behavior. Design research into behavior change also presents *strategies* for modifying behavior and extrapolated *principles* for behavior change. Finally, many theories of change such as the Health Belief Model [6] and Captology [19] hypothesize the *mechanisms* that underlie behavior change.

3. Structure of the BCO

The ontology is constructed with seven main classes that capture the different facets of behavior change present in existing knowledge. In the case of *problem types* and *mechanisms*, we were able to further distil the existing knowledge into a short list. Therefore, we present these lists in whole. The other classes contain many more members and therefore are only described overall. A reference schematic of the BCO is presented in Fig. 1. The schematic includes the main classes and some of the properties that connect them. Due to space constraints, only some of the connecting properties between nodes are illustrated. In the ontology, all classes can be connected to all other classes through different properties.

3.1. Problem types

Problem types explain the kind of behavior change that is to be performed. It contains seven levels. The first level has to do with promoting a behavior that is completely new to the operator; the operator does not have any pre-existing desire to perform the behavior and needs convincing. The second level describes situations where the operator knows and wants to adopt a new behavior but needs educating on how to go about it. The third level describes situations where operators want to adopt a new behavior, know how to do it, but need impetus to follow through. At the fourth level, the operator is already performing a new behavior and needs support to continue maintaining it. At the fifth level, the operator has adopted a new behavior but needs to increase or intensify its performance. At the sixth level, the operator has a behavior of which he/she wants to reduce the performance. At the seventh and final level, the operator has a behavior that he/she wants to cease performing.

3.2. Barriers

Barriers describe the obstacles that operators face in making behavior changes, including lack of information about problems, social restrictions around behaviors, and limitations of time or money. Psychology studies that examine operator motivations and design studies that aim to capture operator needs are good sources for barriers to behavior change. Many behavior-change interventions also impose new barriers to effect new behaviors.

3.3. Principles

Principles are the generalized approaches for changing behavior that researchers have discovered after reviewing case studies of behavior-change interventions. Almost all of the background studies used for constructing the ontology present their own principles. Principles have also been presented under different names, such as *strategy categories* [7]. Principles are excellent explanatory devices in literature as they take information from many different examples and converge them to one abstracted point. Unfortunately, this also makes them difficult to use as a starting point for design. Because they are abstract and general, they may lack the details designers need to guide them toward solutions.

3.4. Strategies

Strategies are more specific than principles and describe the particular way(s) that an intervention is intended to affect behavior. Strategies are more prescriptive (e.g., provide warnings

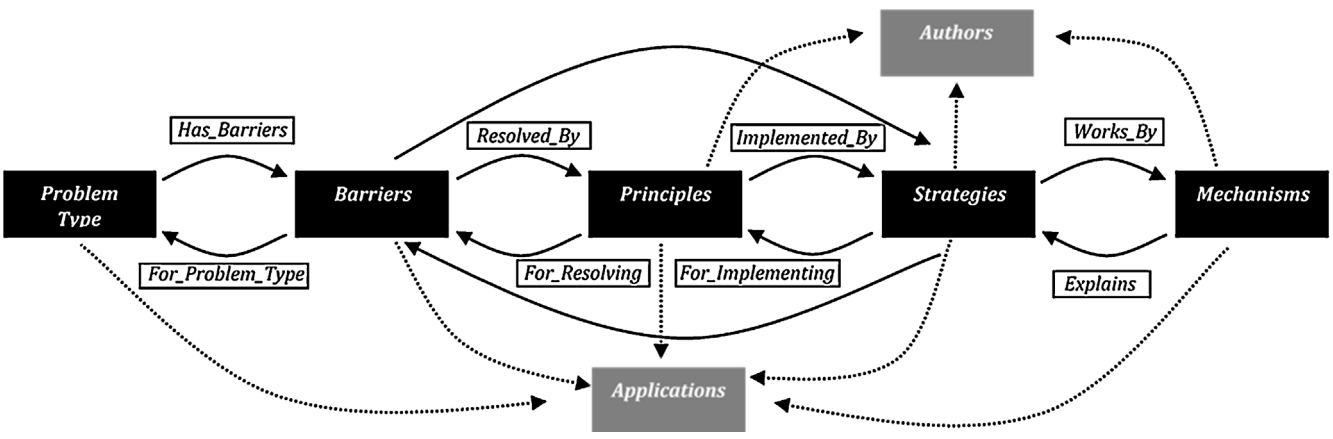

Fig. 1. General schematic for the Behavior-Change Ontology.