Designing Behaviour Change: *A Behavioural Problem/Solution (BPS) Matrix*

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Behavioural design has emerged as a critical new area of research and practice. However, despite the development of extensive lists of possible problem features and suggested solution principles there is little guidance on how these should be connected. Therefore, in this work we systematically examine interactions between major problem features and solution principles, based on an analysis of 218 behavioural design interventions drawn from 139 cases across design domains and foci. This forms the basis for a number of contributions. First, we bring together behavioural and designerly perspectives on problem characterisation via two proposed problem features: change demand and behavioural constraint, related in a two-by-two framework. Second, we synthesised recommendations from across domains and foci to operationalise a list of 23 solution principles relevant to designers. Third, we link these insights in a proposed *Behavioural Problem/Solution (BPS) matrix*. Further, we identify a number of potential systemic challenges in the reporting and evidencing of behavioural design interventions. Together, these insights substantially extend both theory and practice surrounding problem-solution mapping in behavioural design, and form a foundation for further theory development and synthesis in this area.

Keywords – Behavioural Design, Design for Behaviour Change, Design for Sustainable Behaviour, Problem-Framing, Persuasive Design, Persuasive Technology.

Relevance to Design Practice – This work describes operational problem features, and solution principles for behavioural design, linked in a behavioural problem/solution matrix. This provides concrete guidance for defining behavioural problems and subsequently identifying relevant solution principles, both individually and in combination.

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Introduction

Behavioural design has emerged as a critical new area of research and practice (Cash et al., 2017a; Niedderer et al., 2016; Tromp, 2013). This stems from an increasing recognition, in areas such as sustainability (Abrahamsen et al., 2005; Greening et al., 2000), that behaviour change is essential to resolving many of the major challenges currently facing society (European Environment Agency, 2013; Steg & Vlek, 2009). For example, although people are generally concerned with the environment, it is often difficult for them to act accordingly, due to ingrained habits (Verplanken & Roy, 2015). To overcome this attitude-behaviour gap, designers have an increasing interest in understanding how to design for behaviour change. Behavioural design is characterised by a focus on creating positive, ethical behaviour change, which balances individual and collective concerns, through the design of artefacts, systems, and other interventions (Francis et al., 2009; Tromp et al., 2011). This design logic underpins an array of more specific approaches, which range in domain from healthcare (Michie et al., 2011) to sustainability (Bhamra et al., 2011), and in focus from computer interfaces (Kelders et al., 2012) to policy (Dolan et al., 2014). However, designers face two major challenges. First, it is difficult to identify salient problem features affecting design outcomes due to the complexity of behavioural theory (Michie et al., 2014). Second, most behavioural theory is descriptive (Michie et al., 2014). This makes it difficult to connect problem features, i.e., characteristics that determine a problem's nature and challenge, to potential solution principles, i.e., general approaches to problem resolution (Lockton et al., 2013), and necessitates extensive prototyping and exploratory testing in practice (Cash et al., 2017a).

A number of works have separately developed lists of possible problem features and solution principles, primarily based on the synthesis of empirical interventions and observations of behaviour. For example, Fogg (2009a) and Kelly and Barker (2016) describe various problems faced by behavioural designers and differentiate certain problem features, such as the type of change required and how long it should be sustained. Similarly, Kelders et al. (2012), Lockton (2016), Lockton et al. (2010), and Bhamra et al. (2011) respectively list solution principles, such as providing feedback or rewards, in the human computer interaction,

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product design, and sustainability contexts. Bringing these together, Michie et al. (2015) point to characteristic relationships between certain problem features and solution principles, which can be grounded in underlying behavioural theory (Bohlen et al., 2019; Cash et al., 2017b). However, research in this area is scarce, typically based on expert opinion, and currently focused at the policy level. Further, current lists are fragmented across design domains (e.g., healthcare) and foci (e.g., policy). Thus, despite extensive lists of possible problem features and solution principles there is little guidance on how to map their interaction in design.

This lack of problem/solution mapping in behavioural design poses significant challenges for both theory and practice. Specifically, it hampers efforts to leverage the extensive body of behavioural theory in the development of effective design solutions (French et al., 2012), as well as integration between problem and solution understanding essential to co-evolutionary design work (Dorst, 2019). Further, it prevents designers making best use of current lists of problems and solutions, as well as the development of targeted design support. Thus, there is a need to map the links between problem features and solution principles in the behavioural design context.

In order to address this need, we develop a Behavioural Problem/Solution (BPS) matrix, systematically capturing interactions between major problem features and solution principles. We examine interactions with respect to major current models as well as our own proposed matrix. This is built on a review of 218 behavioural design interventions drawn from across design domains and foci. The proposed matrix forms the basis for theoretical and practical contributions to behavioural design.

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Background

In order to develop a problem/solution matrix in the behavioural design context, it is necessary to understand current problem features and solution principles before examining how they can be linked.

Problem Features in Behavioural Design

When discussing problem features in the behavioural design context, designers face a number of challenges. First, scientific understanding of behaviour change is extremely complex and diverse. Michie et al. (2014) identify 83 theories of behaviour change, dealing with 1659—often ambiguously defined—constructs. This makes the development of a coherent set of problem features for behaviour change difficult, due to a lack of theoretical synthesis. Second, the majority of these theories provide explanations of overall variations in behaviour in a population (Michie et al., 2014), which are difficult to connect to individual change mechanisms (Shove, 2010). Further, there are complex interactions between behaviour, user self-image (Cho & Kim, 2012), interaction and experience (Bakker & Niemantsverdriet, 2016; Fokkinga & Desmet, 2013), and perceived intent (Crilly, 2011; Silva et al., 2015). This hampers the operational mapping between problem features and solution principles relevant to designers. Finally, many of these theories are highly specific in domain [e.g., Health Belief Model (Rosenstock et al., 1988) or the Ecological Model for Preventing Type 2 Diabetes in Minority Youth (Burnet et al., 2002)] or in scope such as focusing on specific cognitive or social mechanisms [e.g., Prospect Theory (Kahneman & Tversky, 1979) or Social Norms Theory (Perkins & Berkowitz, 1986)]. Michie et al. (2015) do synthesise these into a number of general theoretical domains relevant to policy makers, which can provide overall guidance for design strategies. However, there remains a need to operationalise these general strategies in concrete principles relevant to designers. This impacts designers' ability to adequately explore the design space and potentially leverage multiple solution principles acting on different aspects of behaviour over different timeframes, which has been shown to be critical to behavioural design (Cash et al., 2017a; Tromp et al., 2011). Thus, current problem features are difficult to operationalise for the design context.

Given the above challenge, we turn to a more designerly perspective in order to distil tractable problem features. Specifically, taking cues from similar problem/solution mapping efforts in the technical design domain, problem features can be conceptualised in terms of an interaction between: the required *change demand* and the degree of *behavioural constraint* (Altshuller & Altov, 1996; Kwong et al., 2011; Lin & Chen, 2002). The first feature, change demand (i.e., *the degree of difficulty associated with a planned behaviour change*), develops insights from the human factors literature where user adaption to new technologies provides a parallel for understanding adaption to behavioural interventions (Liu & Li, 2012; Venkatesh et al., 2003). Fundamental to this understanding is the complexity of the required change, and hence the difficulty of compliance, adoption, and longer-term habit formation (Liu & Li, 2012; McCloskey

& Johnson, 2019). Specifically, a behaviour requiring multiple, unfamiliar actions is more complex than a behaviour requiring a single, familiar action and will thus be harder to change (Liu & Li, 2012). In the behavioural design context, Fogg's (2009a) Behaviour Grid describes some aspects of change demand in terms of type of behaviour and its timespan. The second feature, behavioural constraint (i.e., *the degree of difficulty associated with a planned intervention*), builds on the general concept of design constraints (Pugh, 1989). In the behavioural design context, designers must consider environmental and social constraints on a desired behaviour (Fishbein & Ajzen, 2011; Michie et al., 2011) as well as the degree of freedom within the project to influence these systems (Meadows, 2009). Further, they must also consider the more typical constraints on the degree to which the objects and tools used in a specific behaviour can be altered (Bedny & Karwowski, 2004). For example, many persuasive technology interventions are constrained by a need to integrate with extant technical objects (e.g., a mobile phone), functioning in social and environmental contexts that cannot be substantially influenced (Kelders et al., 2012). Currently, Michie et al. (2011) describe environmental and social opportunity as essential constraints when developing policy, but do not treat product level objects and tools. Thus, while prior works have dealt with specific aspects of change demand and behavioural constraint, none operationalise both of these features with respect to behavioural design.

Solution Principles in Behavioural Design

While change demand and behavioural constraint can provide a lens that limits the scope of problem features, the same is less true of potential solution principles. Here, following the broad scope of behavioural design, there have been numerous suggested lists of models, solutions, interventions, and techniques (Niedderer et al., 2016), ranging from general policy (Dolan et al., 2014; Michie et al., 2015) to detailed computer based (Kelders et al., 2012). While these lists do share common elements, such as providing prompts or leveraging norms (Clune, 2016), there is also a high degree of variation with no clear simplifying lens. Further, one of the most extensive lists of *behaviour change techniques* is provided by Michie et al. (2015), which has a number of distinct limitations when translated to the design context. Specifically, while many operational interventions are listed, these are also mixed with procedural recommendations, such as using experiments, and analytical directions, such as collecting information on antecedents. This mixes a number of distinct aspects of design work (Roozenburg & Eekels, 1995) and hinders direct synthesis with more design-orientated lists, such as those provided by Bhamra et al. (2011) or Lockton et al. (2010). Thus, while there are several possible candidates for solution principle lists these need to be evaluated and synthesised in a broad context.

Linking Problem and Solution

Few works explicitly link problem features and solution principles. For example, while Fogg (2009a) describes various problem features and Tromp et al. (2011) solution principles, their respective connection to solution principles and problem features is more implicit. Similarly, while Hardeman et al. (2005) provide a robust framework for working from behavioural problem through to trial design, their discussion of solution principles is relatively limited. To the authors' knowledge, the most extensive problem/solution mapping in the behavioural design context is offered by Michie et al. (2015). While this is undoubtedly valuable, it has a number of limitations when applied to design. The first is the diversity of the suggested *behaviour change techniques* noted above. In addition, the list is built on a data set of 40 intervention descriptions and subsequently prioritised by expert ranking (Michie et al., 2015). This limits the scope of its application in terms of operational support across design domains and foci. Thus, there is currently no suitable theory for structuring potential problem/solution mappings in the design context.

There are two potential approaches to resolving this gap: adaptation and elaboration of existing models or the development of a new problem/solution matrix. For the first approach, four main candidates emerge from the literature: Fogg's (2009b) Behaviour Model (FBM), Michie et al.'s (2011) COM-B model, Bhamra et al.'s (2011) Design for Sustainable Behaviour (DfSB) Strategies, and Tromp et al.'s (2011) Influence framework. These models are some of the most widely recognised, cover a range of design domains, and draw on different foundations in developing their solution suggestions:

- **FBM** (Fogg, 2009b): developed in the persuasive technology domain, based on basic behavioural theory, and containing three overall solution suggestions: motivation, ability, and triggers.
- **COM-B** (Michie et al., 2011): developed in the health policy domain, based on basic behavioural theory, and containing three overall solution suggestions: motivation, capability, and opportunity.
- **DfSB Strategies** (Bhamra et al., 2011): developed in the sustainable design domain, based on a mix of design heuristics, sustainability theory, and behavioural theory, and containing three overall solution suggestions: energy conservation, energy conservation with force, and energy force, associated with seven sub-solutions: eco-information, eco-choice, eco-feedback, eco-spur, eco-steer, eco-technical intervention, clever design.
- **Influence framework** (Tromp et al., 2011): developed in the pro-social design domain, based on a mix of design heuristics and behavioural theory, and containing four overall solution suggestions: decisive, coercive, seductive, and persuasive.

Each of these models provides a structure for understanding behavioural design solutions. However, all four segment solutions into relatively few categories, e.g., motivation, ability, and triggers (Fogg, 2009b), and thus offer only limited scope for differentiation across problem features. Therefore, while these could form a basis for relating problem features and elaborating solution principles, further analysis is needed to understand if they do indeed differentiate solutions with respect to specific problem features.

For the second approach, a number of works have built up mappings based on inductive, data-driven methods (Michie et al., 2015). This mirrors efforts in the technical context. Most notable of these is the mapping between the TRIZ contradiction matrix (providing a structured set of problem features) and the suggested inventive principles (Altshuller & Altov, 1996), developed based on an inductive analysis of hundreds of thousands of technical cases encapsulated in patent data. Thus, in this work we both examine major models and develop an inductive approach.

Research Framework

Given needs described above, this research aims to develop a general problem/solution matrix for behavioural design. As a starting point for this, we define a framework based on two interacting problem features: change demand–focused on the intended behaviour–and behavioural constraint–focused on the practical limits on the intervention, illustrated in Figure 1. We define these as:

Change demand: the degree of difficulty associated with a planned behaviour change. This comprises sub-features that collectively indicate the overall complexity of the intended behaviour and thus the difficulty of the change (Liu & Li, 2012). These include the novelty or familiarity of the intended behaviour (Fogg & Hreha, 2010; Liu & Li, 2012); the scope, in terms of how extensively the activity framework is modified (Bedny & Karwowski, 2004; Liu & Li, 2012); and the frequency target of the new behaviour, from irregular to habitual (Chatterton & Wilson, 2014; Fogg, 2009a).

Behavioural constraint: the degree of difficulty associated with a planned intervention. This again comprises sub-features that together reflect the practical constraint on the solution space. These include the environmental opportunity or the degree to which the designer can change the physical context of the behaviour, for example the home or workplace (Fishbein & Ajzen, 2011; Michie et al., 2011); the social opportunity or social context of the behaviour, for example family or work colleagues (Michie et al., 2011); and the technical opportunity, or the degree to which objects and tools can be introduced or altered within the behaviour itself (Bedny & Karwowski, 2004).

The selection of problem features was based on two criteria: i) inclusion of practical constraints about what can be changed, and ii) inclusion of features that could be realistically identified in early stage behavioural design. The models proposed by Michie et al. (2011), Bhamra et al. (2011), and Fogg and Hreha (2010) are behaviour focussed and do not include challenges linked to constraints on the physical/social environment or object/tool, which are critical when developing a design (Cash et al., 2017a). Similarly, the identification of factors such as motivation or ability, typically requires extensive in-depth study, making these impractical for informing early stage problem definition. However, formulating barriers in terms of task novelty, complexity, and frequency has already been explored by, for example, Fogg and Hreha (2010). Importantly, scientific understanding about task complexity (Liu & Li, 2012) and technical opportunity (Bedny & Karwowski, 2004) is not currently utilized by behavioural design researchers and practitioners. As relevant solution principles are less obvious, we follow an inductive approach aimed at distilling principles relevant to each quadrant in Figure 1.

Method

Due to the lack of extant theory, a theory-building approach was adopted, specifically focused on relationship building between problem features and solution principles in the behavioural design context (Cash, 2018; Handfield & Melnyk, 1998). In order to build generalisable relationships, a large set of behavioural design interventions were sampled from across domains and foci (Wacker, 2008).

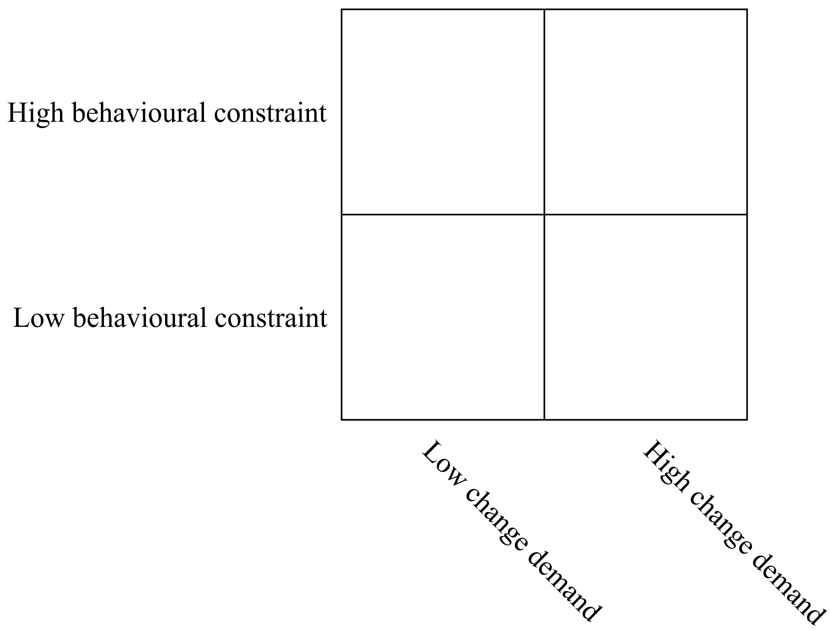

Figure 1. A behavioural problem feature framework relating: Change demand and behavioural constraint.

Sample

The population encapsulates behavioural design interventions from across domains and foci (Bhamra et al., 2011; Cash et al., 2017a; Kelders et al., 2012; Tromp & Hekkert, 2014). Interventions were selected based on the designers' goal to achieve active and deliberate change of behaviour, as well as the general focus on intervention development in the literature (Francis et al., 2009; Michie et al., 2008). Considering that most data on design interventions and their effects on behaviour change are not publicly available, but held in private companies' databases of past projects, a purposive sampling approach was used (Onwuegbuzie & Collins, 2007). This aimed to identify a heterogeneous set of interventions suitable for interrogating interactions between problem features and solution principles across the range of design domains and foci in behavioural design. In addition, a number of criteria were specified in order to ensure the robustness of the data, as outlined in Table 1. The search for interventions followed three main steps (the number of interventions fulfilling the Table 1 criteria are noted for each):

1. Interventions described in reports published by specialist behavioural design companies (28).
2. Snowballed suggestions for interventions and intervention databases from following up with the companies identified in Step 1 (99).
3. Interventions described in academic literature in the behavioural design area (91).

This resulted in a final set of 218 interventions, spread across 139 individual cases, with a further 184 identified but excluded due to a failure to meet the quality and validity criteria in Table 1. Interventions ranged from simple, for example reducing the size of plates to foster lower food consumption or auditory and tactile reminders integrated into workstations to promote healthy posture, to more complex, for example combining signage, floor markings, and new seating to ensure smokers used the correct areas. The full data-set is available upon request.

Data Treatment

All interventions were individually identified, before being discussed in the research team, and archived for analysis. In addition to the core problem/solution information, data was extracted regarding a number of other criteria, noted in Table 2. Here, *quality of evidence* was based on Grimes and Schulz's (2002) taxonomy of evidence for clinical interventions. This provided a well-established framework for judging the quality of intervention claims, ranging from: expert opinion (lowest) to randomised controlled trial (highest). Further, *success claims* were segmented into positive and partially positive (only some measures were positive), verses negative or no effect, building on the prior work of Hamari et al. (2014), who examined the success of 95 persuasive technology interventions.

Coding Problem Features and Solution Principles

The coding of both problem features (Table 3) and solution principles (Table 4) took place in a number of iterations. In the first iteration, 15 interventions (~7%) were double coded by two raters. All results were then discussed in the research team, differences clarified, and definitions of solution principles refined. This

Table 1. Overview of sample inclusion/exclusion criteria.

Criteria	Description
Inclusion 1	**Data quality:** The intervention included a description of both the problem and solution generated as well as all relevant contextual information (see below)
Inclusion 2	**Solution quality:** The intervention included a measure of whether a behaviour change actually occurred as well as detail of the evidence supporting the claimed change
Exclusion 1	**Ethics and scope:** The intervention changed behaviour through unethical force, or was focused on increasing sales, usability, or similar, and did not treat behaviour change
Exclusion 2	**Validity of testing:** The reference point for testing the solution was invalid, e.g., comparing a waste sorting intervention against a group with no opportunity to sort waste

Table 2. Overview of data extracted from each intervention.

Criteria	Description
Overview	The type of design organisation (e.g., a consultancy or government department); the type of client (if relevant); where the data was sourced from
Problem(s)	*The reported problem(s): Coded as described in following section*
Problem rationale	The reported explanation for the cause of the problem
Solution(s)	*The reported intervention solution(s): Coded as described in following section*
Evaluation details	The data, duration, location, sample group and sample size used to evaluate the solution(s)
Quality of evidence	The degree of robustness in the evidence supporting the success claim, specific data type
Success claim	The reported behaviour change achieved: negative or no/positive effect

process was then iterated a further three times, each using a new set of 15 interventions, until a high level of agreement was reached. Agreement in each iteration was evaluated using Krippendorff's alpha (Hayes & Krippendorff, 2007; Krippendorff, 1981). Based on the final iteration, an average alpha of 0.89 was achieved for the problem features, and 0.82 for the solution principles. Given the high level of agreement achieved, the remaining interventions were then split between two raters and coded.

Defining Problem Features

All interventions were coded with respect to the problem features described in our research framework (Figure 1). The operational definition and application of this was based on prior work describing each of the sub-features as described in Table 3. While *novelty*, *frequency*, *environmental opportunity*, and *social opportunity* draw on prior works in the behavioural design domain (Fogg, 2009a; Liu & Li, 2012; Michie et al., 2015), *scope* and *technical opportunity* build on an operationalisation of Activity Theory (Bedny & Karwowski, 2004). In terms of scope, Activity Theory describes a hierarchy of behaviour, where *actions* and *operations* are low-level, and linked directly to cognition, while *tasks* and *activities* are high-level, and deal with multiple lower-level actions. For example, an action might be putting a single piece of plastic in a recycling bin, while a task might capture the sorting of multiple items. Therefore, activities and tasks are more complex, while actions and operations are less complex (Bedny & Harris, 2005; Bedny & Karwowski, 2004). In terms of technical opportunity, Activity Theory defines a number of elements associated with a behaviour, of which the *object* (the thing being worked on) and *tools* (the external thing being used to transform the object) reflect things that can be altered by a design intervention (Bedny & Harris, 2005; Bedny & Karwowski, 2004). As such, the more the objects and/or tools are able to be altered by the designer, the less constrained the solution space. Each of the sub-features were coded as binary (0/1). The scores were then aggregated to provide a binary high/low measure for each problem feature. For change demand, if the score was greater than 1, then we consider the overall feature to be *high*, while behavioural constraint was considered high when the score was greater than 2 (Figure 1). Due to the limited number of interventions, we focus on the overall problem feature results and do not further analyse the individual effect of each sub-feature. However, this decomposition was found to be essential to establishing reliable and consistent coding of the overall problem features in the intervention data.

Defining Solution Principles

The solution principles are not the actual behaviours that ensure the desired outcome, like sustainability or health, but are the ways to achieve the change from current to desired behaviours. Similarly, they do not define the final intervention, rather the designer must develop the specific intervention around these underlying principles. Coding of the solution principles followed six main steps. First, an initial list of 289 candidate principles were identified from the sources listed in Table 4. Second, all candidate principles that were out of scope were excluded (53 removed). This included process-focused candidates, such as *use experiments* by Michie et al. (2015) or usability-focused candidates, such as *pave the cow path* by Lockton (2016). Third, all repeated (same names and descriptions) and overlapping (different names but very similar descriptions) candidate principles were synthesised (61 removed). Third, all candidates at a much higher abstraction level were excluded (39 removed). This included candidates such as *steer* by Bhamra et al. (2011), which provides an umbrella term with multiple lower level candidate principles (the lower level candidates were retained). Fourth, all remaining principles were clustered at a single level of abstraction via iteration within the research team. This resulted in the list of 23 candidate principles in Table 4. Fifth, all interventions were evaluated to ensure that they could be fully coded via these 23 principles, and no additional or excluded candidates emerged. Finally, as no additional candidates were identified the 23 solution principles were coded as a binary not present/present (0/1) for all interventions.

This approach was used for a number of reasons. First, it facilitated the generation and analysis of a generic list of solution principles from across domains and foci, suitable for application by designers. Second, by synthesising existing lists it was possible to evaluate the applicability of current models and lists across the broad set of collected interventions.

Table 3. Operationalisation of problem features.

Feature	Sub-feature	Description	Source(s)
Change demand	Novelty	• Multiple prior experiences (0) / no previous experience (1)	(Fogg, 2009a; Liu & Li, 2012)
	Scope	• Simple: operation or action (0) / complex: task or activity (1)	(Bedny & Karwowski, 2004; Liu & Li, 2012)
	Frequency	• Once, irregular or repeated but not habit (0) / daily habit (1)	(Chatterton & Wilson, 2014; Fogg, 2009a)
Behavioural constraint	Environmental opportunity	• Can (0) / cannot (1) change the physical context	(Fishbein & Ajzen, 2011; Michie et al., 2011)
	Social oppor-tunity	• Can (0) / cannot (1) change the social context	(Fishbein & Ajzen, 2011; Michie et al., 2011)
	Technical op-portunity	• Can (0) / cannot (1) change object • Can (0) / cannot (1) change tool	(Bedny & Karwowski, 2004)

Results

In order to fully address our research aim, the analysis is split into three parts: first, we provide an overview of the intervention data, second, we evaluate the proposed problem features with respect to current models, and third we develop our proposed BPS matrix.

Overview of Interventions

Our aim was to sample interventions from across domains and foci, as such, the range of interventions in the dataset is broad (Figure 2a), and emerged from a range of design organisations (Figure 2b). Seventy-five percent of interventions claimed to

Table 4. Operationalisation of solution principles.

Solution principle	Description	Source(s)
Evoke Emotions	Using supportive emotional cues, pleasure, and fun, to steer behaviour towards desired change	(Dolan et al., 2014; Michie et al., 2013; Tromp et al., 2011)
Impose expectations	Collaboratively agree and explicitly impose the specifications of the desired behaviours	(Michie et al., 2013; Prochaska, 2013)
Set standards	Limiting and unambiguously specifying the possible behavioural choices	(Dolan et al., 2014; Michie et al., 2013)
Enhance commitment	Helping subjects to fulfil the behavioural commitments through motivation or guilt	(Datta & Mullainathan, 2014; Dolan et al., 2014; Prochaska, 2013)
Help construct self-image	Creating a mental prototype of self that is supportive for the desired behaviour	(Michie et al., 2013; Prochaska, 2013)
Provide reward	Positive reinforcement of desired behaviour by rewarding desired behaviour	(Datta & Mullainathan, 2014; Michie et al., 2013; Prochaska, 2013)
Provide Punishment	Repulsing undesired behaviour by arranging negative consequences	(Michie et al., 2013; Prochaska, 2013)
Set goals	Behavioural as well as objective/measurable targets to motivate the desired behaviour	(Michie et al., 2013; Prochaska, 2013)
Provide guidance	Operational as well as psychological knowledge to perform desired behaviour	(Lockton et al., 2010; Tromp et al., 2011)
Provide feedback	Qualitative and/or quantitative evaluation of behaviour with respect to a reference	(Bhamra et al., 2011; Datta & Mullainathan, 2014; Michie et al., 2013)
Practice behaviour	Familiarization with the desired behaviour through physical or mental simulation	(Lockton et al., 2010; Michie et al., 2013)
Present possible consequences	Presenting positive/negative consequences of a desired/undesired behaviour	(Michie et al., 2013; Prochaska, 2013; Tromp et al., 2011)
Prime users	Presenting a stimulus that steers the behaviour in a subconscious manner	(Dolan et al., 2014; Lockton et al., 2010; Thaler & Sunstein, 2008)
Use triggers	Presenting a stimulus that steers the behaviour in a conscious manner	(Fogg, 2002; Lockton et al., 2010; Michie et al., 2013)
Tell or show what others do	Highlight the supportive behaviours of peers to incite the desire for social conformance	(Dolan et al., 2014; Lockton et al., 2010; Michie et al., 2013)
Consider messenger	Introduce and support a behaviour through a respectable, expert, or authoritative person	(Dolan et al., 2014; Michie et al., 2013; Prochaska, 2013; Tromp et al., 2011)
Validate action	Using an additional step to convert a subconscious behaviour to conscious	(Lockton et al., 2010; Thaler & Sunstein, 2008)
Present info figuratively	Using figurative associations to make behaviours interesting and easy	(Lockton et al., 2010; Tromp et al., 2011)
Make it salient	Making the desired behaviours noticeable and stand out	(Dolan et al., 2014; Thaler & Sunstein, 2008; Tromp et al., 2011)
Require action	Coercing the desired action by making it the default or otherwise necessary to perform	(Lockton et al., 2010; Tromp & Hekkert, 2014)
Selectively present choices	Improving the chances of desired behaviour by modifying the available choices	(Lockton et al., 2010; Thaler & Sunstein, 2008; Tromp et al., 2011)
Make it simple	Reducing the complexity of desired behaviour to improve its acceptance	(Datta & Mullainathan, 2014; Michie et al., 2013)
Divert action	Introducing an alternate action that distracts from undesired behaviour	(Lockton et al., 2010; Prochaska, 2013)

result in a successful behaviour change. A chi-square test showed that no confounding interaction was detected between success/failure and our problem feature framework ($\chi^2(3) = 3.48$, $p > .30$), suggesting that the chances of success were relatively even distributed across the four quadrants (see Table 5). Further, the success of the majority of interventions was built on relatively low-quality evidence (Figure 2c), with 51% using cohort or case-based trials and 13% using non-randomised controlled trials. Only 36% reported using some kind of randomised controlled trial, although the quality of the actual study design was often hard to evaluate (Grimes & Schulz, 2002). To illustrate how cases were coded consider the following *low CD-high BC* example. *Case*: moderating the walking speed of hospital patients with breathing difficulties.

Change demand (low):

- Novelty (0): people have multiple prior experiences with slowing down their walking speed.
- Scope (0): changing walking speed is a simple action.
- Frequency (0): changing walking speed is only needed in the hospital and need not be habit.

Behavioural constraint (high):

- Environmental opportunity (1): hospital environment could not be significantly changed.
- Social opportunity (1): hospital staff and family are difficult to change.
- Technical opportunity (1): products could be introduced to change walking speed.

Table 5. Overview of interventions and success rate.

Problem feature framework	Number of interventions	Percentage successful
High change demand / High behavioural constraint	49	82%
High change demand / Low behavioural constraint	33	64%
Low change demand / High behavioural constraint	79	76%
Low change demand / Low behavioural constraint	57	75%

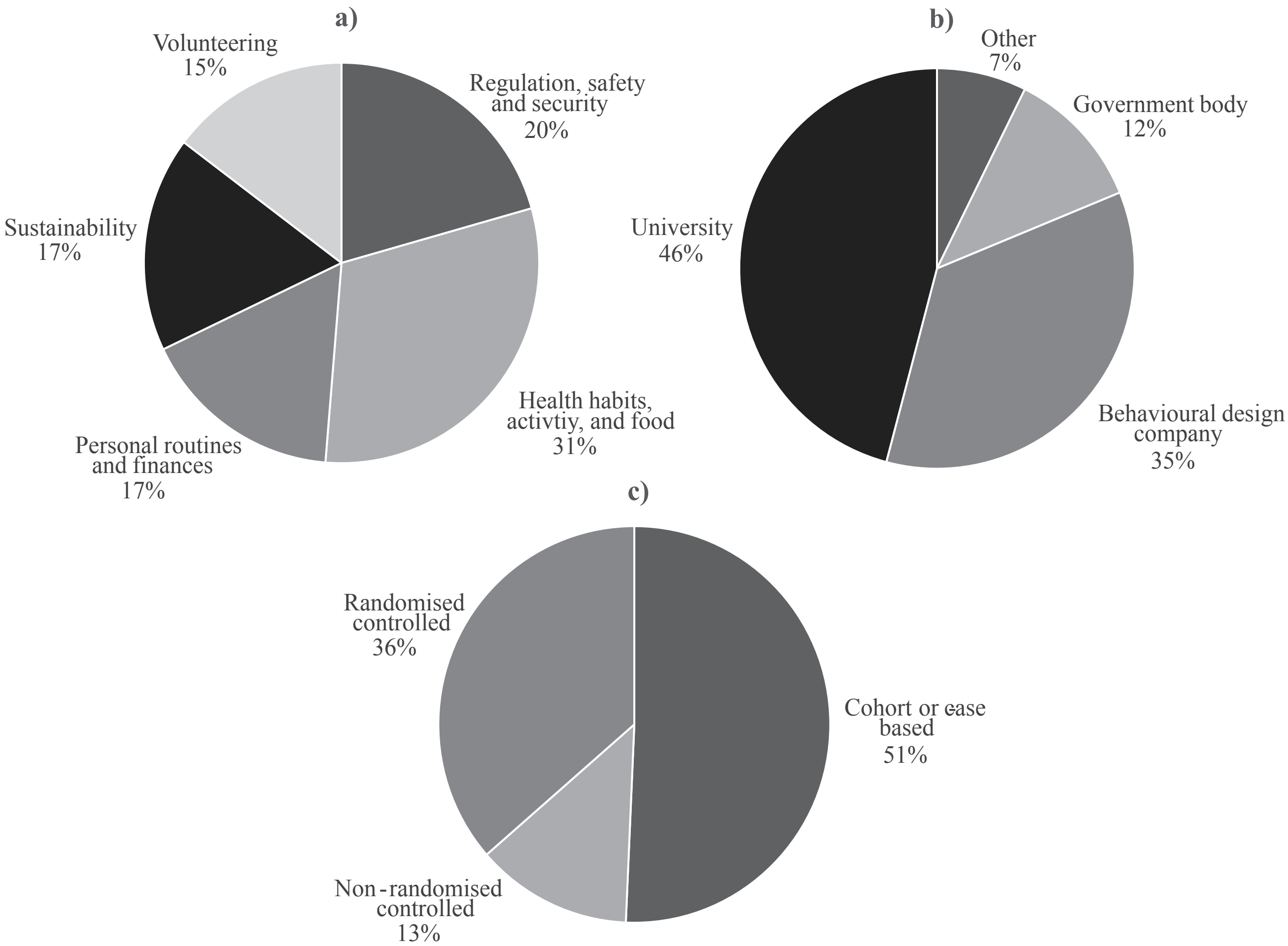

Figure 2. a) Distribution of domains. b) Distribution of organisations. c) Distribution of quality of evidence.

Evaluating Applicability to Current Models

In order to evaluate how current models differentiate solutions with respect to specific problem features, we examine the interaction between our problem feature framework (Figure 1) and the solutions suggested in other models in the literature, that is the FBM (Fogg, 2009b), COM-B (Michie et al., 2011), DfSB (Bhamra et al., 2011), and Influence framework (Tromp et al., 2011). For this analysis, we focused on the 109 interventions that made use of only one solution principle as this enabled us to test the specific relation between problem features and solution principles. For each of these interventions, our solution principles (see Table 4) were matched with the solution suggestions from the three models. For example, the solution principle *provide reward* was linked to *motivation* in the FBM and COM-B models, *energy conservation with force* in the DfSB model, and *persuasive* in the Influence framework. This allocation of solution principles to the categories in the different models were extensively discussed in the research team and in case of doubt the original intervention was checked to decide the most appropriate category for each model (checking was required for an average of 10% of interventions per model). No significant interactions were found for the FBM and DfSB models (p's > .30). However, we did find support for a significant interaction between our problem feature framework and the COM-B model (Fisher's exact test = 18.30, $p < .01$) and a marginally significant interaction between our problem feature framework and the Influence framework (Fisher's exact test = 14.07, $p < .08$).

More specifically, with respect to the COM-B model our findings demonstrated that across the 109 interventions, solution principles related to motivation are most common (44%), followed by opportunity-related principles (36%), and capability-related principles (20%, see Table 6). However, for problems with a high change demand and high behavioural constraint, it is more likely that capability-related solutions are used (67%), whereas opportunity-related solutions are less likely (8%). An opposite effect is found for problems with a low change demand and low behavioural constraint, where opportunity-related solutions are more likely to be used (52%), and capability-related solutions less likely (9%). Capability-related solutions thus seem to be especially relevant for interventions where the change demand is high and people benefit from increasing their psychological and physical capacity (i.e., knowledge and skills).

With respect to the Influence framework, our findings demonstrated that across the 109 interventions, persuasive solution principles are by far the were most common (63%, see Table 7). Although only marginally significant, the results provide preliminary support that persuasive solution principles are less common for problems with a low change demand and low behavioural constraint where only 39% were categorized as persuasive. Overall, more variety in solutions principles was found for these problems. A possible explanation for this is that for problems with low change demand/low behavioural constraint, there are few design restrictions and the desired change demand is relatively easy to attain, resulting in much more diversity in appropriate solution principles.

A proposed Behavioural Problem/Solution (BPS) Matrix

Focusing on the solution principles identified in Table 4, the proposed problem feature framework (Figure 1) allowed for differentiation and ranking across the four quadrants. This was carried out at the solution principle level—because many interventions utilise multiple solution principles—and in terms of overall usage due to the skewed success rate. The top and

Table 6. Distribution of COM-B solution principles with respect to the problem feature framework.

Problem feature framework	Motivation	Capability	Opportunity	Total
High change demand / High behavioural constraint	3 (25%)	8 (67%)	1 (8%)	12
High change demand / Low behavioural constraint	8 (57%)	1 (7%)	5 (36%)	14
Low change demand / High behavioural constraint	24 (48%)	10 (20%)	16 (32%)	50
Low change demand / Low behavioural constraint	13 (39%)	3 (9%)	17 (52%)	33
Total	48 (44%)	22 (20%)	39 (36%)	109

Table 7. Distribution of Influence framework solution principles with respect to the problem feature framework.

Problem feature framework	Coercive	Persuasive	Seductive	Decisive	Total
High change demand / High behavioural constraint	0 (0%)	10 (83%)	1 (8%)	1 (8%)	12
High change demand / Low behavioural constraint	2 (14%)	10 (71%)	1 (7%)	1 (7%)	14
Low change demand / High behavioural constraint	6 (12%)	36 (72%)	6 (12%)	2 (4%)	50
Low change demand / Low behavioural constraint	11 (33%)	13 (39%)	6 (18%)	3 (9%)	33
Total	19 (17%)	69 (63%)	14 (13%)	7 (6%)	109

bottom ranked solution principles for each quadrant are illustrated in Figure 3. Amongst the most widely used principles were providing types of feedback (e.g., via physical visits, emails, ambient lighting on a watch, or digital counters in the home), using triggers (e.g., pop-up signage explaining required action or digital prompts via email or app), and making it salient (e.g., adding coloured floor markings, highlighting areas of a digital document, or translating behaviour into monetary terms). Breaking down the ranking data, each quadrant was distinct from the overall ranking of solution principles aggregated across all interventions. The overall distribution of solution principles, as well as that for each quadrant is illustrated in Figure 4. The raw data for all solution principles is provided in Appendix A.

The use of the various solution principles logically corresponds to the different requirements imposed in each quadrant. For example, in the *high CD–high BC* quadrant the five top principles can all be achieved with means independent of the behaviour. All of these deal with the delivery of person-specific information needed to support the high change demand, which can be achieved via multiple means both within the environment and via personal technologies due to the high behavioural constraint. Similarly, principles in the *high CD–low BC* quadrant prioritise a personal focus due to the high change demand, but have more variety in approach due to the lower behavioural constraint. Mirroring this, in the *low CD–high BC* quadrant, principles again deal with easily presented information (due to the high behavioural constraint), but because there is a lower change demand focus on more generic and easily realised interventions that have more implicit effects, such as making it salient via floor markings. Finally, in the *low CD–low BC* quadrant the set of applied principles is more diverse and include those that require technical or environmental opportunity in the context of the behaviour, such as selective presentation of choices. Hence, there is far less constraint on the principles applied in this quadrant.

The data also revealed the widespread combination of principles, with half of the identified interventions combining two or more solution principles, as illustrated in Figure 5.

The distribution illustrated in Figure 5 was not consistent across the problem feature framework. A chi-square test showed an interaction between the combination of principles and the problem feature framework ($\chi^2(3) = 20.52$, $p < .01$). Specifically, both *low* change demand quadrants were found to favour the use of individual solution principles, while the *high* change demand quadrants favoured combinations. In particular, combinations were identified in nearly four times more interventions than individual principles in the *high–high* quadrant. These results suggest that when the desired change demand is high, it is beneficial to implement combinations of solution principles in order to successfully tackle the various challenges (e.g., lack of motivation, lack of skills) that people may face. Further, each quadrant emphasised distinct combinations, highlighting key synergies between principles. Figure 6 illustrates these results, as well as the combinations most associated with each quadrant, while Appendix B provides the full list of successful combination pairs used more than twice.

Discussion

This research aimed to develop a problem/solution matrix for behavioural design via an analysis of 218 interventions (drawn from 139 cases; Figure 2). This analysis gives rise to a number of contributions.

First, the general intervention data provides two insights related to the success rate and quality of supporting evidence. In terms of the success rate, this was relatively high (75%). This aligns with both prior studies linked to behaviour change, for example Hamari et al. (2014) or Hardeman et al. (2002) who respectively found that 92.6% and *two-thirds* of articles reported some positive result, as well as the general bias toward publishing positive outcomes in the scientific literature (Fanelli, 2015; Vasilev, 2013). The uniformity of this trend could suggest a bias in the reporting of behavioural design outcomes, however, we are not aware of any systematic studies of reporting bias in this context. Such a bias can hamper the proper identification of successful verses problematic solution principles, and highlights the need to encourage reporting of unsuccessful interventions and negative results in the behavioural design context. This is particularly important if further progress is to be made in identifying effective problem-solution relationships.

In terms of the quality of supporting evidence, this was relatively weak (Figure 2), with approximately 51% of interventions using cohort controlled trials, and the majority of the 184 excluded interventions rejected based on a lack of clearly reported evidence. This falls significantly short of the standards associated with typical health interventions (Flay et al., 2005; Grimes & Schulz, 2002; Malterud, 2001), and aligns with prior findings of relatively weak evidence for behaviour change interventions by Hardeman et al. (2002). This supports Wilson et al.'s (2016) appeal for more research on what constitutes intervention success and how this can be fed back into the design process, as well as highlighting calls for more serious discussion of evidential standards for design interventions (Cash, 2018; Daalhuizen, 2014; Gottfredson et al., 2015). This is a critical issue as behavioural interventions continue to grow in importance across design domains.

Second, the interaction between our proposed problem feature framework and Michie et al. (2011) and Tromp et al.'s (2011) models suggests that this could provide a useful means for directing designers towards solution principles across a range of contexts, depending on their focus. However, this must be balanced against the nature of the model at hand, as illustrated by the range of interaction results. Specifically, there was no significant interaction with the more strategic model of Bhamra et al. (2011) or the general framework of Fogg (2009b). For the later, Fogg's (2009b) *triggers* are generic to almost all interventions and thus lack discrimination across problems. Similarly, the strategies offered by Bhamra et al. (2011) encapsulate many solution principles, both behavioural and designerly. Further, while the interaction with Michie et al.'s (2011) explicitly behavioural model is strong, the interaction with Tromp et al.'s (2011) more designerly model is only marginal. Explanations for this marginal

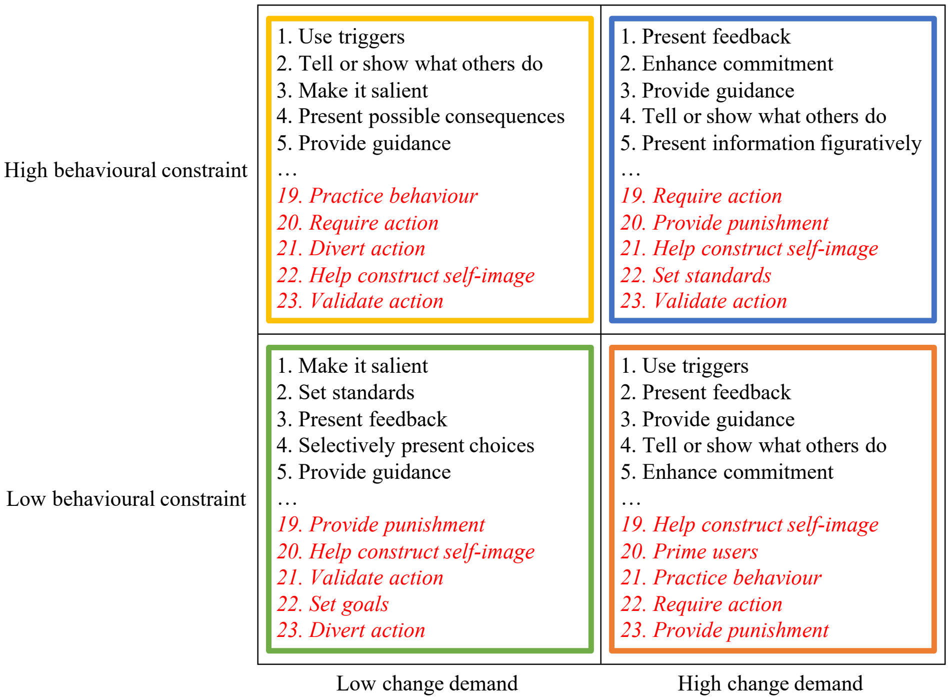

Figure 3. Most and least frequent solution principles for each quadrant of the problem feature framework.

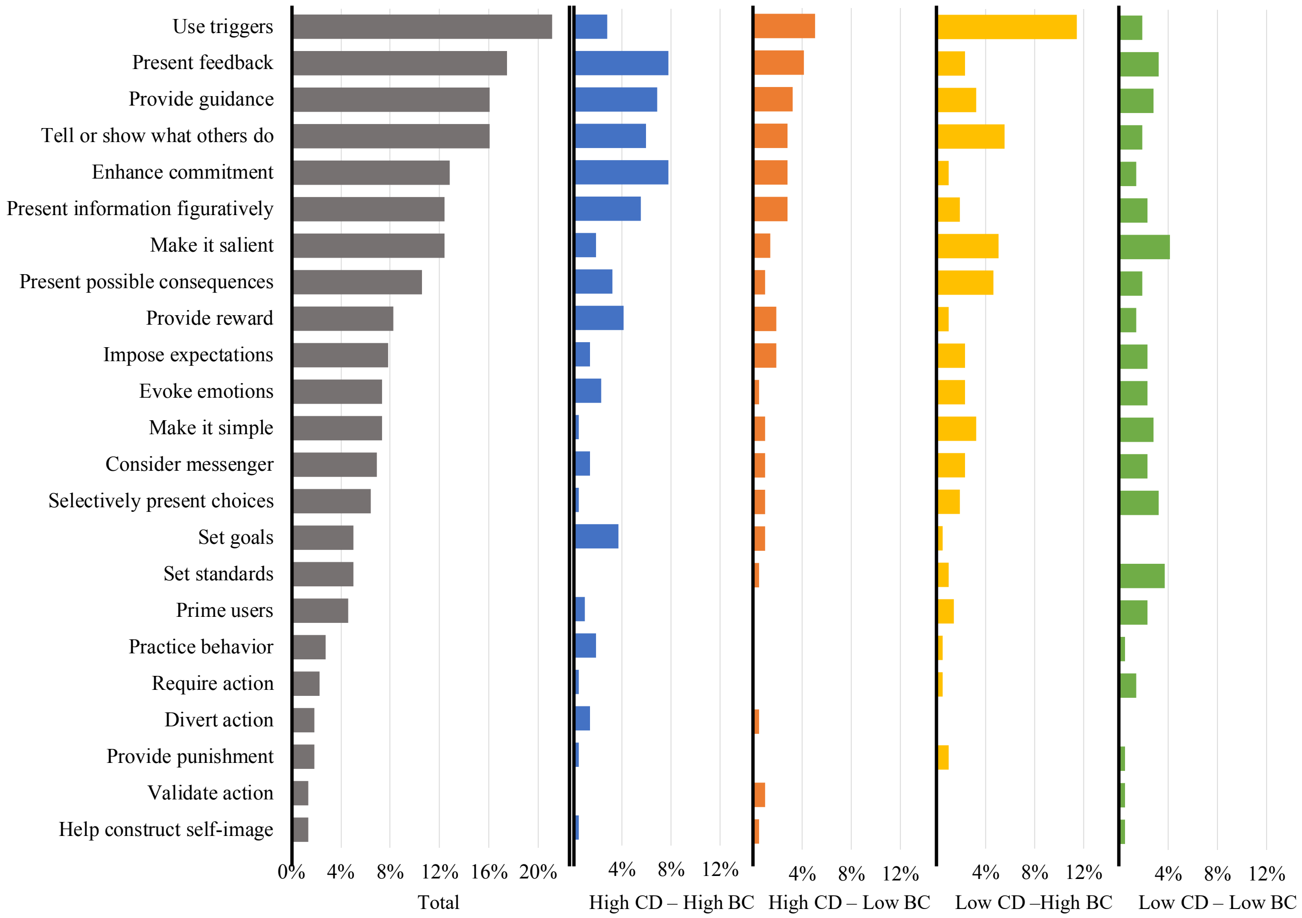

Figure 4. Solution data for each quadrant of the problem feature framework:
Change Demand (CD) verses Behavioural Constraint (BC).

effect could lie in the user focused framing of Tromp et al.'s (2011) model or the skewed focus within the data towards persuasive solutions. Thus, while our initial results offer a promising foundation developing a more general means of differentiating design solutions based on specific problem features, further work is needed to unpick the detailed mechanisms driving these interactions and at what level of granularity they become relevant.

Third, our proposed BPS matrix and its associated problem features/solution principles support a number of insights (Figure 1). Specifically, the problem features elaborate prior discussions, for example by Fogg (2009a) and Michie et al. (2011), by demonstrating the critical interaction between change demand and behavioural constraint, and the subsequent impact on solution selection. In particular, the introduction of a design constraint focused dimension is critically important to facilitating real world application by designers, and extends prior models, which have primarily focused on behavioural aspects (Michie et al., 2015). Thus, we take a step towards synthesising behavioural and designerly perspectives on behavioural design problems.

Further, the proposed solution principles extend prior works (Figure 4), which have typically focused on specific design domains or foci (Kelders et al., 2012; Lockton et al., 2010; Niedderer et al., 2016), or dealt with high-level strategies (Bhamra et al., 2011) or policy focused mechanisms (Michie et al., 2015). The combinations of principles (Figure 6) identified in this work share a number of commonalities with the higher-level groupings described in the recent work of Bohlen et al. (2019). As such, the proposed solution principles operationalise insights at the design level and complement the higher-level segmentation of behavioural design solutions.

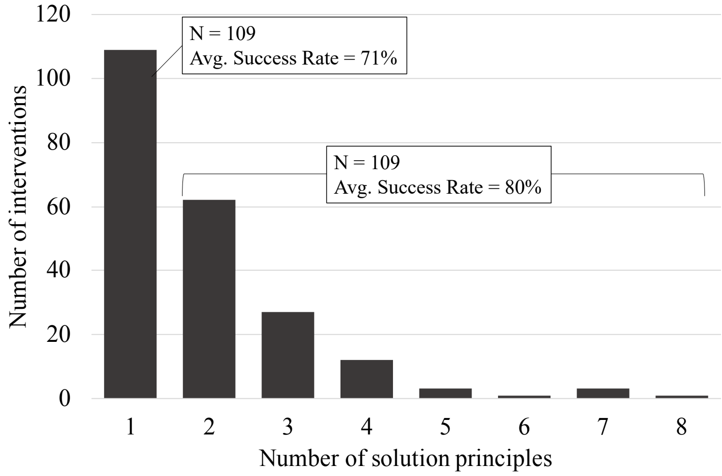

Figure 5. Frequency distribution of combinations of solution principles.

	Low change demand	High change demand
High behavioural constraint	**50 individual** 29 combined Use triggers & a) Present possible consequences (5) b) Tell or show what others do (5) c) Evoke emotions (3)	12 individual **37 combined** Present feedback & a) Tell or show what others do (7) b) Present information figuratively (6) b) Set goals (5) c) Provide reward (4) Provide guidance & a) Enhance commitment (6) b) Use triggers (4) Provide reward & Set goals (4)
Low behavioural constraint	**33 individual** 24 combined Present feedback & Present information figuratively (3)	14 individual **19 combined** Use triggers & Enhance commitment (3)

Figure 6. Most frequent solution principle combinations for each quadrant of the problem feature framework.

Bringing these together, the proposed BPS matrix substantially extends prior works, by systematically linking problem and solution domains in the behavioural design context. The proposed matrix provides a framework for designers seeking to identify the most relevant solution principles for their specific problem. This also supports the identification of other toolkits, via works such as that by Niedderer et al. (2016, Fig. 1), or combinations of solution principles, via integration with works such as that by Bohlen et al. (2019) or Lockton et al. (2013). As such, we provide a design level complement to prior policy level works (Dolan et al., 2014; Michie et al., 2015), and bring together recommendations from across domains and foci to provide an operational framework for problem/solution mapping in behavioural design. An overview of the major solution principles and combinations for each quadrant in the problem feature framework is provided in Figure 7, while full details for all principles are provided in the Appendix.

Limitations and Further Work

Before evaluating the implications of this work, three main limitations should be considered. First, behavioural theory is complex and multi-faceted. Therefore, further work is needed in order to evaluate how design related theory regarding problem formulation can be effectively linked to wider, descriptive behaviour change theory (Michie et al., 2015). This could facilitate more fluid iteration between descriptive analytical and prescriptive designerly activities within the design process (Cash et al., 2017a), as well as greater knowledge transfer between behavioural and design researchers in this area. Despite this, the proposed problem feature framework did discriminate both individual and combined solutions in line with prior models built on behavioural theory (Michie et al., 2011), and thus could form a potential foundation for this further work.

	Low change demand	**High change demand**
High behavioural constraint	**Use individual principles** *Major principles:* 1. Use triggers 2. Tell or show what others do 3. Make it salient 4. Present possible consequences 5. Provide guidance *Combinations:* Use triggers & a) Present possible consequences b) Tell or show what others do c) Evoke emotions	**Combine Principles** *Major principles:* 1. Present feedback 2. Enhance commitment 3. Provide guidance 4. Tell or show what others do 5. Present information figuratively *Combinations:* Present feedback & a) Tell or show what others do b) Present information figuratively b) Set goals c) Provide reward Provide guidance & a) Enhance commitment b) Use triggers Provide reward & Set goals
Low behavioural constraint	**Use individual principles** *Major principles:* 1. Make it salient 2. Set standards 3. Present feedback 4. Selectively present choices 5. Provide guidance *Combinations:* Present feedback & Present information figuratively	Combine Principles *Major principles:* 1. Use triggers 2. Present feedback 3. Provide guidance 4. Tell or show what others do 5. Enhance commitment *Combinations:* Use triggers & Enhance commitment

Figure 7. A proposed Behavioural Problem/Solution (BPS) **matrix; summary of major solution principles and principle combinations.**

Second, the sample of interventions considered in this study were designed and studied with the specific purpose to change people's behaviour. This enabled us to include the success of the interventions in our analysis. However, designers may also create solutions that change people's behaviour without explicitly treating these as interventions. Despite this, the large and diverse sample of interventions, as well as consistent of the results across models suggests our findings are robust. Nevertheless, it would be interesting for future research to replicate our BPS matrix for designs that change behaviour less intentionally.

Finally, while the number of examined interventions is substantial [exceeding a number of notable prior works (Hamari et al., 2014; Kelders et al., 2012) and matching state-of-the-art work by Bohlen et al. (2019)] there is still significant potential to expand this dataset, particularly to include negative results and specific implementation approaches of the 23 solutions principles. For example, providing feedback via a physical visit may be more influential than via email. Further, as noted in the discussion, the data also reflects a number of reporting biases. As such, the results must be considered as a reflection of current expert practice, particularly as they primarily originate from highly experienced behavioural design consultancies. While this is comparable to other efforts to identify solution principles (Bohlen et al., 2019; Michie et al., 2008), more systematic data would support more robust distillation of relationships between problems and solutions. However, this can only be addressed by incremental development of best practices and reporting systems, as in other domains. Specifically, efforts in the technical domain have built on extensive patent databases. While no such standard templates yet exist in the behavioural design context, further research could explore what variables are essential to report in order to facilitate meta-analysis and aggregation, as well as how potential reporting biases could be overcome. An important avenue of further work that could be supported by such a database would be better understanding potential conflicts between principles and other common side-effects. Thus, while current systems do not support such analysis, this research could be used as a basis for further aggregation efforts.

Implications for Theory

This work has three main implications for behavioural design theory. First, we highlight a number of major challenges surrounding the reporting and evidencing of behavioural design interventions. Here, there is need for a wider evaluation of potential systemic biases in the reporting of behavioural intervention outcomes. Further, discussion is needed as to what constitutes robust evidence in the behavioural design context, particularly given its reliance of building up suggested solution lists from meta-analytical reviews (Bohlen et al., 2019; Kelders et al., 2012). Second, the interaction between our proposed framework and prior models suggests opportunity to integrate behavioural and design perspectives on change theory and intervention development. This could form the basis for significant theoretical synthesis and offer new insights for human focused design work. This could also provide a basis for integration of design-level problem features/ solution principles with the higher-level frameworks described in prior models, such as Michie et al.'s (2011) COM-B model or Tromp et al.'s (2011) Influence framework. Third, our work points to underlying relationships between problem and solution in the behavioural design context, which could provide the foundation for further development and theory building following a similar path to that in the technical domain.

Implications for Practice

This work has two main implications for design practice. First, the behavioural problem feature framework (Figure 1) provides a means for decomposing behavioural challenges. Specifically, designers can use the binary questions associated with each problem feature, and their sub-features (Table 3), to identify high/ low change demand and behavioural constraint at various levels of detail. This can be used to draw together the array of observations and research typically carried out during the problem definition stage of behavioural design, in order to develop a concrete behavioural problem statement (Cash et al., 2017a). For example, behavioural observations typically illustrate the environmental and social context of a behaviour as well as the degree to which this can be changed. Similarly, observations, interviews, and other user studies can be used to identify the degree of novelty (*have users done something similar in the past?*), the scope (*how elaborate is the behaviour in question and to what degree is it connected with other behaviours?*), and the frequency in daily life. While these questions allow a design team to segment their population with respect to their different features (Figure 1), a more typical approach would be to focus on addressing a simple majority or dealing with a specific focus group. Notably, where a population is segmented, the matrix in Figure 7 could allow designers to identify principles common across areas, such as presenting feedback in various forms. Thus, the problem feature framework provides a specific set of questions informing the behavioural problem statement (Cash et al., 2017a).

Second, the proposed solution principles and combinations provide designers with ranked suggestions for how to resolve behavioural challenges across domains and foci (Figures 3 & 6), complementing other works in this area (Bohlen et al., 2019). This is particularly important during the transition from behavioural problem statement to intervention development (Figure 7; Cash et al., 2017a), and complements other, higher-level, works in the behavioural design context (Bhamra et al., 2011; Fogg, 2009b; Michie et al., 2011; Tromp et al., 2011). For example, a design team can start the intervention development stage by identifying the top ranked principles and combinations in order to support their own ideation or to move directly into structured A/B testing (Mirsch et al., 2018). Typical practice already involves companies following such an approach based on their own in-house databases of prior solutions. Thus, the proposed Behavioural Problem/ Solution matrix (Figure 7) serves to expand the scope of these company-specific databases, potentially revealing new principles and combinations not possible to identify from the more limited datasets typically held by individual companies.

Conclusions

In this work we aimed to develop a problem/solution matrix for behavioural design, systematically capturing interactions between major problem features and solution principles. To this end we examined 218 behavioural design interventions drawn from 139 cases across design domains and foci. This formed the basis for a number of contributions. First, we were able to bring together behavioural and designerly perspectives on problem characterisation via two proposed problem features: *change demand* and *behavioural constraint*, related in a two-by-two framework. This framework proved robust in differentiating both high-level solution principles in prior models, as well as the detailed principles identified in this work. Second, we synthesised recommendations from across domains and foci to operationalise a list of 23 solution principles relevant to designers. These extend and complement prior, higher-level, models. Third, we link these insights in a proposed *Behavioural Problem/Solution (BPS) matrix*. This forms a foundation for systematically linking problem and solution domains in the behavioural design context. Further, we identify a number of potential systemic challenges in the reporting and evidencing of behavioural design interventions. Thus, this work takes a first step towards an integrated view of problem and solution in the behavioural design context.

Acknowledgments

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References

1. Abrahamsen, W., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology, 25*(3), 273-291.
2. Altshuller, G., & Altov, H. (1996). *And suddenly the inventor appeared: TRIZ: The theory of inventive problem solving*. Worcester, MA: Technical innovation center.
3. Bakker, S., & Niemantsverdriet, K. (2016). The interaction-attention continuum: Considering various levels of human attention in interaction design. *International Journal of Design, 10*(2), 1-14.
4. Bedny, G. Z., & Harris, S. R. (2005). The systemic-structural theory of activity: Applications to the study of human work. *Mind, Culture, and Activity, 12*(2), 128-147.
5. Bedny, G. Z., & Karwowski, W. (2004). Activity theory as a basis for the study of work. *Ergonomics, 47*(2), 134-153.
6. Bhamra, T., Lilley, D., & Tang, T. (2011). Design for sustainable behaviour: Using products to change consumer behaviour. *The Design Journal, 14*(4), 427-445.
7. Bohlen, L. C., Michie, S., Bruin, M., Rothman, A. J., Kelly, M. P., Groarke, H. N. K., …Johnson, M. (2019). *Do combinations of behaviour change techniques that occur frequently in interventions reflect underlying theory?* Retrieved from file:///C:/Users/30452/Downloads/Manuscript_Study4TaT_PsyArxiv.pdf
8. Burnet, D., Plaut, A., Courtney, R., & Chin, M. H. (2002). A practical model for preventing type 2 diabetes in minority youth. *The Diabetes Educator, 28*(5), 779-795.
9. Cash, P. (2018). Developing theory-driven design research. *Design Studies, 56*, 84-119.
10. Cash, P. J., Hartlev, C. G., & Durazo, C. B. (2017a). Behavioural design: A process for integrating behaviour change and design. *Design Studies, 48,* 96-128.
11. Cash, P., Holm-Hansen, C., Borum Olsen, S., Christensen, M. L., & Thi Trinh, Y. M. (2017b). Uniting individual and collective concerns through design: Priming across the senses. *Design Studies, 49*(C), 32-65.
12. Chatterton, T., & Wilson, C. (2014). The 'four dimensions of behaviour' framework: A tool for characterising behaviours to help design better interventions. *Transportation Planning and Technology, 37*(1), 38-61.
13. Cho, E., & Kim, Y. (2012). The effects of website designs , self-congruity , and flow on behavioral intention. *International Journal of Design, 6*(2), 31-39.
14. Clune, S. (2016). Design for behavioral change. *The Journal of Design Strategies, 4*(1), 68-75.
15. Crilly, N. (2011). Do users know what designers are up to? Product experience and the inference of persuasive intentions. *International Journal of Design, 5*(3), 1-15.
16. Daalhuizen, J. (2014). *Method usage in design: How methods function as mental tools for designers* (Doctoral dissertation). Delft, the Netherlands: Delft University of Technology. Retrieved from https://repository.tudelft.nl/islandora/object/uuid%3A4ac01165-c6b5-4057-a2fe-3418907f251e
17. Datta, S., & Mullainathan, S. (2014). Behavioral design: A new approach to development policy. *Review of Income and Wealth, 60*(1), 7-35.
18. Dolan, P., Hallsworth, M., Halpern, D., King, D., & Vlaev, I. (2014). *Mindplace: Influencing behaviour for public policy.* London, UK: Institute of Government.
19. Dorst, K. (2019). Co-evolution and emergence in design. *Design Studies, 65,* 60-77. https://doi.org/10.1016/j.destud.2019.10.005
20. European Environment Agency. (2013). *Achieving energy efficiency through behaviour change: What does it take*? (Tech. Rep. No. 5/2013). European Environment Agency.
21. Fanelli, D. (2015). Negative results are disappearing from most disciplines and countries. *Scientometrics, 90*(3), 891-904.
22. Fishbein, M., & Ajzen, I. (2011). *Predicting and changing behavior: The reasoned action approach.* New York, NY: Psychology.

23. Flay, B. R., Biglan, A., Boruch, R. F., Castro, F. G., Gottfredson, D., Kellam, S., …Ji, P. (2005). Standards of evidence: Criteria for efficacy, effectiveness and dissemination. Prevention Science, 6(3), 151-175.
24. Fogg, B. J. (2002, December). Persuasive technology: Using computers to change what we think and do. *Ubiquity*, 89-120. https://doi.org/10.1145/764008.763957
25. Fogg, B. J. (2009a). The behavior grid: 35 ways behavior can change. In *Proceedings of the 4th International Conference on Persuasive Technology* (No. 42). New York, NY: ACM.
26. Fogg, B. J. (2009b). A behavior model for persuasive design. In *Proceedings of the 4th International Conference on Persuasive Technology* (No. 40). New York, NY: ACM.
27. Fogg, B. J., & Hreha, J. (2010). Behavior wizard: A method for matching target behaviors with solutions. *Persuasive Technology, 6137*, 117-131.
28. Fokkinga, S. F., & Desmet, P. M. A. (2013). Ten ways to design for disgust, sadness, and other enjoyments: A design approach to enrich product experiences with negative emotions. *International Journal of Design, 7*(1), 19-36.
29. Francis, J. J., Stockton, C., Eccles, M. P., Johnston, M., Cuthbertson, B. H., Grimshaw, J. M., …Stanworth, S. J. (2009). Evidence-based selection of theories for designing behaviour change interventions: Using methods based on theoretical construct domains to understand clinicians' blood transfusion behaviour. *British Journal of Health Psychology, 14*(4), 625-646.
30. French, S. D., Green, S. E., O'Connor, D. A., McKenzie, J. E., Francis, J. J., Michie, S., …Grimshaw, J. M. (2012). Developing theory-informed behaviour change interventions to implement evidence into practice: A systematic approach using the theoretical domains framework. *Implementation Science, 7*(38), 1-8.
31. Gottfredson, D. C., Cook, T. D., Gardner, F. E. M., Gorman-Smith, D., Howe, G. W., Sandler, I. N., & Zafft, K. M. (2015). Standards of evidence for efficacy, effectiveness, and scale-up research in prevention science: Next generation. *Prevention Science, 16*(7), 893-926.
32. Greening, L. A., Greene, D. L., & Difiglio, C. (2000). Energy efficiency and consumption–the rebound effect–A survey. *Energy Policy, 28*(6-7), 389-401.
33. Grimes, D. A., & Schulz, K. F. (2002). An overview of clinical research: The lay of the land. *The Lancet, 359*(9300), 57-61.
34. Hamari, J., Koivisto, J., & Pakkanen, T. (2014). Do persuasive technologies persuade? A review of empirical studies. In A. Spagnolli, L. Gamberini, & L. Chittaro (Eds.), *Persuasive technology* (pp. 118-136). Berlin, Germany: Springer.
35. Handfield, R. B., & Melnyk, S. A. (1998). The scientific theory-building process: A primer using the case of TQM. *Journal of Operations Management, 16*(4), 321-339.
36. Hardeman, W., Johnston, M., Johnston, D., Bonetti, D., Wareham, N., & Kinmonth, A. L. (2002). Application of the theory of planned behaviour in behaviour change interventions: A systematic review. *Psychology & Health, 17*(2), 123-158.
37. Hardeman, W., Sutton, S., Griffin, S., Johnston, M., White, A., Wareham, N. J., & Kinmonth, A. L. (2005). A causal modelling approach to the development of theory-based behaviour change programmes for trial evaluation. *Health Education Research, 20*(6), 676-87.
38. Hayes, A. F., & Krippendorff, K. (2007). Answering the call for a standard reliability measure for coding data. *Communication Methods and Measures, 1*(1), 77-89.
39. Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47*(2), 263-292.
40. Kelders, S. M., Kok, R. N., Ossebaard, H. C., & Van Gemert-Pijnen, J. (2012). Persuasive system design does matter: A systematic review of adherence to web-based interventions. *Journal of Medical Internet Research, 14*(6), e152.
41. Kelly, M. P., & Barker, M. (2016). Why is changing health-related behaviour so difficult? *Public Health, 136*, 109-116.
42. Krippendorff, K. (1981). *Content analysis: An introduction to its methodology.* Thousand Oaks, CA: Sage.
43. Kwong, C. K., Ye, Y., Chen, Y., & Choy, K. L. (2011). A novel fuzzy group decision-making approach to prioritising engineering characteristics in QFD under uncertainties. *International Journal of Production Research, 49*(19), 5801-5820.
44. Lin, L., & Chen, L. (2002). Constraints modelling in product design. *Journal of Engineering Design, 13*(3), 205-214.
45. Liu, P., & Li, Z. (2012). Task complexity: A review and conceptualization framework. *International Journal of Industrial Ergonomics, 42*(6), 553-568.
46. Lockton, D. (2016). *Design with intent.* Retrieved from http://designwithintent.co.uk/
47. Lockton, D., Harrison, D. J., Cain, R., Stanton, N. A., & Jennings, P. (2013). Exploring problem-framing through behavioural heuristics. *International Journal of Design, 7*(1), 37-53.
48. Lockton, D., Harrison, D., & Stanton, N. A. (2010). The design with intent method: A design tool for influencing user behaviour. *Applied Ergonomics, 41*(3), 382-392.
49. Malterud, K. (2001). Qualitative research: Standards, challenges, and guidelines. *The Lancet, 358*(9280), 483-488.
50. McCloskey, K., & Johnson, B. T. (2019). Habits, quick and easy: Perceived complexity moderates the associations of contextual stability and rewards with behavioral automaticity. *Frontiers in Psychology, 10*(July), e1556.
51. Meadows, D. H. (2009). *Thinking in systems – A primer* (D. Wright, Ed.). London, UK: Earthscan.
52. Michie, S., Atkins, L., & West, R. (2015). *The behaviour change wheel: A guide to designing interventions.* London, UK: Silverback Publishing.
53. Michie, S., Campbell, R., Brown, J., West, R., & Gainforth, H. (2014). *ABC of behaviour change theories.* London, UK: Silverback Publishing.
54. Michie, S., Johnston, M., Francis, J., Hardeman, W., & Eccles, M. (2008). From theory to intervention: Mapping theoretically derived behavioural determinants to behaviour change techniques. *Applied Psychology, 57*(4), 660-680.

55. Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., …Wood, C. E. (2013). The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: Building an international consensus for the reporting of behavior change interventions. *Annals of Behavioral Medicine, 46*(1), 81-95.
56. Michie, S., van Stralen, M. M., & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science, 6*(1), 1-11.
57. Mirsch, T., Lehrer, C., & Jung, R. (2018). Making digital nudging applicable: The digital nudge design method. In *Proceedings of the 39th International Conference on Information Systems* (pp. 1-16). Atlanta, GA: Association for Information Systems, AIS Electronic Library.
58. Niedderer, K., Ludden, G., Clune, S., Lockton, D., Mackrill, J., Morris, A., ...Hekkert, P. (2016). Design for behaviour change as a driver for sustainable innovation: Challenges and opportunities for implementation in the private and public sectors. *International Journal of Design, 10*(2), 67-85.
59. Onwuegbuzie, A. J., & Collins, K. M. T. (2007). A typology of mixed methods sampling designs in social science research. *The Qualitative Report, 12*(2), 281-316.
60. Perkins, H. W., & Berkowitz, A. D. (1986). Perceiving the community norms of alcohol use among students: Some research implications for campus alcohol education programming. *International Journal of the Addictions, 21*(9-10), 961-976.
61. Prochaska, J. O. (2013). Transtheoretical model of behavior change. In M. D. Gellman & J. R.Turner (Eds.), *Encyclopedia of behavioral medicine* (pp. 1997-2000). New York, NY: Springer.
62. Pugh, S. (1989). Knowledge-based systems in the design activity. *Design Studies, 10*(4), 219-227.
63. Roozenburg, N. F. M., & Eekels, J. (1995). *Product design: Fundamentals and methods*. Chichester, UK: John Wiley Sons Chichester.
64. Rosenstock, I. M., Strecher, V. J., & Becker, M. H. (1988). Social learning theory and the health belief model. *Health Education Quarterly, 15*(2), 175-183.
65. Shove, E. (2010). Beyond the ABC: Climate change policy and theories of social change. *Environment and Planning A, 42*(6), 1273-1285.
66. Silva, O., Crilly, N., & Hekkert, P. (2015). How people's appreciation of products is affected by their knowledge of the designers' intentions. *International Journal of Design, 9*(2), 21-33.
67. Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology, 29*(3), 309-317.
68. Thaler, R. H., & Sunstein, C. R. (2008). *Nudge: Improving decisions about health, wealth, and happiness*. London, UK: Penguin.
69. Tromp, N. (2013). *Social design: How products and services can help us act in ways that benefit society*. Delft, the Netherlands: Delft University of Technology.
70. Tromp, N., & Hekkert, P. (2014). Social implication design (SID) – A design method to exploit the unique value of the artefact to counteract social problems. In *Proceedings of the International Conference on Design Research Society* (pp. 584-598). Umea, Sweden: Umeå Institute of Design.
71. Tromp, N., Hekkert, P., & Verbeek, P.-P. P. (2011). Design for socially responsible behavior: A classification of influence based on intended user experience. *Design Issues, 27*(3), 3-19.
72. Vasilev, M. R. (2013). Negative results in European psychology journals. *Europe's Journal of Psychology, 9*(4), 717-730.
73. Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly, 27*(3), 425-478.
74. Verplanken, B., & Roy, D. (2015). Consumer habits and sustainable consumption. In L. Reisch & J. Thorgersen (Eds.), *Handbook of research on sustainable consumption* (pp. 243-253). Cheltenham, UK: Edward Elgar.
75. Wacker, J. G. (2008). A conceptual understanding of requirements for theory-building research: Guidelines for scientific theory building. *Journal of Supply Chain Management, 44*(3), 5-15.
76. Wilson, G. T., Bhamra, T., & Lilley, D. (2016). Evaluating feedback interventions: A design for sustainable behaviour case study. *International Journal of Design, 10*(2), 87-99.

Appendix

Appendix A. Full list of solution principals for each quadrant of the problem feature framework, ranked by use percentage.

High CD–High BC		High CD–Low BC		Low CD–High BC		Low CD–Low BC	
7.8%	Enhance commitment	5.0%	Use triggers	11.5%	Use triggers	4.1%	Make it salient
7.8%	Present feedback	4.1%	Present feedback	5.5%	Tell or show what others do	3.7%	Set standards
6.9%	Provide guidance	3.2%	Provide guidance	5.0%	Make it salient	3.2%	Selectively present choices
6.0%	Tell or show what others do	2.8%	Present information figuratively	4.6%	Present possible consequences	3.2%	Present feedback
5.5%	Present information figuratively	2.8%	Enhance commitment	3.2%	Make it simple	2.8%	Make it simple
4.1%	Provide reward	2.8%	Tell or show what others do	3.2%	Provide guidance	2.8%	Provide guidance
3.7%	Set goals	1.8%	Impose expectations	2.3%	Consider messenger	2.3%	Prime users
3.2%	Present possible conse-quences	1.8%	Provide reward	2.3%	Evoke emotions	2.3%	Consider messenger
2.8%	Use triggers	1.4%	Make it salient	2.3%	Impose expectations	2.3%	Evoke emotions
2.3%	Evoke emotions	0.9%	Validate action	2.3%	Present feedback	2.3%	Impose expectations
1.8%	Practice behaviour	0.9%	Set goals	1.8%	Selectively present choices	2.3%	Present information figu-ratively
1.8%	Make it salient	0.9%	Selectively present choices	1.8%	Present information figuratively	1.8%	Present possible consequences
1.4%	Divert action	0.9%	Consider messenger	1.4%	Prime users	1.8%	Tell or show what others do
1.4%	Consider messenger	0.9%	Make it simple	0.9%	Provide punishment	1.8%	Use triggers
1.4%	Impose expectations	0.9%	Present possible consequences	0.9%	Set standards	1.4%	Require action
0.9%	Prime users	0.5%	Help construct self-image	0.9%	Provide reward	1.4%	Provide reward
0.5%	Help construct self-image	0.5%	Divert action	0.9%	Enhance commitment	1.4%	Enhance commitment
0.5%	Provide punishment	0.5%	Set standards	0.5%	Require action	0.5%	Help construct self-image
0.5%	Require action	0.5%	Evoke emotions	0.5%	Practice behaviour	0.5%	Validate action
0.5%	Selectively present choices	0.0%	Provide punishment	0.5%	Set goals	0.5%	Provide punishment
0.5%	Make it simple	0.0%	Require action	0.0%	Help construct self-image	0.5%	Practice behaviour
0.0%	Validate action	0.0%	Practice behaviour	0.0%	Validate action	0.0%	Divert action
0.0%	Set standards	0.0%	Prime users	0.0%	Divert action	0.0%	Set goals

Appendix B. Most common successful solution principle combinations.

Solution principles	Total	High CD–High BC	High CD–Low BC	Low CD–High BC	Low CD–Low BC
Present feedback & Present information figuratively	11	6	2	0	3
Present feedback & Tell or show what others do	10	7	2	1	0
Use triggers & Present possible consequences	10	3	1	5	1
Enhance commitment & Provide guidance	8	6	2	0	0
Use triggers & Provide guidance	8	4	2	2	0
Use triggers & Tell or show what others do	8	1	2	5	0
Enhance commitment & Tell or show what others do	7	3	2	1	1
Use triggers & Enhance commitment	7	3	3	1	0
Present feedback & Provide Reward	6	4	1	0	1
Provide reward & Set goals	6	4	2	0	0
Present feedback & Set goals	5	5	0	0	0
Present information figuratively & Provide guidance	4	2	1	0	1
Use triggers & Consider messenger	4	1	1	2	0
Use triggers & Evoke emotions	4	1	0	3	0
Use triggers & Present feedback	4	1	2	1	0
Enhance commitment & Divert action	4	3	1	0	0
Tell or show what others do & Provide guidance	3	3	0	0	0
Tell or show what others do & Impose expectations	3	0	2	0	1