A framework for modeling health behavior protocols and their linkage to behavioral theory

Leslie Lenert a,b,*, Gregory J. Norman b, Mark Mailhot c, Kevin Patrick b,c

a Health Services and Research and Development, Veterans Administration San Diego Healthcare System, USA
b University of California at San Diego, School of Medicine, USA
c University of California, San Diego—San Diego State University Preventive Medicine Residency Program, USA

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Abstract

With the rise in chronic, behavior-related disease, computerized behavioral protocols (CBPs) that help individuals improve behaviors have the potential to play an increasing role in the future health of society. To be effective and widely used CBPs should be based on accepted behavioral theory. However, designing CBPs while at the same time specifying their linkages to behavioral theory and developing reusable CBP components (interventions) are challenges to developers of CBPs. Having an ontology with which to describe CBPs could help with these issues. As a first step towards creating such an ontology, we modeled PACE-Adolescent, a theory-based behavioral protocol that uses the Stages of Change Model and Social Cognitive Theory, using PROTE ´ GE´-2000, an ontology editor and knowledge acquisition system. We created a three-part knowledge model. Two sub-ontologies described behavioral interventions and psychological theories. The third component, implemented using Guideline Interchange Format (GLIF3), provided a way to describe the structure of a protocol and to link intervention resources and groups of actions to elements of psychological theory. Using this framework, we formally described the PACE-Adolescent protocol. Creating knowledge models such as this may lead to improvements in the design and evaluation of computerized health behavior protocols.

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1. Introduction

Chronic conditions such as heart disease and cancer have replaced acute infectious diseases as the leading causes of mortality in the United States. Diseases related to lifestyle that were once limited to adults such as type II diabetes are beginning to affect children [1]. Many of these diseases can be prevented or ameliorated through behavior changes such as reducing dietary fat intake, increasing physical activity, or quitting smoking [2–4].

Effecting meaningful and sustained behavioral change is difficult. In medical contexts, efforts to motivate change are often based on theories of human behavior such as the Health Belief Model [5], the Stages of Change Model (SCM) (known formally as the Trans-theoretical Model, [6,7]) and Social Cognitive Theory (SCT) [8].1 While each theory has a unique perspective, theories often contain overlapping constructs. For example, the construct of self-efficacy (the concept of a person’s confidence in their ability to self-manage problems and overcome obstacles) can be found in both the Stages of Change Model and in Social Cognitive Theory.

* Corresponding author. Fax: +1 858 552 4321.
E-mail address: llenert@ucsd.edu (L. Lenert).

1 A description of the latter two theories, both of which are relevant to the present project, can be found in Appendix.
To change behaviors, researchers and clinicians develop behavior change programs that draw upon the constructs posited in psychological theories. We define a protocol as a behavior change program that may be implemented in clinical, worksite, home or school settings that combines multiple modes for changing behavior. We define an intervention to be a single instance within a protocol where a suite of methods is used to motivate or enable change for a particular behavior or set of behaviors. Conceptually protocols can be thought of as combinations of interventions. Temporally and physically, protocols are made up of a series of sessions, each session containing elements of interventions delivered at a particular time. Interventions apply theoretical constructs that can be measured and combinations of interventions can be delivered at different sessions. A construct can belong to more than one theory at a time and may be addressed by many interventions. Fig. 1 summarizes our model of the relationships between psychological theories, constructs, protocols, interventions, and sessions.

An ontology is a formal language for the description of a domain or area that is created to highlight distinctions between concepts and to create classes that allow generalization among concepts [9]. In this paper, we present an ontology, based on the relationships shown in Fig. 1, describing theories, constructs, interventions, and protocols underlying the development, deployment, and evaluation of a successful health behavior change program.

Ontologies are often useful in computer applications where they serve to define the vocabulary used and provide an intellectual framework that facilitates rapid or even automated construction of the application [10,11]. Computerized behavioral protocols (CBPs) are potentially important tools to improve public health because of the low marginal cost for delivery of an intervention or protocol, particularly for those that are Web based. If only a small percentage of the people using a popular Web site change their behavior, the net impact on the population would still be large. CBPs can take advantage of marketing strategies to fine-tune their message to their audience by using targeting, in which general characteristics of a group (e.g., income level, age bracket) are used to adjust the message, or tailoring, in which more personalized messages are created using individual characteristics (such as height, weight, likes or dislikes). Besides the Web, other computer-based media include computer-generated e-mail, printouts, and telephone calls, kiosks, and standalone programs. The creation of all of these types of applications may be facilitated by the use of ontologies.

Relationships between theory and practice are sometimes obscured in behavior change protocols, so much so that it may be difficult to recognize which theory, if any, underlies a particular approach. In some cases, no explicit theoretical basis for a protocol is given. For example, in a recent review of published articles describing computer-generated outpatient behavioral programs only 23 of the 37 articles included specified the theoretical framework or frameworks upon which the CBPs had been based [12]. Factors impeding the use of theory in designing behavioral protocols include the difficulty in designing assessments and in providing tailoring based on the assessments [13]. Formal ontologies describing the relationships between theory, constructs, protocols, and interventions may help make investigators more aware of the need for theoretical

![Fig. 1. Ontology of Theories and Constructs linking relationships between theories (e.g., Social Cognitive), constructs (e.g., self-efficacy), Interventions (e.g., goal setting), sessions (e.g., interaction with counselor in month 1), and protocols (e.g., PACE-Adolescent).](image-url)
underpinnings to their protocols. They may also help by providing reusable behavioral protocol components that are theoretically based.

The design of protocols and interventions draws heavily upon the developers’ practical experiences in motivating change and thus must have a balance between practical and theoretical elements. Because the evaluators of protocols have, in the past, primarily focused on success in achievement of change (i.e., outcome effects) rather than evaluation of the mechanisms of change (i.e., process effects) [14] developers have often combined several theoretical models with both independent and overlapping constructs to produce what they hope will be a clinically effective protocol. However, the results of mixing and matching of theory, constructs, and practical implementation is that it is often difficult to evaluate which components of a protocol have the greatest impact. Even when a protocol references a single theory, it is difficult to determine which components of the protocol have been the most effective. Specifying precisely these components, the underlying constructs and the links to theoretical models using an ontology may be useful in understanding the relative contribution of components of protocols.

Even when a protocol or intervention is explicitly theoretically based, it is hard to gauge its adherence to theory. For example, a given protocol supposedly based on the Stages of Change Model (SCM) could group its participants into stages of change; even better, it could target different interventions to participants based on their stage of change; better still, the targeted interventions could correspond to those suggested by the authors of the SCM [7]. A recent review by Doshi and co-authors examining the content of physical activity motivation Web sites demonstrates the problem of assessing the degree of adherence of an application to a theory. In their review, the authors focused their analysis on a description of whether or not there was evidence of a theoretical basis for various sites’ content. They were able to address this issue only indirectly, by reporting whether a Web site contained one or more theory-based constructs [15]. A more explicit description of the linkages between protocol and behavioral theory such as that provided by an ontology might better help determine how and to what extent protocols implement a particular theory.

In this paper, we present the development of a formal ontology for behavioral protocols. Our efforts have focused upon the first year of a protocol called PACE-Adolescent, which applies the SCM and Social Cognitive Theory to help adolescents develop a healthier lifestyle including regular physical activity and improved dietary behaviors [16]. We have attempted to address the issue of ontology development in a way that can be potentially generalized to many types of behavioral protocols with multiple constructs and theories of behavioral change.

2. Methods

PACE-Adolescent is a one-year behavioral protocol aimed at promoting healthy physical activity and dietary behaviors in adolescents. It consists of three components: an initial computerized assessment and goal setting program, a counseling session by the primary care provider, and extended follow-up by telephone with a personal health counselor. The telephone follow-up consists of monthly phone calls using a structured manual that tailors information by stage of change. Although PACE-Adolescent is not a computerized behavioral protocol, it has served as the a model for other PACE studies (different populations) in which extended follow-up is being delivered via the web and e-mail.

PACE-Adolescent targets and helps participants set specific goals for four behaviors: physical activity, sedentary behavior (e.g., watching television, playing video games), fruit and vegetable consumption, and fat consumption (see Table 1, PACE-Adolescent target behaviors). Participants are initially assigned a stage of change for each behavior based on their current pattern of activity and their expressed willingness to change. The stages used in the intervention—Precontemplator, Contemplator, Preparer, and Active/Maintainer—correspond to the comparable stages in the SCM. The stages of all subjects are reassessed at six months and one year after the beginning of the intervention, but depending on a participant’s reported performance and at the discretion of intervention coordinators, a subject can be assigned to a different stage of change for a given behavior at other times.

Monthly phone calls are about 15 min in length. During the first half of the year, participants work with their counselor on two of the four behaviors (one exercise and one eating behavior); during the second half of the year, the remaining two behaviors are addressed. Each intervention in the protocol (each telephone call) is designed to encourage positive behavioral change, and is tailored to the individual using constructs from the Stages of Change Model and Social Cognitive Theory. For example, during the second month, a participant in the Precontemplation stage for physical activity works on a “benefits of change” module. The counselor reviews the concept of benefits with the participant and then prompts him or her, using a worksheet, for specific desired benefits of increased physical activity. Alternatively, a participant at month 2 who is in the Preparation Stage works on a module about goal setting and self-efficacy. Both participants next review their activity behavior with the counselor, gauging progress
and setting goals for the next month, and then cover the appropriate module for the second behavior (fruit and vegetable or fat consumption). Table 2 shows the schedule of interventions for the first six months. According to this table, a participant who remains a preparer for one of his or her behaviors over a six month period would go through Modules 1, 5, 6, 7, 8, and 11 during these first six months; someone who started out as a preparer but became an active/maintainer after the third month of intervention would go through Modules 1, 5, and 6 (as a preparer), and then 9, 10, and 11 (as an active/maintainer). The schedule for the second half of the year is similar.

2.1. Ontology development

To develop our ontology we used the PROTEGE-2000 program (version 1.8, build 1074), an open-source ontology and knowledge base authoring tool written in Java [17]. We modeled the 12 months of PACE-Adolescent in a stepwise, iterative fashion, with one author (M.M.) designing the ontology and knowledge base and another author (L.L.) providing the majority of feedback. While the PACE-Adolescent protocol included both interventions and measurements of outcomes, we restricted the scope of our modeling to the intervention components. Through the modeling process, one objective was to link PACE-Adolescent interventions to psychological theory. A second objective was to discover components of PACE-Adolescent that implemented specific constructs and could be reused in other protocols. We also tried to keep the knowledge model of PACE-Adolescent as general as possible so that other protocols could be described using the same model.

In modeling PACE-Adolescent, we obtained most of our information about its structure and content from the manual given to PACE participants and the call guide and call schedule used by phone counselors. Other sources of information included review of the grant application for PACE and observation of intervention and measurement sessions. When necessary, we clarified details about the PACE-Adolescent protocol by talking with various researchers working on the project (e.g., G.N.). The textbook by Glanz et al. [18] served as a source of information about psychological theories and concepts.

After becoming familiar with the structure of PACE-Adolescent, we built a representation using PROTEGE-2000 of the individual actions making up interventions. We also built a simple model of psychological theory and input information about the two theories, the SCM and Social Cognitive Theory, which were used in PACE-Adolescent. In modeling psychological theory, we also included psychological constructs that were mentioned in the PACE material but did not appear in either of the two theories.

The PACE-Adolescent protocol was made up of a series of time-structured events, including simultaneous events, sequences of events, and events conditional upon participant choices and characteristics, which we represented using the Guideline Interchange Format, version 3.4 (GLIF3) [19] extensions for PROTEGE 2000. GLIF3 provides a framework enabling one to describe

<table>
<thead>
<tr>
<th>Content of phone call</th>
<th>Precontemplation</th>
<th>Contemplation</th>
<th>Preparation</th>
<th>Action/maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction/Welcome, knowledge, review goal sheets</td>
<td>X1</td>
<td>X1</td>
<td>X1</td>
<td>X1</td>
</tr>
<tr>
<td>2. Benefits (short and long term)</td>
<td>X2</td>
<td>X2</td>
<td>X2</td>
<td>X2</td>
</tr>
<tr>
<td>3. Decisional balance</td>
<td>X3</td>
<td>X3</td>
<td>X3</td>
<td>X3</td>
</tr>
<tr>
<td>4. Self-monitoring</td>
<td>X4</td>
<td>X4</td>
<td>X4</td>
<td>X4</td>
</tr>
<tr>
<td>5. Goal setting/self-efficacy</td>
<td>X5</td>
<td>X5</td>
<td>X5</td>
<td>X5</td>
</tr>
<tr>
<td>6. Barriers/stimulus control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Environment</td>
<td>X6</td>
<td>X6</td>
<td>X6</td>
<td>X6</td>
</tr>
<tr>
<td>8. Self-reward/self-talk</td>
<td>X7</td>
<td>X7</td>
<td>X7</td>
<td>X7</td>
</tr>
<tr>
<td>9. Social support</td>
<td>X8</td>
<td>X8</td>
<td>X8</td>
<td>X8</td>
</tr>
<tr>
<td>10. Relapse prevention/anticipating roadblocks/long-term planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Review of progress/restage/set new goals</td>
<td>X9</td>
<td>X9</td>
<td>X9</td>
<td>X9</td>
</tr>
</tbody>
</table>

An X1 means that the content is covered during call 1; an X2 that the content is covered during call 2; etc.
a medical algorithm as series of distinct steps and view
the algorithm as a flowchart. Algorithms are described
using five basic types of steps. In Action Steps, one or
more actions take place (e.g., “Take chest X-ray; take
12-lead EKG”). Decision Steps allow the patient or phy-
sician to make a choice based on structured criteria (e.g.,
“If the chest X-ray shows pneumonia, start antibiotic
treatment”) or personal preference. Patient State Steps
describe a patient’s current condition (e.g., “Patient is
taking acetaminophen”). Finally, Branching Steps and
Synchronization Steps allow multiple actions to be
undertaken simultaneously or in series and then to be
brought back together again, respectively. Medical
guidelines such as the recommendations for managing
a chronic cough or hypertension have been encoded in
GLIF3 [20].

As a last step, we linked psychological entities to
intervention entities. This involved adding components
to GLIF3 as described below.

3. Results

A protocol does not exist in a vacuum but has a tar-
get application area. Accordingly, the ontology included
some general details about the overall application area:
(1) the target audience (in this case, adolescents 11–15
years old), (2) the locale of the protocol (physician’s of-
cine, home), and (3) channels over which communication
took place (e.g., face-to-face, phone).

The overall ontology consisted of three smaller sub-on-
tologies: an ontology of psychological theories and con-
structs, an ontology of “PACE entities” that included
intervention materials and actions, and the GLIF3 frame-
work for representing sequences of events.

4. Ontology of Theories and Constructs

As depicted in Fig. 1, we modeled psychological the-
ories as collections of constructs. Constructs in turn had
four attributes (known in ontology parlance as
“slots”)—“name,” “definition,” “source,” and “mea-
ure.” The item representing the construct “self-efficacy,” for example, had name “self-efficacy,” definition
“the person’s confidence in performing a particular
behavior” and source “pace, sct, scm” (indicating that
it was found in both Social Cognitive Theory and the
SCM and independently as a construct in PACE). The
measure slot had the name of the measure, reflecting
the developer of the measure, e.g., ‘Sallis-Self-efficacy
Scale’ [21]. The slot would potentially link to a sub-on-
tology of construct measures that would have additional
attributes such as number of items in the scale, number
of sub-scales, and reliability and validity coefficients.
Refinements in the ontology could include an additional

Construct slot for the ‘intermediate goal,’ where the va-
alue would be the magnitude of change in the construct
expected to maximize the probability of desirable
change in stage in the SCM model or a desired behav-
ioral change. However, this would require considerable
empirical data to estimate the ‘intermediate goal’ value
and this value would likely vary by behaviors and pop-
ulation segments.

Stage_of_Change was created as a subclass of Con-
struct and had an additional slot, “follows_stage,”
which took another Stage of Change as its value. In this
way we were able to represent the fact that the Stage of
Change “Contemplation” follows the stage “Precontemplation.”

The class Intervention connected constructs to the
PACE entities Resources and Channels. The class Ses-
son linked interventions and actions and determined
when and to whom (Targets; stages) the interventions
would be delivered. It is at the Session level where the
three sub-ontologies interface. The class Protocol con-
tained slots for the target behavior(s), the measure of
each target behavior, and the hypothesized magnitude
of change (i.e., outcome goal) for the behavior. PACE-
Adolescent is an instance of the class Protocol and the
ultimate goal would be the ability to add other Protocol
instances from behavioral science research to the
ontology.

Fig. 2 shows the representation of the theory “Social
Cognitive Theory,” with its 11 concepts shown at the
bottom of the figure. After inputting information from
the two theories related to PACE-Adolescent and infor-
mation about constructs found only in PACE-Adoles-
cent, there were a total of 47 psychological constructs,
of which 13 psychological constructs were drawn from
the PACE-Adolescent materials but not associated with
either the SCM or SCT.

The links among the ontology classes Protocol, Interven-
tion, Construct, and Theory provide a detailed
description about a protocol. The ontology makes ex-
plcit what behaviors are being targeted by the proto-
col, what theories frame the protocol, what behavior
change constructs are expected to be affected by the
protocol interventions, which in turn are expected to
affect behavior change of the participants receiving the
protocol.

5. Ontology of PACE entities

The ontology of PACE entities described the Re-
ources, People, Channels, Actions, and Interventions
associated with PACE-Adolescent. Resources referred
to objects used in the PACE protocol such as work-
sheets, readings, and tip sheets. Depending on their
type they were described by the attributes (slots) of
title, section number, associated behaviors and/or
associated psychological constructs. For example, “Worksheet 10b-pa: Relapse Cues and Coping” was associated with section number 10, behavior “Physical Activity” and the psychological construct “Relapse Prevention.” People contained information about roles such as “primary care physician” and “intervention research assistant.” Channels referred to channels of communication such as “e-mail,” “face-to-face,” and “phone.”

6. GLIF3 framework

Processes and rules for activities within the protocol are represented using GLIF3. Actions within a protocol take place at an Action Step in the GLIF3 representation. Actions in this context refer to individual intervention actions (“teach subject about self-efficacy”) performed by the counselor designed to bring about a desired specific psychological effect. Actions occur during encounters between client and the counselor. Encounters are the composite set of actions that occur at a single-point-in-time that are, designed to produce attainment of the desired goals or states, as specified in the Intervention model. While patient states are a model class within GLIF3, we leave to future work specific representation of other intermediate states of internal psychology.

Within the GLIF framework, the most analogous entity to describe an encounter with a client is the Action_Step. Within an Action_Step, specific tasks are defined by the GLIF3 class Action_Specifications. Action_Specification contained slots for “name,” “description,” and “intention.” To adapt the GLIF3 specification to protocol representation, we created the Action step subclass of Encounter. The class Encounter contained extra slots “resources,” “addresses_constructs” and “targets_stages” not found the generic Action Step. The slot “resources” referred to objects (worksheets, tip sheets, etc.) used in the intervention, the slot “addresses_constructs” to slots specifically addressed, and the slot “targets_stages” to Stages of Change that the intervention targeted. To represent actions taken within an encounter PACE, we created the Action_Step subclass of PACE_Action. This class had additional slots consisting of “channel,” “participants,” and “resources.” Required by our representation. Channels was defined as the modality of delivery (telephone, in person, etc.), participants as the types of personnel involved, and resources would refer to printed material or other material (web based, videos, etc.) used in the Pace_Action. For example, a typical PACE_Action might be named “(with RA) review section 4,” its description and intention would be left blank, the channel would be Phone, resource Reading Section 4 and participants Intervention Research Assistant and Participant. The PACE_Action is only one type of Action Specifications. Protocols could also contain other types of Action_Steps than PACE_Actions.

Finally, the elements described above, along with GLIF3 entities like Decision Steps, were interconnected to form an algorithmic diagram. The diagram in Fig. 3 shows part of the algorithm, the GLIF3 representation of the decision tree in Table 2, using
a network of Patient State nodes (the diamonds at top and bottom labeled “begin appropriate section algorithm” and “end algorithm,” respectively), Decision nodes (other diamonds) and Action nodes (squares). Starting from the “begin appropriate section algorithm” node, control passes to the first decision node, labeled “month?” According to the month number, control passes to the next appropriate decision node (“month 2,” “month 3,” “month 4,” or “month 5”) or, during months 1 and 6, directly to modules 1 and 11, respectively, via the arcs labeled “M1” and “M6.” From the second set of decision nodes, control passes to the appropriate intervention (here called a “module”) according to whether the participant is in precontemplation (“pre”), contemplation (“con”), preparation (“prep”) or action/maintenance (“a/m”). The algorithm ends with the patient state node “end algorithm.”

Thus, we linked resources and interventions but not actions to psychological constructs. Resources were linked to constructs via the slot “involves_constructs,” and interventions were linked via the slot “addresses_constructs.” In addition, interventions were linked to Stages of Change via the slot “targets_stages.” Since most PACE_Actions involved one or more Resources (e.g., worksheets or readings), they were indirectly linked to constructs as well, though not directly linked. Under this semantic, resources and interventions touched upon constructs directly, but actions, only indirectly.

7. Discussion

We created a framework with which to describe the PACE-Adolescent protocol, a structured behavioral protocol based on the Stages of Change Model and Social Cognitive Theory. Within this framework, we modeled a theory-based behavioral protocol as a GLIF3 algorithm in which individual actions could each be linked to people, resources, and channels of communication. Sets of actions along with their associated resources could be grouped into units called interventions, and both resources and interventions could be linked directly to constructs contained in psychological theories.

One of our goals in creating this ontology was to facilitate the reuse of protocol components. Two components in particular—Resources and Interventions—were envisioned as possible reusable components. Both resources and interventions target a specific behavior or behaviors using a limited number of psychological constructs. Furthermore, both are designed to be accomplished or used within a limited time frame.
To facilitate their reuse, it would be helpful to add a concise description about their content and/or objectives (e.g., “a module to help improve self-efficacy regarding physical activity”). Adding some information about the intended target audience and behavior would help facilitate adaptation to new audiences (such as middle-aged men) or behaviors (such as smoking).

Another goal in creating this ontology was to help make the linkages between protocols and theories more explicit. We brought this about through linking interventions and resources to psychological constructs. Thus, it was clear from our model not only that the PACE-Adolescent protocol was built upon the Stages of Change Model and Social Cognitive Theory, but also that individual components were linked to specific constructs from those theories. Furthermore, by linking the class Intervention to the class Stage_Of_Change, we were able to reflect the fact that the intervention was tailored to participant stage of change, with different interventions for different stages of change. In the protocol, there were some psychological constructs present that were not explicitly mentioned or represented in our model. For example, counselors calling participants on the telephone was a form of social support and of helping relationships (both constructs in the SCM). Nevertheless, our model represents a first attempt at describing behavioral protocols and their underlying theoretical basis in a detailed fashion.

A third goal was to aid in the evaluation of protocols and protocol components. By forcing a protocol to be formally described in terms of its components, we hope we have enabled researchers to test the effects of individual components. By making linkages to psychological theory more explicit, we hope to have taken another step in the assessment of how well a protocol implements a given theory. There is more room for more growth in this area. For example, there was no representation as to whether the protocol for various stages of change was appropriate or inappropriate according to the Stages of Change Model. We could accomplish this by adding more links between constructs—for example, a link that indicated that teaching about “stimulus control” is best applied to people in action or maintenance.

GLIF3, although designed for medical protocols, was very useful in helping link behavioral intervention actions into a logical sequence. We added an extension to the GLIF3 description of actions to associate actions with people and objects, something that was not provided for in GLIF3; and we created Intervention as a subclass of Action_Step to capture the idea of a behavioral module that dealt with a discrete set of constructs. Both extensions helped us to tie elements of the PACE Adolescent protocol to psychological constructs. The GLIF3 knowledge model is very rich, and has other aspects that could be used in future versions of the ontology. For example, GLIF3 provides support for Concepts and Data Models that could be adapted to describe Psychological Constructs and Theories. A second useful feature of GLIF3 is the ability to make guidelines not just intelligible, but computable. We believe that, like medical guidelines, behavioral protocols have the potential to be interchangeable and exchangeable, and hope for other contributions in this area.

It is important to note that the resulting ontology is a first step in the modeling of health behavior protocols. Refinements and additions to the model would further add to its utility and its generalization to protocols other than PACE: Adolescent. For example, the present ontology does not model patient state. GLIF3 includes a class for explicit representation of patient state, and an ontology of discrete patient states might also be created that reflected theories in use in the protocol. Additional modeling could incorporate how patterns of construct values and patient states would direct decision rules for delivering particular protocol resources (Action_steps) [22]. Modeling explicit construct relationships would enhance the ontology’s knowledge base and inform researchers during the development of a protocol as to the multivariate intermediate outcomes needed to increase the probability of a behavior change. While this is a difficult task, such an enhancement would also help the generalizability of the ontology to other protocols that tailor program content based on multiple constructs (e.g. [23]).

This paper documents our efforts to develop a representation of the content of behavioral change protocols but does not include a formal evaluation of the ontology. Our representation language focuses only on the Pace-Adolescent protocol. A first step in evaluation might be reapplying the ontology to other PACE protocols and examining the content coverage and extensions required to encode the protocol. Subsequent evaluation work would extend beyond PACE to behavioral change interventions created by other research groups. Ultimately, the best test of the ontology might be its usefulness to protocol designers as a tool for aiding in the creation of new interventions.

Specific extensions might be needed to aid authorship of valid protocols. Ontology in its current form does not have features to evaluate the validity of a protocol or the validity of the construct relationships. That is, the knowledge base cannot address questions regarding whether or not the protocol successfully changed targeted behaviors (e.g., increased physical activity) or changed intermediate outcomes (e.g., increased physical activity self-efficacy). Incorporating outcome results from protocol trials would allow the
ontology to track the state-of-the-science evidence-base that can in turn inform future research directions and delineate ‘best practices’ for applied applications. There is also the potential to facilitate meta-analytic research with this knowledge base where statistical procedures can determine outcome and process effect sizes across all protocol instances in the ontology. These additions will enhance the ontology to make it a living representation of a protocol and open the possibility to dynamic adaptation of content delivered in the protocol as evidence evolves.

In summary, we have created the initial versions of an ontology aimed at describing the relationship between theory and practice in behavioral change. The approach models both abstract content, implemented content and processes. Further enhancements to this work are planned which will expand the scope and enable use of the ontology to drive and maintain automated computer systems supporting behavioral change.

Appendix. Health behavior theories

PACE-Adolescent is based on two common theories of health behavior: the Transtheoretical Model (TTM) and Social Cognitive Theory (SCT). The following is a brief description of these theories.

The Transtheoretical Model, developed by Prochaska in 1979, integrates principles and concepts from different behavioral theories using the concept of the “stage of change.” According to the Transtheoretical Model, people go through a sequence of six distinct stages—Precontemplation, Contemplation, Preparation, Action, Maintenance, and Termination—on their way to adopting a new behavior or quitting an old one. The stages are defined as follows:

- **Precontemplation**: the person has no intention of adopting the new behavior within the next six months.
- **Contemplation**: the person intends to adopt the new behavior within the next six months, but has no plans to do so within the next month.
- **Preparation**: the person intends to adopt the new behavior within the next month and is making steps towards doing so.
- **Action**: the person has adopted the new behavior within the last six months.
- **Maintenance**: the person has maintained the new behavior for over six months.
- **Termination**: the person has practiced the new behavior for over five years, feels 100 percent confidence in performing the new behavior and no temptation to revert back to the old behavior.

In addition to the stages of change, there are at least nine processes of change by which people advance from one stage to the next. Processes like consciousness raising (becoming aware of the negative effects of tobacco and the positive effect of quitting) or dramatic relief (experiencing either directly or indirectly the distress caused by the health consequences of tobacco) are useful in motivating Precontemplators to move to Contemplation. Other processes like stimulus control (becoming aware of and reducing cues that lead to smoking) or helping relationships (establishing new relationships or changing old ones so that friends and family members will help in staying quit) are useful when a person is in Action and is trying to maintain their quit status. Finally, the TTM includes the concepts of self-efficacy and decisional balance. Self-efficacy is a person’s perceived ability to change his or her own behavior, and is composed of confidence and temptation. Decisional balance is the difference between the personal factors supporting behavior change (“pros”) and the personal factors in opposition (“cons”).

Social Cognitive Theory (SCT) is a broad theory that explains behavior and behavioral change by integrating cognitive, emotional and behavioral factors with factors in the external world. The central principle of SCT is that of “reciprocal determinism,” according to which a person (including emotions and cognitions), his or her behavior and the environment (the world external to the person) form an interacting and interrelated triad that is constantly changing, a change in one component affecting the other two. Social Cognitive Theory takes into account a person’s capability to think symbolically and to anticipate the outcomes of an action. Thus, learning can take place either through direct experience or through “observational learning,” in which one person learns from another’s actions. Observational learning takes into account a process called “vicarious reinforcement,” where a reinforcer (reward for good behavior) for one person acts as reinforcement for another. Reinforcement for learning can also be either external (something recognized by others as valuable) or internal (for example, self-praise). Persons also control their behavior through self-control, involving self-monitoring, goal setting, and self-reward. Factors in the environment are important, but the person’s perception of the environment (the “situation”) is also important. By taking into account the environment and cognitive and emotional factors, Social Cognitive Theory provides many more methods of change beyond that of simple operant conditioning, in which behaviors are followed by rewards or punishments.

The following table summarizes the major constructs in the Transtheoretical Model and Social Cognitive Theory.
Major constructs in the Transtheoretical Model and in Social Cognitive Theory

<table>
<thead>
<tr>
<th>Construct</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transtheoretical Model</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Stages of change: the stages on the way to behavioral acquisition</strong></td>
<td></td>
</tr>
<tr>
<td>Precontemplation</td>
<td>Has no intention to take action within the next 6 months</td>
</tr>
<tr>
<td>Contemplation</td>
<td>Intends to take action within the next 6 months</td>
</tr>
<tr>
<td>Preparation</td>
<td>Intends to take action within the next 30 days and has taken some behavioral steps in this direction</td>
</tr>
<tr>
<td>Action</td>
<td>Has changed overt behavior for less than 6 months</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Has changed overt behavior for more than 6 months</td>
</tr>
<tr>
<td>Termination</td>
<td>Has changed overt behavior; has 100 percent self-efficacy and no temptation</td>
</tr>
<tr>
<td><strong>Processes of change: the activities used to advance through stages</strong></td>
<td></td>
</tr>
<tr>
<td>Consciousness raising</td>
<td>Finding and learning new facts, ideas and tips that support the healthy behavioral change</td>
</tr>
<tr>
<td>Dramatic relief</td>
<td>Experiencing the negative emotions (fear, anxiety, worry) that go along with unhealthy behavioral risks</td>
</tr>
<tr>
<td>Self-reevaluation</td>
<td>Realizing that the behavioral change is an important part of one’s identity as a person</td>
</tr>
<tr>
<td>Environmental reevaluation</td>
<td>Realizing the negative impact of the unhealthy behavior or the positive impact of the healthy behavior on one’s proximal social and physical environment</td>
</tr>
<tr>
<td>Self-liberation</td>
<td>Making a firm commitment to change</td>
</tr>
<tr>
<td>Helping relationships</td>
<td>Seeking and using social support for the healthy behavioral change</td>
</tr>
<tr>
<td>Counterconditioning</td>
<td>Substituting healthier alternative behaviors and cognitions for the unhealthy behaviors</td>
</tr>
<tr>
<td>Contingency management</td>
<td>Increasing the rewards for the positive behavioral change and decreasing the rewards of the unhealthy behavior</td>
</tr>
<tr>
<td>Stimulus control</td>
<td>Removing reminders or cues to engage in the unhealthy behavior and adding cues or reminders to engage in the healthy behavior</td>
</tr>
<tr>
<td>Social liberation</td>
<td>Realizing that social norms are changing in the direction of supporting the healthy behavioral change</td>
</tr>
<tr>
<td><strong>Decisional balance: the balance between pros and cons</strong></td>
<td></td>
</tr>
<tr>
<td>Pros</td>
<td>The benefits of changing</td>
</tr>
<tr>
<td>Cons</td>
<td>The costs of changing</td>
</tr>
<tr>
<td><strong>Self-efficacy: made up of confidence and temptation</strong></td>
<td></td>
</tr>
<tr>
<td>Confidence</td>
<td>Confidence that one can engage in the healthy behavior across different challenging situations</td>
</tr>
<tr>
<td>Temptation</td>
<td>Temptation to engage in the unhealthy behavior across different challenging situations</td>
</tr>
<tr>
<td><strong>Social Cognitive Theory</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Construct</strong></td>
<td><strong>Definition</strong></td>
</tr>
<tr>
<td>Environment</td>
<td>Factors physically external to the person</td>
</tr>
<tr>
<td>Situation</td>
<td>Person’s perception of the environment</td>
</tr>
<tr>
<td>Behavioral capability</td>
<td>Knowledge and skill to perform a behavior</td>
</tr>
<tr>
<td>Expectations</td>
<td>Anticipatory outcomes of a behavior</td>
</tr>
<tr>
<td>Expectancies</td>
<td>The values that the person places on a given outcome, incentives</td>
</tr>
<tr>
<td>Self-control</td>
<td>Personal regulation of goal-directed behavior or performance</td>
</tr>
<tr>
<td>Observational learning</td>
<td>Behavioral acquisition that occurs by watching the actions and outcomes of others’ behavior</td>
</tr>
<tr>
<td>Reinforcements</td>
<td>Responses to a person’s behavior that increase or decrease the likelihood of recurrence</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>The person's confidence in performing a particular behavior</td>
</tr>
<tr>
<td>Emotional coping responses</td>
<td>Strategies or tactics that are used by a person to deal with emotional stimuli</td>
</tr>
<tr>
<td>Reciprocal determinism</td>
<td>The dynamic interaction of the person, the behavior, and the environment in which the behavior is performed</td>
</tr>
</tbody>
</table>

Table adapted from: Glanz et al., Table 4.1, p. 62 (Transtheoretical Model Constructs) and Table 8.2, p. 157 (Major Concepts in Social Cognitive Theory and Implications for Intervention).
References