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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

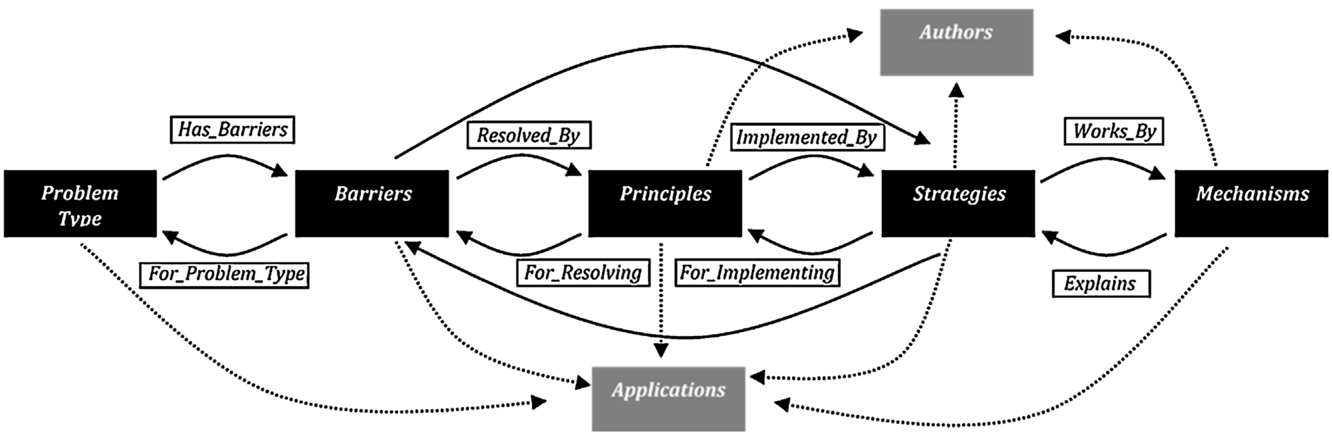

Fig. 1. General schematic for the Behavior-Change Ontology.

when users deviate from the planned course of action) and are easier for designers to use for generating ideas. The Design-with-Intent (DWI) framework [9] provided 101 of the strategies listed in the BCO. As DWI provides a large number of strategies (called *patterns* in their parlance), it is a logical place to start. Additional strategies can be added in the future if they are sufficiently different from one of the strategies already present in the ontology.

3.5. Mechanisms

Mechanisms are postulated explanations for why a particular strategy succeeded or failed to change a behavior. After identifying strategies from case studies, researchers often try to determine the underlying mechanisms behind the strategy [19,20]. A review of behavior-change literature has led us to make the following list of six principal mechanisms (based on [19,20]) that describe how strategies enable behavior change.

3.5.1. Obtrusiveness

Many behavior-change strategies succeed by increasing or decreasing the obtrusiveness of a product feature for the operator. For example, the *Are You Sure* strategy [9], which suggests having the operator reconfirm a decision before executing the desired command, works by increasing the obtrusiveness of the decision feature [20]. Machines that require operators to use both hands to power them on (in order to prevent injury) are examples of highly obtrusive behavior-changing features.

3.5.2. Operator ability

Behavior-change strategies also increase or decrease the operator's ability to perform certain actions in order to get him/her to change. For example, the *Conveyor Belt* strategy [9] gets the object of the behavior right to the operator, thereby increasing the operator's ability to perform that behavior by reducing physical effort. The modification of factors such as time available, money, physical effort, brain cycles and social pressure all affect operator ability [19]. The consistent use of the color red for shutdown buttons reduces operators' cognitive effort and increases their ability to find the button quickly when required.

3.5.3. Comparison

Behavior-change strategies often work by comparing an intended behavior against other behaviors. The *Framing* strategy for example suggests presenting an intended behavior in attractive terms, usually by presenting it alongside unattractive alternatives. Control displays in chemical processing can show the state of process variables in simplified form, sometimes as a circle moving across a line with its optimal position being at the center of the line.

3.5.4. Trigger

Many behavior-change strategies make use of cues to prompt operators to begin a behavior. This is commonly seen with strategies that make use of physical affordances in products. These typically work by triggering associations in the operator's mind between a feature in a product and a particular behavior, reminding him/her to perform the behavior [19]. In manufacturing, assembly fixtures are shaped such that it is easy for the operator to understand how to place parts on them.

3.5.5. Motivation

Behavior-change strategies that focus on influencing the antecedents of behavior typically aim to alter operator motivation for performing a behavior. For example, the *Social Proof* strategy promotes a behavior by showing the operator examples of his/her peers performing the desired behavior [19]. Factories use charts that show defect and return rates of the products manufactured there as a way of motivating workers to reduce the error rate.

3.5.6. Control

Finally, many behavior-change strategies work by increasing or decreasing the amount of control the operator has when performing a behavior. For example, the *Defaults* strategy [9] sets the designer-intended mode of use as the default setting and takes away some control from the operator to encourage a particular behavior. This can be seen in some production lines, where the speed of the line is set to maintain a production rate.

3.6. Applications

The applications class contains the examples that show where the behavior-change strategies and principles have been used. This is helpful to designers looking for suggestions relevant to a particular product or behavior domain.

3.7. Authors

Finally, the authors class lists the researchers responsible for reporting each concept.

4. Navigating the ontology

Information stored in the BCO as well as the relationships between concepts of the BCO can be accessed through queries. The data for the BCO is stored in an OWL 2 file and can be queried using a web-query language such as SWI Prolog. Designers can create queries such as 'find applications that employ the mechanism of changing operator control.' The logic processing ability of SWI Prolog also allows designers to ask more complex questions with multiple conditions such as 'find applications that overcome the barrier of lack of money, and are also relevant to cases where the operator wants to intensify an existing behavior.'

5. Benefits of the ontology

The BCO provides benefits to both academics and design practitioners. The benefits to researchers in the field of behavior change are the ability to: unify and add to existing literature in the field, find similarities between different proposed theories, analyze behavior-change literature, and synthesize insights.

The BCO presents a flexible and open structure that can easily be appended to or modified by researchers as they collect additional relevant work. Many studies in the area of behavior-change research are reviews of case studies. The BCO offers a standardized way of collecting and storing the data that describe a case study. Doing so also makes the case studies comparable with existing data in the ontology. The seven main classes in the BCO are able to explain the concepts and relationships from the literature cited. If future studies produce information that cannot be properly stored in this ontology, new classes can also be added easily. The ontology has enabled the description and transfer of over 100 behavior-change interventions between application areas. For example, using the class framework, interventions used in advertising can be compared to interventions from public health programs.

The BCO also allows researchers to identify overlaps among research findings by comparing the properties of concepts. As an example, if we were to review the *Defaults* strategy [9] in the ontology, it would be apparent that it shared similarities with the *OptOuts* strategy [9]. Both are connected to the principle of *Steering*. Both use the mechanism of changing user *Control*. Both were also relevant to the *Software Installation Wizard* application. Thus, the BCO reveals that the two strategies can be used interchangeably and can be linked together.

Finally, the BCO helps organize behavior-change research in a way that facilitates analysis and development of insights. By examining relationships between concepts, researchers can find new connections. For example, one could notice that the *Bundling* strategy is often applied to medical/drug related behavioral interventions. Further analysis could reveal some attributes of the strategy that make it well suited for that type of intervention.

For designers, the networked nature of the BCO allows them to quickly identify the strategies that are relevant for the type of behavior-change problem on which they are working. The main classes relevant to designers are problem type, barriers, strategies and applications, as these are most important for problem solving. Designers can avoid becoming trapped in the multiple levels of abstraction that result from the categorization of ideas and the induction of principles, by avoiding the principles and mechanisms classes all together. Designers can enter into the ontology what they know based on the work they have done to that point (e.g., the problem type, the barriers faced by their operator or even the type of application) and navigate their way toward relevant strategies for that problem. Regardless of the starting information the designers possess, they should be able to find their way to applicable strategies. The principles and mechanisms classes are useful for researchers to explain how behavior-change interventions work.

6. Example

We present a scenario to demonstrate how a designer could use the BCO as a tool for generating ideas. Green scheduling, i.e., optimizing the scheduling of when plant machinery is on or off, is a goal for sustainable manufacturing [21]. The traditional approach has been to employ technologies that automatically detect and power down machines that are not required [21]. This problem can also be tackled through behavior change of machine operators, who would be tasked with powering down machines when they are not required. We will illustrate use of the BCO to devise solutions for this problem.

Beginning with *Problem Type*, this falls under the category of adopting a behavior that the operator knows how to perform, but for some reason does not perform regularly. The ontology can then be queried for strategies that relate to starting familiar behaviors. In SWI Prolog syntax, the query is: **find_strategies_from_problems (Needs_to_Maintain, X)*.

The function searches through barriers associated with the Needs_to_Maintain behavior problem type, which include Lack_of_Cues and Lack_of_Interest (to perform behavior). These barriers are then connected to principles *Feedback, Encouraging, Guiding, Steering* and *Forcing*. Those principles are in turn connected to the strategies of *Mazes, Kairos, Hiding Things, Interlock, Did You Mean, Rewards, Unpredictable Reinforcement, Challenges* and *Targets*, etc. We can select one or more of these strategies and generate ideas. The *Kairos* strategy could lead to a solution that involves giving feedback at the right time. This could be implemented as a simple indicator that lights up when the machine is idle or the machine upstream of a particular machine has shut down or is idle. The *Challenges and Targets* strategy could lead to a visual display that provides feedback on the current energy usage of the machine, and compares it to a target value for energy consumption. We could also select more than one strategy and devise a multi-part solution. Using the *Interlock* and *Rewards* strategies together, we could create a system where machine operators would not be able to perform their normal use actions without first checking which machines in the vicinity were idle or otherwise candidates for powering down. There could also be a count of the number of machines that were idling at any one time for every operator; the more efficient an operator was, the more he/she would receive as a performance bonus. Thus, we see how the BCO can be used as an idea generation tool for eliciting a particular type of behavior.

7. Conclusion

In this paper, we described an ontology for behavior-change research that captures and organizes existing work under a simple, Class/Property structure. The ontology offers researchers a method for: categorizing and adding new work, determining overlaps among concepts, and identifying new insights. Designers can use the ontology to find strategies relevant to their problem of interest. Future work includes improving the usability of the ontology, available for download under the title *Behavior-Change Ontology*, at http://webprotege.stanford.edu.

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