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A theory-driven design framework for smartphone applications to support healthy and sustainable grocery shopping

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Abstract

Modeling behavior has been a core topic of Psychology and the Social Sciences since their respective inception as academic disciplines. This has resulted in a fractured landscape of different theories, all addressing different aspects of behavior. At the same time the need to formalize the design of computer and smartphone applications has spawned the field of User Experience (UX). With the convergence of everyday behavior and the use of mobile devices the overlap between these two fields becomes ever more important. In this paper we present a comprehensive model of behavior, integrating five well-established theories, with the aim of creating a design framework for smartphone applications that foster motivation and promote the execution of a target behavior. The operationalization of the approach is demonstrated by showing how to design and implement a prototypical application to support healthy and sustainable grocery shopping behavior. While the framework proposed is not limited to this application, it is used to exemplify the relation with previous design approaches, and the concrete implications of the model-derived framework on its implementation. Our view is that both areas of research can benefit from each other: findings from behavioral theory can inform application design, while at the same time the ubiquitous integration of mobile applications allows to dynamically apply, operationalize, and implement behavioral models into everyday life.

KEYWORDS

apps, behavioral models, behavioral theory, healthy and sustainable grocery shopping, mobile application design, smartphone, user experience

1 | INTRODUCTION

By definition human behavior is at the core of the behavioral and social sciences, and related disciplines. Of central importance for these disciplines are behavior models, which should not only adequately describe but also successfully predict behavior, and provide the basis for interventions to change behavior (Ajzen, 1985; Bandura, 1999; Hacker, 1986; Locke & Latham, 1990; Ryan & Deci, 2000). A closer inspection of the literature reveals a large range of models, which tend to focus on a variety of aspects. This diversity of choice means that there is no shortage of options in terms of theoretical rationales and tools for conceptualizing technology-mediated health interventions. This diversity, however, can also make it difficult to decide which model to rely on for a given problem at hand (Michie et al., 2005). This often leads to solution designs based on ad hoc considerations using none or very limited theoretical foundations (Davis et al., 2015; Sama et al., 2014). To address the practical problem of designing applications the field of User Experience (UX) has emerged, which specializes in investigating the interaction of people with products, systems, and services (ISO9241, 2019). Nevertheless, it has been pointed out that this discipline is driven by heuristics (Quiñones et al., 2018) and shows a lack of theoretical background and links to existing psychological theories (Maia & Furtado, 2016). Many findings are replicating what has been known previously in the area of behavioral modeling, mainly due to the fact that most behavioral theories do not easily translate into operationalizable concepts that can be readily applied by an application designer. In this context the present paper aims to provide a comprehensive theoretical model which overcomes the respective limitations of these single models, and to guide solution design accordingly. We also elaborate on how theoretical concepts can be translated into concrete design considerations and present a prototypical application that has been designed according to the proposed theoretical model.

While the original scope of most behavioral theories is not in the realm of smartphone application design, nowadays ways of life and, therefore, our behavior is interlinked with the use of such devices, which are ubiquitous and shape the way how we approach many daily tasks. This makes these models especially relevant for the design and integration of applications into a wider context of behavioral and behavior change modeling. Most people have a variety of different applications on their smartphones to support them in their daily activities, for example a weather forecast, a fitness tracker, calendar or grocery shopping and recipe applications, to name a few. Our aim is here to capitalize on the latter as a prototypical exemplar to illustrate the model-based design framework developed in this paper.

While many applications are available in the domain of recipes and grocery shopping (Blanke et al., 2021), we hypothesize that effective behavioral change directed toward more healthy and sustainable grocery shopping might be optimized if the design of applications is fueled by the scientific knowledge derived from psychology and social science models. In this paper our aim is to demonstrate how a comprehensive behavioral model can help in guiding the design process of smartphone applications to support the behavior in question, and to address the criticism that up until now behavioral theories “are not up to the task” in the digital world because many theories only deliver a snapshot of behavior (Spruijt-Metz & Nilsen, 2014). Our view is that the proposed conceptual model can serve as a theoretical background for user experience (UX) design, linking this area of great practical importance and interest back to the large body of previous research on behavioral models and theories.

2 | A COMPREHENSIVE AND CONSISTENT INTEGRATED BEHAVIORAL MODEL

While all behavioral theories have human behavior at their core, they take different perspectives and focus on different areas of interest. For instance, the high-performance cycle (HPC) (Locke & Latham, 1990) and the Action-Regulation Theory (ART) (Hacker, 1986) were developed in the context of work and organizational processes and are, therefore, both centered around improving work motivation and efficiency. In contrast to these, the Social Cognitive Theory (SCT) (Bandura, 1999), the Theory of Planed Behavior (TPB) (Ajzen, 1985), and the Self-Determination Theory (SDT) (Ryan & Deci, 2000) were developed for a broader spectrum of potential applications. Nevertheless, each of these models focus on specific aspects underlying the behavior, with the focus of the SCT being on the interaction of the individual with the environment, the TPB looking at behavioral intentions, while the SDT is concerned with motivational regulation. All of these theories and models can make a significant contribution to designing a solution for assessing and improving a behavior in question; however, the field remains fragmented and difficult to operationalize.

To overcome these limitations, we evaluated the definitions of concepts in each of the respective theories for communalities and overlap, while at the same time identifying gaps and limitations of the individual models. We also looked at the mutual relationships between terms and concepts, and identified mutual links and interdependencies. The result of this in-depth analysis is the nested double cycle of behavior shown in Figure 1. It shows which concepts are drawn from which underlying theory and how they are connected to each other, thus providing a comprehensive and consistent integrated behavioral model.

Each of the underlying theories is more or less useful depending on the area they focus on. By integrating different behavioral models, it is possible to identify overlapping concepts, which are referred to as different terms, yet they also consider unique aspects that justify their integration to develop an integrative conceptual model. Furthermore, it is possible to identify the specific limitations of an individual theory and overcome these by connecting them to another theory which shows particular strength in the missing area and vice versa. Figure 1 shows how the different concepts from the selected theories integrate into each other resulting in a nested double cycle of links and dependencies. Where similar concepts are used but under different terms, the developed behavioral model sums those concepts up and uses the name from the most dominant theory in this area. For instance, the concept of self-efficacy is used implicitly in all models mentioned above; however, only the HPC and SCT make use of the term explicitly, and the concept itself originated from the SCT. Thus, the SCT is considered the dominant theory for the concept in this case. Similar arguments can be made for all concepts contained in the integrated model above.

The integrated theories can also be divided into qualitative and quantitative theories, depending on whether they are purely descriptive or whether they also provide means to operationalize and conceptualize a subset of variables they specify. Using this categorization the HPC, ART, and SCT can be considered qualitative, while the TPB and SDT are quantitative and provide means of assessment through psychometrically validated questionnaires (Ajzen, 2006; Ryan & Deci, 2021).

The HPC provided the foundation of the inner behavioral cycle to which all other theories are connected. It has been originally

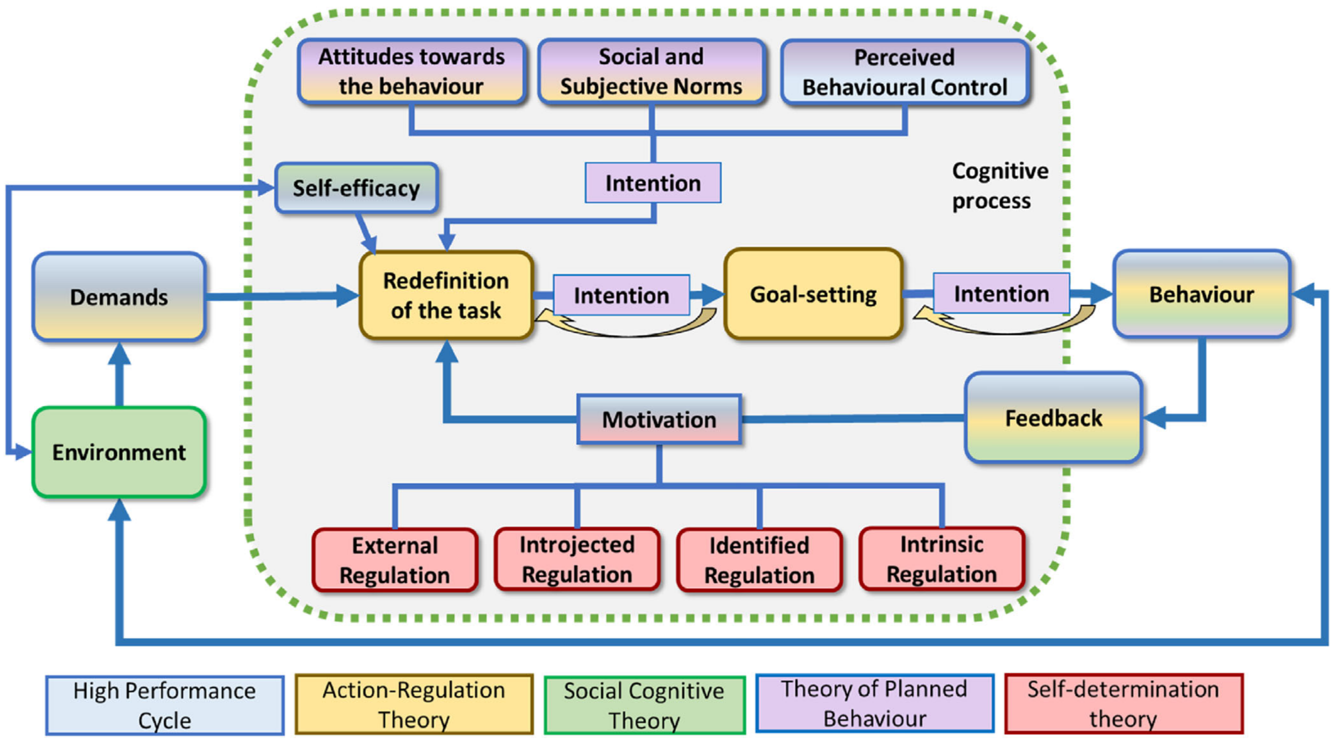

FIGURE 1 Nested double cycle of behavior combining the five underlying base theories into a comprehensive and consistent integrated model of behavior (colors correspond to the underlying theories for each concept: high-performance cycle [blue], Action-Regulation Theory [yellow], Social Cognitive Theory [green], Theory of Planed Behavior [violet], Self-Determination Theory [red])

developed in the context of work and organizational psychology and shown to be successful in improving employee performance and motivation (Borgogni & Dello Russo, 2012; Selden & Brewer, 2000). However, it also lends itself as a qualitative framework that connects important behavioral influence factors in a cyclical structure of continuously improving performance outcomes. We capitalize on its basic structure and broaden its scope to integrate other behavioral theories, making the HPC applicable to a wider area of interest. One of the main identified limitations of the HPC has been its lack of a clear description and visualization how goals are translated into actual behavior (Locke & Latham, 1990), which can be overcome by the ART's very precise picture of how demands or tasks are taken over and personalized by the individual, translated into precise action plans and finally into actual behavior (Hacker, 2003). While the HPC and ART were both developed in organizational and work psychology and are primarily applied to optimization of organizational process design (Hörisch et al., 2020; Selden & Brewer, 2000), the introduction of the SCT can help to overcome this narrow perspective on work performance. The integration of the SCT into the cyclical structure provided by the HPC widens the scope of the behavioral model by introducing a well-defined connection between the interaction of the individual with his/her environment. The SCT has been applied to assess behavior in various domains including health (Strong et al., 2008) and sustainability (Phipps et al., 2013). While these three theories together already provide a good picture of relevant variables concerning human behavior, they are qualitative in nature and lack quantitative components to measure relevant behavioral parameters. While this shortcoming can be overcome by adapting existing inventories and mapping them to the concepts defined by the models (e.g., Hörisch et al., 2020; Selden & Brewer, 2000; Swindle et al., 2016), it is possible to formalize inventory design by introducing explicitly quantitative theories such as the TPB (Ajzen, 2006) and the SDT (Ryan & Deci, 2000). The TPB focuses on the quantification of intention, which is understood as the condition shortly before showing the behavior in question (Ajzen, 2006), while the SDT evaluates the motivation, which can be defined as the general tendency to show a certain behavior in a particular area of interest. Figure 1 shows how these quantifiable parameters can also be integrated into the proposed conceptual model resulting in a consistent view of the factors (qualitative and quantitative) affecting a particular behavior.

3 | MODEL-DRIVEN DESIGN FRAMEWORK

The behavioral model outlined in the previous section indicates the relevant concepts and their mutual dependencies, which are identified by the underlying behavioral theories as relevant and should be addressed to achieve maximum impact. Designing an application with the goal of supporting or influencing a behavior, therefore, needs to ensure that all these different aspects are considered comprehensively and in an integrated way. The proposed conceptual model provides a list of concepts that can be used in a design framework to identify and evaluate necessary features to support the behavioral cycle accordingly. We conjecture that following a model-driven approach that focuses on the application user's cognitive process to execute a desired behavior has the potential to promote more optimal application design than following an ad hoc approach essentially based on the ease of implementation of certain features, as is too often the case for many smartphone applications. In this paper we will use a smartphone application to support healthy and sustainable grocery shopping as an exemplar to demonstrate how the proposed design patterns can be translated into a real-world application (cf. HealthStainable, Blanke & Beder, 2020), although the design framework is broader and not limited to a specific application domain. It can be applied to a variety of behavioral processes, which are volitional and conscious, focusing on the social-cognitive interaction of the individual with his/her surrounding, neither driven by inner forces nor automatically shaped and controlled by the environment alone (Bandura, 1989).

It should be noted that designing for supporting behavioral aspects impacts both the front-end and the back-end of a smartphone application architecture. In particular it is not limited to UI/UX design only, and can affect all components of the application ecosystem, which can include requirements on back-end databases, formation and presentation of information delivered to the user, or mechanisms for ecological momentary assessments (Shiffman et al., 2008), to name a few. In the following we describe the concepts identified by the model individually, briefly define how they are assumed to impact behavior, and how design patterns can be derived to affect or support these concepts as part of a theory-based design framework.

According to the HPC and ART behavioral processes are triggered by *demands* (Locke & Latham, 1990), which can be both internal (e.g., hunger) or external. The latter can be understood as external guidelines and policies, which originate from the outside and are communicated to the individual through the application. Demands are the translations of broader challenges into individual challenges, which have been shown to be a significant contributor to performance (Selden & Brewer, 2000). In the context of the design framework this can be understood as the overarching design goals of the application. It is important that such demands can be operationalized. For instance, a desired outcome of application design could be to improve healthy and sustainable diets, which then imposes constraints on the design process to ensure that these goals can be integrated into the application. More specifically, demands usually have very specific implications on how the back-end of the application is created to ensure that general guidelines and policies can be operationalized into tangible application features. For example, the design of underlying databases needs to be informed by the required information relevant to the demands, such as accurate nutritional and carbon footprint data in the case of an application targeting improving healthy and sustainable diet behavior.

The ART describes the *redefinition of the task* (Blanke, 2008; Hacker, 2003) as the process how abstract and general demands are translated into personalized and meaningful goals by the individual. The same demands can be interpreted very differently by different people and it has been shown that personalization of smartphone applications correlates with perceived usefulness (Tossell et al., 2012). In the context of an application design framework, this process should be facilitated and supported by suitable features, ideally by providing individualized information relevant for the application user in his/her respective context, that help to translate externally set demands into individualized goals. Designing features for supporting the redefinition of the task therefore should focus at the different expected types of application users and define which information from the underlying databases is relevant for which group of users, and how the information needs to be transformed to be presented adequately. This relates to the creation of personas, which have been proposed in the context of UX design frameworks (Matthews et al., 2012).

The next step of the cognitive process leading to a behavior according to the ART is *goal-setting* (Hacker, 1986, 2005), which corresponds to the way superordinate goals are broken down into subgoals and ultimately into precise and visualizable action plans. The performance gain achieved by goal-setting has been found to be empirically supported by many studies (Locke, 1996; Tubbs, 1986). An application designed to be embedded into an everyday activity needs to ensure that it precisely meets the expectation of the application user in accordance with these individualized action plans. The better the flow of the application matches the actual execution of the behavior, and the more precise the presented data and information matches the requirements during this execution the more useful the application becomes in supporting the target behavior. For example, a grocery shopping application should ensure that the consecutive behavioral process of meal planning, shopping list creation, and grocery shopping is supported through application features such as recipe selection, consistent recipe aggregation, and flexible shopping list management. For instance, by ensuring consistency of units of ingredients or combining recipes into one unified shopping list (both not common features in many grocery shopping applications), an improvement of the perception of utility of the application potentially leading to more positive behavioral outcomes can be expected. The ART also stresses the importance of dynamic feedback loops as part of the goal-setting, which help to ensure that action-plans stay current and are updated with suitable alternatives as required. Dynamic adaption to emerging requirements is a key strength of smartphone applications; however, it is important to enable such features to optimally support goal-setting and execution.

The SCT introduces the concept of *self-efficacy* (Bandura, 1991, 1999), which focuses on the self-perceived ability of (in this context) the application user that needs to be considered in the design process. There is broad empirical support for the role of self-efficacy in behavior change processes (Harrison et al., 1997; Zhang et al., 2019). As a consequence, all provided information should be evaluated by the application designer if it is easily perceived and can be translated into appropriate behavior by the expected target audience. Self-efficacy is conceptualized as the person's own perception of what he/she believes he/she can do under the current circumstances. It is, therefore, important in this step of the design process to identify potential external circumstances that may arise while using the application and analyze how the different targeted application users will perceive the difficulty to adjust their behavior accordingly.

Feedback is defined in the HPC and SCT as the reflection of how far progressed a behavior is with respect to the goal that needs to be achieved (Bandura, 1999; Locke & Latham, 1990). It can be either externally sourced, that is, as a result of some form of behavior evaluation, or originate internally, that is, as the result of a comparison between what is perceived as achieved so far and what is the desired outcome of a behavior. Both can lead to the potential adjustment of the behavior during execution. Feedback also has an influence on motivation and intention to stay engaged with a plan and to show a desired behavior accordingly. Therefore, feedback needs to occur throughout the entire activity. Meta-analysis of feedback research shows that informative feedback can positively influence motivation and behavior (Wisniewski et al., 2020). Application design can facilitate this by appraising behavior directly, or also by encouraging self-reflection and self-feedback. The SDT defines the motivational type through a continuum of self-determination (Ryan & Deci, 2000), which determines the type of feedback a particular application user needs to receive to stay motivated. This can range from encouragement for intrinsically motivated individuals to monetary incentives for extrinsically motivated people and could also cover aspects such as reward schemes and gamification.

The SCT focuses on the reciprocal causal relationship between the individual and the *environment* (Bandura, 1999). It is therefore well-suited to serve as the theoretical underpinning for all forms of ubiquitous computing, which aims at integrating the interaction of the user with the application with outside activities and circumstances. Application design can address this idea by anticipating the different contexts in which the application is used, which barriers are likely to occur and which alternatives are available to be chosen by the user. To optimally support a behavior the application designer needs to very clearly identify, which aspects of the user's environment are immutable, which aspects can be chosen amongst a limited number of alternatives, and which aspects can be adapted to define relevant application features accordingly. For example, in a grocery shopping situation preplanned recipes can be met with unavailability of certain products, which can be mitigated by application features to change or alter these plans accordingly while the behavior is executed.

Although the primary goal of quantitative behavioral theories is to assess drivers of behavior and their impact on motivation and intention, they can also be applied to inform application design aiming at improving these indicators. Applications that target these drivers are more likely to increase the motivation and create a positive impact on the behavior in question. The TPB outlines how attitudes toward the behavior, social and subjective norms, and perceived behavioral control all affect the immediate intention to act (Ajzen, 1985, 2016). The TPB is widely used and there is broad empirical support for its usefulness and relevance in the context of promoting health and sustainable behaviors (Biasini et al., 2021). Application design can target these aspects separately and implement features specifically to address the beliefs of individuals accordingly. In scenarios where application users show a positive attitude toward the behavior, the intention to act accordingly can be improved by presenting information first and foremost, while this approach is deemed less effective for people showing more negative attitudes. The effect on individuals who show high awareness of social and subjective norms can be improved by providing comparative messages and creating peer-pressure (Keizer & Schultz, 2018; Steg & Vlek, 2009), for instance by implementing aspects of gamification into the application (Berger, 2019). When *perceived behavioral control* is a predominant issue impeding a behavior in question, this can be supported by an application design aimed at overcoming this perception and providing guidance and explanation accordingly. The TPB provides the means of assessing all three aspects independently, enabling application designers to identify the relevant personas to target their features.

A similar argument can be made for improving long-term motivation to use the application. This topic can be addressed by the SDT (Ryan & Deci, 2000), which defines *relative autonomy* as the key indicator describing general motivation. Autonomous motivation has been found to be positively influencing changes in health behavior (Ntoumanis et al., 2021) as well as sustainability (Schösler et al., 2014). According to SDT, individuals can be categorized on a spectrum from external to intrinsic motivation, which can be used as a gauge to decide if and what type of incentives need to be provided to entice a target behavior. Hence, understanding the relative autonomy of individual application users can help to design appropriate incentive schemes and targeted feedback in a way to maximize long-term behavior change. The SDT measures four types of regulation, all of which can be targeted by application design. The two factors negatively influencing relative autonomy are external regulation, which explains that some individuals need strong support or external incentives to show a desired behavior, and introjected regulation, which is concerned with the avoidance of negative consequences. The presence either requires application designers to provide external incentives, or at least to implement other schemes such as gamification and regular positive feedback, to get and keep people engaged. On the other hand, the two factors positively influencing autonomy are identified regulation, which describes the internalization of superordinate goals and the need to act accordingly, and intrinsic regulation, which applies to individuals who do something because they like to and enjoy it. Both are addressable by providing sufficient information as well as simple ways to translate demands into goals and further into subgoals and action plans. The SDT allows to assess all these four aspects individually and to identify the target audience to design application features accordingly.

All of the above concepts are derived from established behavioral theories, which were not developed with smartphone application design in mind. Instead, their focus is on providing defined (mostly social-cognitive) concepts and testable associations among them with the aim to predict and change behavior. For their use in smartphone applications they need to be supplemented by design guidelines specific for the implementation of modern-day cloud-based applications. For example, issues like trust, data sparsity, ubiquity, cost-efficiency, scalability, usefulness, low-barrier access, or usability all have an impact on application design, but are not covered by these behavioral models directly.

4 | EXAMPLE: HEALTHY AND SUSTAINABLE GROCERY SHOPPING

4.1 | Model-driven application design

To demonstrate the applicability of the proposed model-based design framework we describe in the following the design of an application to support healthy and sustainable grocery shopping. The resulting Android application can be downloaded freely from the Google Play Store from https://play.google.com/store/apps/details?id=com.HealthStainable.

The *demands* for this application are to promote a healthy and sustainable diet, in which grocery shopping plays a major role to achieve this goal. While health has been the priority up until now with regards to creating dietary guidelines, sustainability is receiving more and more attention (de Schutter, 2015; Hoek et al., 2017). The first step in designing an application targeting these demands is to focus on a clear definition of the two concepts. A healthy diet is defined by the World Health Organization (WHO) as the consumption of plenty of vegetables and fruit, less fat, in particular animal-based fat, a reduction in the intake of sugars and salt (WHO, 2020). These guidelines can be operationalized by implementing specific nutritional values. An example of such an approach is the food labeling scheme of the UK National Health Service (NHS) (NHS, 2021), which is based on the European food labeling directive (Council of the European Union, 1990), and provides standardized values for energy in kcal/100 g, as well as fats, saturates, carbohydrates, sugar, protein and salt content in g/100 g. There have also been attempts to operationalize sustainability in the context of food consumption and food production (Dötsch-Klerk et al., 2015; Food and Agriculture Organisation of the United Nations, 2010); however these guidelines are very broad, encompassing environmental impact, biodiversity, social and ethical factors all of which are difficult to quantify and implement. To implement these broad demands into a mobile application, therefore, a narrower and more focused definition is required. It has been suggested to focus on environmentally friendly diets (Hoek et al., 2017; Verain et al., 2017), which require the reduction of the ecological footprint related to carbon emission and energy use as well as the transition from an animal-based to a more plant-based regime. To operationalize this demand in a mobile application we propose to use a metric similar to the nutritional food labeling based on the carbon emission per energy provided, which can be measured in gCO2e/100 kcal. Although healthy and sustainable diets overlap to some extent, this does not hold across all product categories. For instance, reducing the intake of sugary drinks or cakes and cookies has only a moderate effect on sustainability but a significant effect on health (de Schutter, 2015); vice versa, eating fish is a healthy source for many nutrients but has a negative impact on fish stocks and, therefore, on sustainability (Dötsch-Klerk et al., 2015).

In conclusion, operationalizable indicators for health and sustainability can be defined, with the aim to drive the development of features which support behavior change in the desired direction. The main significance of this explicit definition of demands on application design is that it provides requirements for the databases to include consistent information on key nutritional values and carbon footprint, for each recipe and ingredient. While the U.S. Department of Agriculture (USDA) provides a standard reference database for nutritional values (USDA, 2021), there is currently no similar widely accepted standard database for carbon footprint. Even with a standardized reference database available, most popular grocery shopping applications do not link to such data sources (Blanke et al., 2021) and rely on unstructured and crowd-sourced recipe and ingredient lists instead, which makes rigorously targeting specific demands such as health and sustainability difficult to implement. To our knowledge most existing applications in this domain do not create a clear translation of input data into demands on the behavior of the individual, resulting in suboptimal behavioral support with respect to the two targeted dimensions of health and sustainability discussed in this example. Overcoming this issue is costly, as it requires creating relevant databases, which seems to be beyond the commercial scope of most currently existing developments.

While the demands mostly affect the back-end design, other aspects of the behavioral model can be used to influence the front-end design (cf. Figure 2). The redefinition of the task needs to be implemented to allow personalization of external demands taking individual user characteristics, such as attitudes toward the behavior, subjective norms, and perceived behavioral control, as well as the user's self-efficacy into consideration. Based on the relevant information from the demand-derived databases, this information needs to be presented in a suitable format by the application through features embedded into the user's context. For example, to optimally support individual's attitudes towards the behavior the nutritional values and carbon footprint information are presented for each recipe and each ingredient, raising awareness toward health and sustainability. Social and subjective norms are supported by embedding this information into a traffic-light style presentation for both food labeling and carbon footprint information, providing a basis to compare this information with general expectations. Perceived behavioral control and self-efficacy, that is, the personal anticipation if a certain behavior can be executed under the current circumstances in concordance with one's abilities, is supported by presenting all information so that it is easy to understand and matches common expectations by adapting to existing food labeling guidelines and augmenting these toward sustainability indicators. These are all examples illustrating how the redefinition of the task can be facilitated for the different categories of end users, but of course every front-end feature should be designed to support this process in some shape or form.

User experience approaches propose to utilize personas to achieve a very similar goal of personalizing the design toward different anticipated user groups; however, there is evidence that their use in the application design process is limited (Matthews et al., 2012). Instead, we propose to specifically design application features toward the concepts introduced in the behavioral theories as outlined above. A limited, yet comprehensive, list of variables that can be addressed to guide the decision process and thereby improve the intention to carry out a behavior in question, may provide a means for deciding on

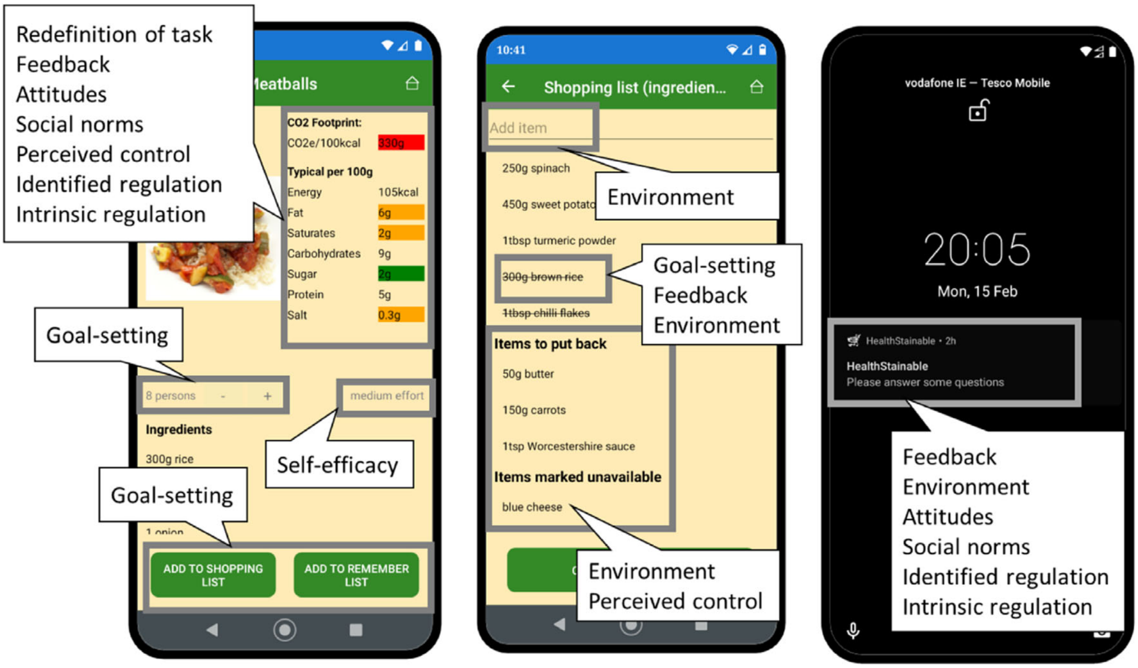

FIGURE 2 Screenshots of the HealthStainable (Blanke & Beder, 2020) application and relevant concepts of the model relating to functionality and user Interface (UI) elements

application features that enable easy translation of high-level goals into concrete action plans for the majority of application users. Another benefit of utilizing established behavioral theories is that the indicators for the different variables can be assessed by suitable inventories (Ajzen, 1985), which allows to determine the distribution of potential end users and to focus on the design and implementation of the application toward the most likely target audience.

A second important step of the cognitive process as identified by the behavioral model is goal-setting, which describes the translation of general goals into a hierarchical system of subgoals and precise action plans to elicit the behavior accordingly. This concept is matched in UX design by creating appropriate application flows to match the user journey to what is presented in the application. This is to map the interactions of the individual with the application with the activities and cognitive tasks that are to be supported by the application. In a grocery shopping application this amounts to a flow of activities starting from selecting recipes and summarizing them into individual shopping lists, followed by functions to dynamically manage and adapt these shopping lists, and then finally help with the actual execution of the behavior.

Throughout this user journey the reciprocal relationship between the individual with his/her environment impacts behavior. Application design needs to take this into account and allow for adaptions of the flow of the application to external circumstances and triggers. Foreseeing potential obstacles and enabling continuous mitigation, both within the interaction with the application and externally, can improve application design and make it useful for the behavior in a wider range of circumstances. In particular, allowing for situations where external obstacles are encountered and where backtracking within the action plan is necessary will greatly improve the effectiveness of an application according to the behavioral models. For instance, shopping situations can change if unanticipated events, for example the nonavailability of an ingredient, derails the prepared meal plans and shopping lists. This can be mitigated by the application through allowing for an option to mark ingredients on the shopping list as unavailable, followed by the automatic creation of a list of items to put back, and suggestions of alternative recipes which do not include the unavailable ingredient. Automatically adjusting recipe and shopping lists throughout the application and providing suitable and actionable plans how to proceed will likely improve the overall experience and make the application usable in situations where obstacles in the real world are encountered.

Because the use of smartphone applications is embedded into real-world activity it is important during the application design to consider the application flow within this external context. Goal-setting and the reciprocal relationship with a dynamically changing environment are the relevant concepts from behavioral theory describing this process. Stressing the importance of anticipation of circumstances and events and creating precise and operationalizable interactions to support the adaption of hierarchical action plans should be at the core of application feature development. It is important to put the focus on the user's daily activities and outside context as opposed to the inward-looking analysis of interactions with the application, for example through website and app usage tracking, to optimally support the target behavior.

Regular and suitable feedback is essential to keep users motivated and engaged with the application and the topics concerned. To be effective and to increase motivation, feedback needs to be tailored toward the individual, very similar to how the redefinition of the task is personalized toward the target end-user group. The behavioral models suggest that in the case of motivational feedback the motivational type falls onto a spectrum between extrinsic and intrinsic, which can be measured by assessing the different types of regulation: external, introjected, identified, and intrinsic. While extrinsically motivated people require a lot of support and incentives, intrinsically motivated people are already interested in the topic and their motivation can be maintained by providing information and regular reminders. Nevertheless, sending regular reminders and push notifications to nonintrinsically motivated application users often has the opposite effect and is susceptible to discourage the continuation and even giving-up the target behavior. It is important, therefore, to understand application users and tailor the messaging accordingly. The benefit of applying behavioral theories to application design is again, that there are established inventories and methodologies (Ajzen, 1985; Bandura, 1999; Hacker, 1986; Locke & Latham, 1990; Ryan & Deci, 2000) that allow to assess the application user and understand his/her motivational type before sending potentially counterproductive feedback messages and notifications.

Different types of motivational mechanisms for the different types of users could be implemented. External and introjected regulation can only be targeted with external incentives. This type of user can, therefore, only be reached in a wider context usually outside the scope of mobile application development. Identified and intrinsic regulation are both addressable by providing meaningful information, hence accurate nutritional and carbon footprint information will appeal to this target audience. Nevertheless, it is important that the information provided is accurate and meaningful, imposing the same constraints on application design as already discussed above in the context of demands. Finally, intrinsic regulation can be addressed by regular push notifications, reminding the application user to check back and to interact and engage with the application. It is only this group of people, however, who will positively respond to this type of interaction, and application designers should make sure to avoid any negative impact on the long-term motivation to engage with the application.

4.2 | Model-driven design evaluation

The behavioral model is not only useful for devising a targeted design methodology, it can also be used to evaluate the resulting application with respect to improving behavioral outcomes. The inventories provided by the quantitative approaches of the TPB and the SDT allow to assess changes in motivation and intention of individual application users with respect to the given topic. An example questionnaire designed accordingly for assessing intentions and motivations with respect to healthy and sustainable grocery shopping is available for download on the Open Science Framework (OSF) from https://osf.io/usp6f/.

We propose to apply a two-step design evaluation approach: first, a survey without reference to the application should be conducted to establish a baseline of intentions and motivations with respect to the topic in question. Then, individual application users are asked to answer the same questions and their responses are tracked in relation to the baseline over a period of time while using the application to be evaluated. This can be operationalized by sending regular push-notifications to application users and requesting them to answer a set of questions from these inventories.

To demonstrate the applicability of this approach the proof-of-concept application HealthStainable (Blanke & Beder, 2020) also implements such a single-subject case study methodology to assess the potential change of individual user's intention and motivation with respect to healthy and sustainable grocery shopping behavior. It assesses the Behavioral Intention defined by the TPB (Ajzen, 2006) as the weighted sum

$$\mathrm{BI} = w_A A + w_{\mathrm{SN}} \mathrm{SN} + w_{\mathrm{PBC}} \mathrm{PBC},$$

of the attitude toward the behavior A, the subjective norms SN, and the perceived behavioral control PBC. Depending on whether the respective attribute is positive or negative, we can also define eight distinct personas P as shown in Table 1.

Similarly, we also assess the Relative Autonomy Index as defined by the SDT (Ryan & Deci, 2021; Sheldon et al., 2017) as a measure of motivation to be the weighted sum

$$\mathrm{RAI} = 2R_{\mathrm{Intrinsic}} + R_{\mathrm{Identified}} - R_{\mathrm{Introjected}} - 2R_{\mathrm{External}},$$

of the intrinsic regulation $R_{\mathrm{Intrinsic}}$, the identified regulation $R_{\mathrm{Identified}}$, the introjected regulation $R_{\mathrm{Introjected}}$ and the external regulation R_{External}, all of which assessed through suitable questionnaires. The TPB and SDT therefore provide six quantifiable indicators, three for healthy grocery shopping ($\mathrm{BI_H}$, $\mathrm{RAI_H}$, and $\mathrm{P_H}$) and three for sustainable grocery shopping ($\mathrm{BI_S}$, $\mathrm{RAI_S}$, and $\mathrm{P_S}$).

Following the proposed evaluation methodology, a baseline study with $n = 144$ participants was conducted (available for download on the OSF from https://osf.io/usp6f/). From this the distribution of Behavioral Intention values with respect to health ($m_{\mathrm{BI_H}} = 2.33$, $\mathrm{SD}_{\mathrm{BI_H}} = 1.45$ and sustainability ($m_{\mathrm{BI_S}} = 0.92, \mathrm{SD}_{\mathrm{BI_S}} = 1.28$), as well as the distribution of Relative Autonomy Index scores with respect to health ($m_{\mathrm{RAI_H}} = 2.12, \mathrm{SD}_{\mathrm{RAI_H}} = 2.48$) and sustainability ($m_{\mathrm{RAI_S}} = 2.04$, $\mathrm{SD}_{\mathrm{RAI_S}} = 2.02$) were calculated. We also determined the persona segments in the assessed population sample with respect to healthy and sustainable grocery shopping behavior. The distribution histograms are visualized in Figure 3.

These results are now used to put the single-subject case studies into context, allowing to understand individual application users and the relative change each individual undergoes with respect to the empirical SDs within the wider population determined by the baseline study. The application has been published on the Google Play Store (Blanke & Beder, 2020) and between October 2020 and January 2021 six anonymous subjects submitted at least one set of answers; three of those submitted two sets of answers spaced 2 weeks apart while using the application. The results are summarized in Table 2.

TABLE 1 All possible persona segments depending on personal beliefs

P	Attitude	Social pressure awareness	Perceived behavioral control
A	Positive	High	High
B	Positive	Low	High
C	Positive	High	Low
D	Positive	Low	Low
E	Negative	High	High
F	Negative	Low	High
G	Negative	High	Low
H	Negative	Low	Low

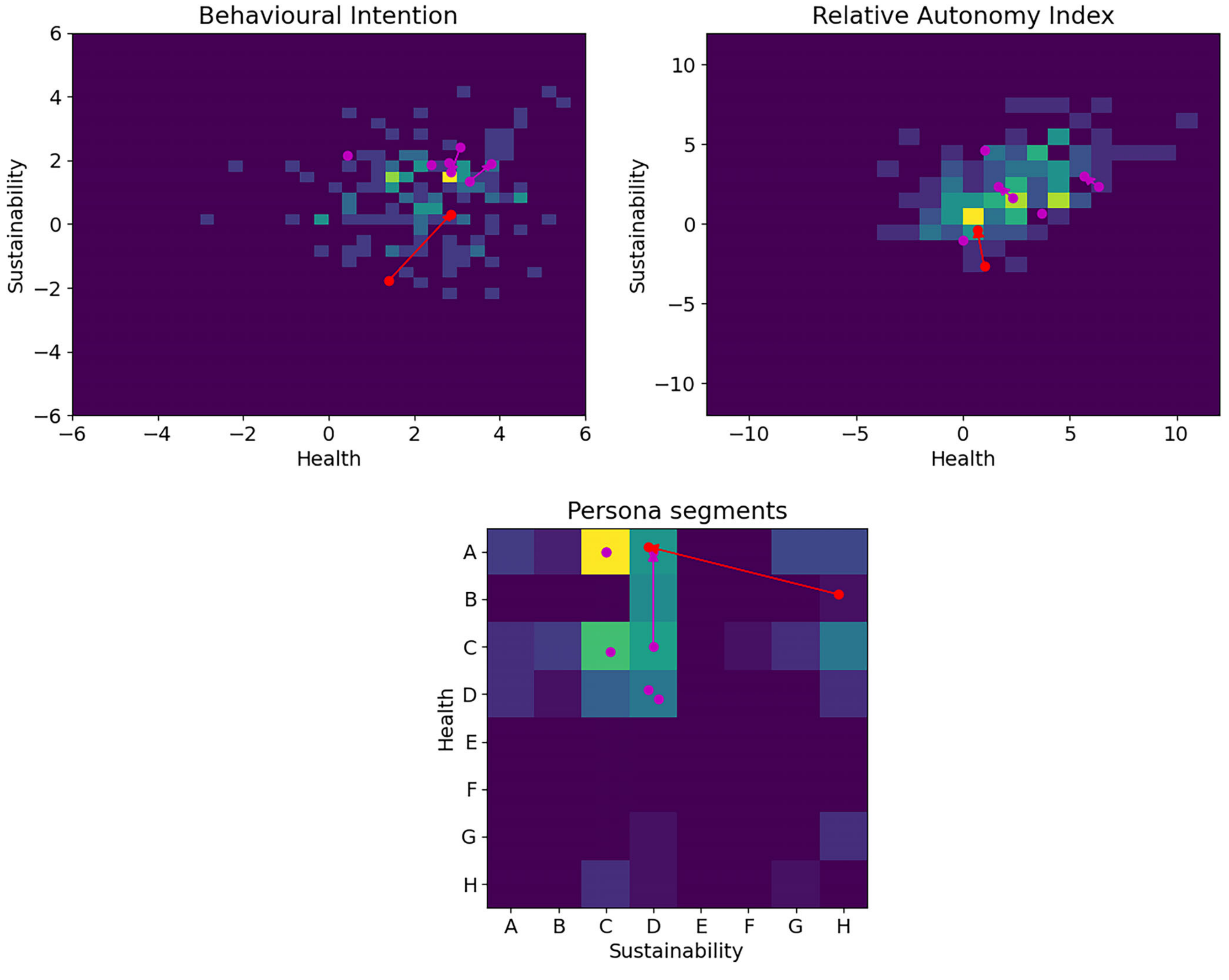

FIGURE 3 Change of participants' behavioral intention (top-left), relative autonomy index (top-right), and persona (bottom) in the context of the distribution in the wider population; participant 4 (red) showed the biggest change in all three indicators

For the three participants who replied to the questionnaire twice, it was possible to determine the change of the behavioral intentions and relative autonomy indexes and evaluate this change in the context of the distribution within the wider population as assessed by the prestudy. The resulting changes are shown in Table 3.

From these data it can be seen that participant 4 showed the most significant change, with the behavioral intention to buy healthy groceries increasing 1.0 times the SD, the behavioral intention to buy sustainable groceries increasing 1.63 times the SD, and the relative autonomy index to buy sustainable groceries increasing 1.15 times the SD seen in the reference population assessed through the

TABLE 2 Assessment results for the six participants

Participant	#1	#2	#3	#4	#5	#6
Age	18–24	45–54	18–24	35–44	18–24	18–24
Gender	F	F	M	M	F	F
BI_H – first assessment	2.8	3.3	0.43	1.4	3.08	2.4
BI_H – second assessment		3.8		2.87	2.87	
RAI_H – first assessment	1.0	2.33	0.0	1.0	6.33	3.67
RAI_H – second assessment		1.67		0.67	5.67	
BI_S – first assessment	1.92	1.35	2.17	−1.78	2.42	1.85
BI_S – second assessment		1.88		0.32	1.63	
RAI_S – first assessment	4.67	1.67	−1.0	−2.67	2.33	0.67
RAI_S – second assessment		2.33		−0.33	3.0	
Persona (health) – first assessment	D	C	D	B	A	C
Persona (health) – second assessment		A		A	A	
Persona (sust.) – first assessment	D	D	D	H	C	C
Persona (sust.) – second assessment		D		D	C	

Abbreviations: BI_H, Behavioral intention, health; BI_S, Behavioral intention, sustainability; RAI_H, Relative autonomy index, health; RAI_S, Relative autonomy index, sustainability.

TABLE 3 Change of behavioral intention and relative autonomy index relative to the population's SDs

Participant	ΔBI_H	ΔBI_S	ΔRAI_H	ΔRAI_S	$\frac{\Delta BI_H}{SD_{BI_H}}$	$\frac{\Delta BI_S}{SD_{BI_S}}$	$\frac{\Delta RAI_H}{SD_{RAI_H}}$	$\frac{\Delta RAI_S}{SD_{RAI_S}}$
#2	0.5	0.53	−0.67	0.67	0.34	0.41	−0.27	0.33
#4	1.47	2.1	−0.33	2.33	1.0	1.63	−0.13	1.15
#5	−0.22	−0.78	−0.67	0.67	−0.15	−0.61	−0.27	−0.33

Abbreviations: BI_H, Behavioral intention, health; BI_S, Behavioral intention, sustainability; RAI_H, Relative autonomy index, health; RAI_S, Relative autonomy index, sustainability.

prestudy. The persona of participant 4 changed from H to D with respect to sustainability and from B to A with respect to health, indicating that the attitude toward sustainability became positive and the perception of social norms with respect to health became important.

The presented results are for each individual of a single-subject case study, therefore it has not been the intention to derive the efficacy of a particular intervention. Instead, the applicability of a rigorous behavioral modeling approach to design evaluation based on single-subject data has been demonstrated. The benefit of such an approach is that it allows for cost-effective evaluation of designs based on a few relevant test subjects.

5 | LIMITATIONS

To follow the proposed design methodology application developers have to translate model concepts into actual application features. While the definitions and the mutual relationships identified and discussed in this paper can guide this process, the translation is not sufficiently defined and, therefore, presents a practical limitation that needs to be overcome in the future to achieve good application design.

The presented methodology has been derived from some of the most cited behavioral theories and models (Davis et al., 2015). Nevertheless, the proposed model is not final and should allow for the integration of further aspects where required and appropriate. This theory development should be guided by the requirements arising from the practical application of behavioral modeling tools, which has the potential to improve the communication between the two disciplines of UX design and behavioral sciences, thereby contributing to synergies in both directions.

6 | CONCLUSION

We presented a comprehensive behavioral model based on five established behavioral theories including the HPC (Locke & Latham, 1990), the ART (Hacker, 1986), the SCT (Bandura, 1999), the Theory of Planned Behavior (Ajzen, 1985), and the SDT (Ryan & Deci, 2000). We demonstrated their integration with the aim to fully account for the social-cognitive decision process with regards to healthy and sustainable food shopping behavior. We translated the findings into application design patterns that can be operationalized to guide the application design and evaluation process, demonstrating how the model can be applied practically by implementing relevant features within the application. We discussed the relationship of feature design based on behavioral modeling with more commonly used application design approaches and identify communalities and differences.

While there is a significant overlap between UX approaches and the findings of behavioral modeling, both areas can learn and benefit from each other. Behavioral models developed in Psychology and the Social Sciences can inform application design by identifying relevant aspects of human behavior that help maximize behavioral impact and long-term motivation. Furthermore, these theories also provide a means of measuring and assessing the individual's psychological characteristics, promising a more rigorous approach than using more ad hoc techniques, for example, personas based on stereotypical assumption rather than theory-derived surveys, as is often the case in present day application design.

While application design and development should be informed by behavioral models, behavioral research can learn from UX and other application design patterns, in that their use will show how their models and theories can be operationalized and applied in a practically relevant context. Integration into mobile applications will enable a more dynamic view of behavioral modeling, showing a direction of future research in this domain.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/hbe2.307.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in OSF at https://osf.io/usp6f/.

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