Design to Eat Smart! A Design Framework for Pervasive Interventions of Eating Habits

Zuoyi Zhang
University of Manitoba
zhangz53@myumanitoba.ca

Teng Han
Institute of Software, Chinese Academy of Sciences
hanteng@iscas.ac.cn

John Swystun
University of Manitoba
jswystun@auxesys.com

Yumiko Sakamoto
University of Manitoba
yumiko.sakamoto@umanitoba.ca

Pourang Irani
University of Manitoba
pourang.irani@cs.umanitoba.ca

ABSTRACT

Seemingly trivial eating habits, such as eating too fast, have been linked to diverse and rather serious health issues. While technology-mediated interventions have leveraged several strategies to promote healthy dietary habits, designing successful pervasive interventions remains challenging. This paper offers three contributions with the aim to assist the design of eating interventions: 1) a review of 62 studies focusing on interventions targeting eating habits; 2) a generative design framework with multiple design parameters; 3) and, an exploration of the potential efficacy of the developed framework. These contributions will improve the ability of designers to understand trends in the design landscape and the current state of the art. The work here presented aims to validate the generative nature of our design framework and further propose new exploratory directions.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Interaction design theory, concepts and paradigms**.

KEYWORDS

Eating habit interventions, design space, design framework, persuasive technology, behavior intervention, design guidelines

1 INTRODUCTION

The development of poor eating habits often leads to undesirable outcomes. Researchers have identified strong links between frequent snacking and obesity [10]; as well as fast eating rates and obesity [84]. In contrast, habits such as reducing eating speed are linked to positive outcomes such as earlier satiety during the course of meal [61], preventing excess energy intake [101]. Surprisingly, such immediately acceptable eating habits can underlie some of the major epidemics our society faces today (i.e. obesity [79]).

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To tackle poor eating habits in a non-clinical context, numerous technology-mediated interventions have been developed on various platforms, such as websites [92], video games [111], mobile and wearable devices [56], and smart tableware [39]. These emerging solutions leverage a variety of persuasive technologies [28] as well as strategies to ultimately improve users' eating habits. Nonetheless, designing new interventions is not trivial. Designers face challenges when selecting suitable strategies for behavior change and when attempting to map them onto appropriate technologies. Designers rely greatly on an intimate understanding of technology platforms, persuasion approaches, and behavior modification theories [87, 95]. Designers also face challenges caused by the lack of well-established design guidelines for practical interventions within the field. Furthermore, clear investigations of existing interventions are difficult to perform, due to the lack of a standard matrix which describes existing design factors.

To assist designers in navigating the design process and in making suitable design choices, we propose a novel design framework. Employing an iterative, bottom-up analysis, design parameters from 62 related academic projects were extracted, and used to develop a generative design framework. This framework contains design dimensions with corresponding design parameters(see Figure 1). The interrelationships between parameters have been visualized following previous approaches (e.g., [24, 45, 78]), in order to understand the key trends amongst existing works (see Figure 2). A design study was also conducted with seven participants, each with a design background. Using the newly developed framework, participants (N=7) were able to generate a significant number of novel ideas (22) for new technology-based eating interventions.

Our contributions are threefold: (i) a review of research projects aimed at intervening with poor eating habits; (ii) a design framework which outlines commonly used persuasive strategies and key design parameters; and, (iii) a validation of the generative nature of the developed framework in assisting designers to produce novel design ideas.

2 BACKGROUND

2.1 Design Frameworks

A design framework (or, design space [8, 74]) usually provides a classification and taxonomy of design dimensions, with corresponding parameters to support design practices. Designers often used design frameworks as conceptual guidelines to support creative exploration [24]. Design frameworks have also shown value in categorizing design factors in emerging fields, such as personal visual analytics [45]; such categorization helps to summarize previous trends and inspire future design decisions. A design framework can also be used to help designers evaluate existing design ideas in a systematic manner and enable the identification of the potential design gaps [8, 74, 78, 117]. A framework allows designers to explore many alternatives conceptually, without risking the full costs of production. For example, a multi-dimensional framework was developed to aid for the design of windshield applications in a car [37]. However, a design framework for interventions on eating habits is still missing.

2.2 Unhealthy Eating Habits

Unhealthy eating habits are quite common. For instance, children are often distracted during a meal, consequently prolonging meal time [49, 71], which, in turn, hinders efficient nutritional intake. In contrast, eating too rapidly has been shown to lead to overweightness and obesity [84]. Obesity can then lead to various physical and psychological issues [3, 79]. Likewise, reducing eating speed has been shown to reduce energy intake [101], and consequently help prevent obesity. Moreover, eating fast has been shown to lead to other health concerns, such as endoscopic erosive gastritis [59]. Furthermore, in North America, researchers have found that fruit and vegetable intake among adolescents is decreasing [65], while the consumption of fast-food is highly prevalent [66]. In addition, picky eating among children is also capturing the attention of researchers [49]. Research shows that making healthy food choices and eating less high-fat snacks is important for good health [64, 89, 102].

2.3 Digital Technologies for Eating Intervention

Various solutions have been proposed to reduce unhealthy eating habits (e.g., policy interventions via public campaigns or nutritional labeling [14]). Moreover, school-based interventions have been developed for providing healthier meals [106]. Meanwhile, less complicated digital interventions (e.g., meal journaling on smartphones) have been proposed. This paper focuses not only on digital solutions but also persuasive technologies for improving eating habits in the context of Human-Computer Interaction (HCI).

The goal of persuasive technologies is to influence the attitudes and/or behaviors of users [28]. Persuasive technologies have contributed to improving user health and wellness [38, 87] via diet or through physical activity [103]. Designing persuasive systems has been investigated by generations of researchers [85]. However, unlike works that investigated behavior change theories [80, 95, 116] or Behavior Change Techniques (BCT) [1] , this paper focuses on providing a design framework which bridges the theories with practical considerations, in order to guide eating intervention design. Note, healthy eating is a subjective term and applies differently to each person. Here, we did not split these variances of health eating in our paper.

3 GENERATING THE DESIGN FRAMEWORK

A literature search was conducted using the ACM digital library for two keywords; "eat" and "diet" (2018 October). To identify applicable papers, only papers exploring the two specific topics were included; 1) designs for improving eating habits; and 2) interventions on eating habits. Technical papers which focus solely on eating detection were eliminated (e.g. [110]), since this topic is not closely related to our goal. Relevant papers were collected using review papers on the topic [38, 87, 103]. When multiple papers targeted similar designs, only the latest one was included to reduce redundancy. A snowballing search was conducted on the reference lists of articles included. Finally, papers from other prominent domain-based venues such as the journals *Appetite* and *Applied Nursing* were included. These selection steps yielded 62 relevant papers, all of which were published between 2005 and 2018.

Adopting commonly used methods [24, 45, 78], a bottom up approach was employed first. Specifically, an open coding process on the design parameters was conducted. Based on this process, a set of design factors for eating interventions were generated. Subsequently, a careful refinement of these factors yielded seven dimensions and two categories (see Figure 1). Once drafted, the framework was carefully reviewed, revised, and verified by three HCI researchers. Note the goal of this framework was to provide a principal starting point for future intervention design. For this purpose, it was not intended to be exhaustive. Rather, the framework was developed as to be widely applicable across platforms and strategies. Finally, since eating habit intervention technologies represent a growing field, it must be acknowledged that the framework will evolve further.

4 DESIGN FRAMEWORK OVERVIEW

4.1 Theoretical Considerations

Behavior change models and persuasive strategies play a crucial role in the design of digital interventions from a theoretical perspective.

4.1.1 *Persuasive Strategy (PS).*

When composing new tactics for intervention, a strong understanding of persuasive strategies is of great benefit when selecting an appropriate design strategy. Persuasive strategies are not limited to a single approach. In some cases, various persuasive strategies are integrated to achieve the desired outcomes.

PS1: Feedback. A user's self-awareness is often heightened by providing feedback (or assessment of task performance) when attempting to reduce undesirable habits or increase desirable ones [40, 60] for behavior shaping. Typical feedback approaches include visual (e.g., flashing light on a dinning board [69]), audio (e.g., sound from a fork [50]), tactile (e.g., a smart fork vibrates [39]), or mixed cues (e.g., vibration on a wristband plus light flashing on a table unit [56, 57]). In general, the main purpose of feedback is to provide either positive reinforcement or punishment [49] [93]. A delicately balanced combination of reinforcement and punishment can facilitate the improvement of behaviors (e.g., earning points as positive reinforcement in a game [71]). For instance, smart devices (e.g., smart wristbands [56, 57], smartwatches [55], and smart forks [39]) often provide vibration to disrupt a user (i.e., positive punishment by providing undesirable stimuli). When applied appropriately, reinforcement and punishment through feedback can gradually increase the frequency of desirable eating habits while also reducing the frequency of undesirable habits.

Level	Dimension	Values							
Theoretical	Persuasive Strategies	Feedback	Education	Self-control	Advice & Reminder	Monitoring	Social influence	Food estimation	Goal setting
Practical	Technology Modalities	Gaming	Application	Website	Smart device	Tableware	Multimedia		
	Stage	Single-process	Multiple-process						
	Timing	Before-meal	During-meal	After-meal					
	Frequency	Per-meal	Daily	Weekly					
	Social	Single	Group						
	Personalization	General	Tailored						

Figure 1: Design framework elements extracted from a review of key papers (N=62) for eating intervention design.

PS2: Education. According to the Knowledge-Attitude-Behavior model (KAB model), education strategy focuses on facilitating learning experiences [83]. Education strategy has the potential to improve users' attitudes, when applied to eating interventions [83]. For example, researchers executed an in-classroom internet/video delivered education program for students to decrease the percentage of dietary fat consumed [30]. Modern technologies also allow for the design of more interactive approaches in education, such as "serious games", which have been used successfully to facilitate the knowledge acquisition process [20]. For example, "Escape from Diab", was designed to teach young players to reduce their risk of Type 2 Diabetes and obesity [111]. The underlying premise of an educational strategy is to facilitate individual information acquisition, which can lead to the heightened awareness of eating habits.

PS3: Self-control. According to the Dual Process model (i.e. behavior is a result of two processes, either automatic and unintentional or deliberative and conscious), one important determinant of eating unhealthy food is the automatic and impulsive process [43, 67, 107]. Self-control strategy can improve eating habits by training individuals to avoid eating unhealthy food [12]. For instance, researchers leveraged a training task, "go/no-go", which presented users with images of healthy as well as unhealthy food options [114]. Participants were asked to decide "go" or "no-go" to the stimuli, to train their self-control abilities [114]. In another project, researchers developed a chocolate machine which can automatically release chocolate balls and the users could choose to resist the chocolate balls to train their self-control [52]. Another approach to improve self-control focused on directing users' attention to their long-term dieting goals, termed as implementation intentions (i.e. reminding users of their goals to prompt diet improvement) [114]. Implementation intentions can follow an "if-then" structure, which aims to create a strong link between a specific situation and a response that allows users to select the right response to the specific situation [15]. Giving control back to the user and assisting with making appropriate decisions is the goal of self-control strategy.

PS4: Advice and Reminder. Suggestions and reminders, especially when users are not fully aware of their habits, have been shown to be an effective motivator. For example, nutrition-recommendation systems providing meal alternatives have been designed based on users' health goals and preferences [118]. Recommendation applications have also been created for easy access to health consultation [81]. Researchers have also employed reminders about healthy diets through email [96] and short messages [33] to influence eating and snacking [51].

PS5: Monitoring. Tracking and monitoring eating also provides an opportunity to boost individuals' awareness of their dietary habits [19]. For example, an eating-journal application called Weight Management Mentor promotes self-reflection by allowing users to log food intake and perform regular eating behavior analysis [31]. In other works, food purchase tracking is proposed to encourage a balanced diet [11]. A monitoring strategy is also be applied to a customized scale device, the Mandometer [1], which can assess food consumption in order to guide eating rate regulation [29]. To supplement food journaling, these approaches usually provide feedback on monitoring results [113]. In addition, using pictures of food to track consumption was proposed for user's convenience [115]. The pursuit of eating monitoring has been a challenge since the efficacy largely depends on the accuracy of the eating monitoring.

PS6: Social influence. Eating behavior is known to be strongly influenced by social contexts [42]. Social-Cognitive Theory (SCT) emphasizes that social factors, combined with existing behaviors and personal cognition, influence behavioral outcomes [105]. From SCT, eating behaviors are influenced by behavioral expectations, environment (including social factors), and factors relating to unique individuals. Social support can be provided with family-level socio-technical interventions for improving healthy eating patterns [73]. This support can also be provided through social media (e.g. comments and liking on food tracking in Instagram) [18]. Competitive

[1] https://mando.se/en/mandometer-method/the-mandometer-device/

awareness has also been implemented through ranking the healthiness of a meal in order to motivate users [23]. One study induced expectation assimilation, which described how others' evaluation of the healthiness of a meal could influence the evaluation of food quality [109]. In that project, researchers developed a social media system which unconsciously improved users' eating habits through covertly increasing the others' evaluation of the healthy food [109]. Overall, social influence is effective in promoting healthy eating habits among groups [70].

PS7: Food estimation. Food volume is commonly estimated using cues such as food weight, unit amounts, food type, and energy density [4, 34]. However, without technological support, human perception often produces ambiguous and unrealiable results when analyzing food volume. Food estimation strategy manipulates the perception of food quantities to influence food consumption in an unconscious way (termed as Mindless Computing [2]). Several designs have proposed using Augmented Reality (AR) to change the apparent visual amount of food with Head-Mounted Displays (HMD) [82], or to change the visual perception of the plate or virtual dish to influence human perception of food [2, 104]. A tableware called MindFull has been designed to influence users' sensory perception by using heavy materials to create a sense of density to control potion size [6]. This food estimation strategy extends the design space through allowing users to modify their eating habits without conscious effort. One limitation is that implementations usually rely on additional devices to manipulate perceptions.

PS8: Goal setting. According to Goal Setting Theory [72], a suitable goal can motivate individuals to develop better eating habits in a step-by-step manner, no matter if they are long-term, large goals or, short-term, small goals [88]. For example, the Crumbs project provides a daily challenge to motivate users to increase eating mindfulness and learn about nutrition [26]. Many projects combine goal setting with other strategies, such as using daily challenges with social influence strategy, to promote healthy eating in a company [16], or with the feedback strategy to review goal achievement.

4.2 Practical Considerations

To Implement the aforementioned behavior change models, various design factors should be considered when developping and deploying a design.

4.2.1 Technology Modalities. Designers must determine which Technology Modality (TM) is best suited for their intervention design.

TM1: Gamification. A gamification strategy is often applied not only for entertainment but also for educational purposes (i.e., a serious game [22]), when delivering nutritional information [22]. Since video games normally involve complicated visual effects, storylines [94], and operations [111], their design and development can be costly. Games which offer shorter and simpler sessions (i.e., casual games) have been leveraged for healthy eating education [88]. Gaming interventions can be engaging and effective in motivating health eating [46], especially for children and adolescents [76]. For example, Grocery Hunter is a children's game in which players look for healthy grocery store items based on clues to help children make healthy food choices [53]. Games can also be designed for multiple players to leverage social influence [7].

TM2: Applications. Many software applications (or Apps) have been designed to monitor eating patterns [31] and/or to provide feedback [54]. This modality may be deployed on a myriad of hardware including smartwatches [55], head-worn displays [108], and projectors [32]. Designers can develop various digital intervention apps with functionally rich tools to achieve fast prototyping practices.

TM3: Website. Websites are a dominant intervention platform (i.e. online forums [92], online cooking tutorials [27], and eating intervention programs [17]). A clear benefit of using a website is that its content is deployed in browsers, without requiring the installation of extra software, and can be updated easily with an internet connection.

TM4: Smart Device. Smart devices are designed specifically to support eating regulation (i.e. a combination of a wrist band and a table unit to provide feedback [56, 57], a novel belt to provide pressure feedback on the body [93], and a chocolate machine to help users to train self-control [52]). These smart devices helped designers to translate their design concepts in a tangible way.

TM5: Tableware. Interventions embedded in tableware could improve awareness of eating patterns throughout the course of a meal. Tableware interventions include smart utensils, trays [58], and mixed gear [47]. However, such intervention is often restricted by the unconventional sizes and shapes of the tableware when being deployed in an eating environment or used over a lengthy period.

TM6: Multimedia. Multimedia tools deliver information to support dietary habit improvement for various audience, and include various digital media (i.e. online videos [112], short messages [9], and social media [18]). Deliberately generated multimedia content can be conveyed to target users passively, making this digital platform useful in promoting improved comprehension.

4.2.2 Stage. Eating intervention approaches were classified into single-stage or multi-stage processes. Projects leveraging a single-stage process focus on one aspect of the behavioral change to alter eating habits (e.g., providing real-time feedback while users are eating [39]). In contrast, projects employing a multi-stage process focus on two or more steps. The Transtheoretical Model (TTM) [97], for instance, views behavior change as a multi-stage process, starting with the gaining of awareness of healthy behavior to action of behavior change, followed by maintenance of behavior, and ending with upholding maintenance and avoiding a return to the original behavior. Several projects have been designed [30] and/or evaluated based on TTM [36]. In addition, Playful Tray [71] is a device designed based on a three-stage intervention model (volition, performance, and habituation). In general, the stage dimension can provide designers with a longitudinal perspective of behavioral change and a stage-based approach. Typically, single-stage interventions are simpler and easier to implement than multi-stage interventions, which are usually more complex and require more time.

4.2.3 Timing. Timing refers to the temporal phases to a meal when considering an intervention (i.e., Before-meal, During-meal, and After-meal). Reminders and/or recommendations [118] are given "before-meal" to produce an inoculation effect to avoid unhealthy eating. During-meal refers to interventions applied while users are eating. For example, a smart eating fork [2], provides real-time light and vibrational feedback during a meal to regulate eating rate [39]. Moreover, an interactive robot and a plate were designed by Randall *et al.*, which can provide feedback during a meal to help improve eating habits in children [98]. Another example is Foodworks, which digitally augments a plate by projecting animations and light on the meal table and plate to encourage eating vegetables in children [32]. During-meal interventions can contribute to an in-situ effect [5, 99]. After-meal refers to approaches which follow a meal, such as a summary of the food consumption on tracking applications [115]. After-meal approaches are valuable in providing users with a review of their eating habits to encourage reflection.

4.2.4 Frequency. Frequency describes how often an intervention is administered to target users (i.e., per meal, daily, and weekly). Per meal interventions provide guidance for each meal (i.e., real-time feedback on a tray [71]). Daily interventions often provide a daily reminder to guide users' eating [51, 96]. Weekly refers to interventions that provide guidance on a weekly basis, such as an online website providing a weekly intervention [48]. Daily and weekly are not limited to how many times the approach applies to the user in a given day or week. For example, a weekly-based design sends personal healthy eating messages three times per week [33]. While higher frequency of the intervention could induce heightened awareness more continuously at the beginning of the intervention, it may also annoy the user and lead them to boredom.

4.2.5 Social. The social dimension focuses on whether solutions were implemented to an individual or to a group. One example of group design is an intervention to encourage healthy eating within a family [73]. The group design leverages social influence to improve eating habits, including updates and overviews from friends, family, and peers via social media [63]. For example, a two-player augmented reality (AR) game [7] was designed for co-diners to engage in proper mastication in an enjoyable way. Without setting up social interactions, deploying the solitary design to a single individual is simple. For example, a nutrition knowledge game [90] can be played by one user, and the results depend on the user's performance only. In contrast, the group design requires setting up a group and its effects depend on the social interactions of those users.

4.2.6 Personalization. Nowadays, interventions are customized to a given user's personality and his/her living environment (i.e. a system tailors food recommendations to each individual based on the user's preferences and needs [81]). In contrast, educational videos targeting numerous students are not personalized [30], as they are intended to be presented to the general population. Research indicates that personalization can improve the effectiveness of a game designed to promote healthy eating [86]. Personalized intervention targets users individually, based on their characteristics to improve effectiveness. Naturally, personalization requires more data input to build the user model (e.g., Body Mass Index information).

[2]http://www.slowcontrol.com/en/

5 EMERGED PATTERNS

Frameworks generally offer a multidimensional matrix that maps out the various projects to identify the gaps in the design space (for example, see [8, 78]) or by visually plotting the interrelatedness (for example, see [24, 45]). To explore the categories and show potential design directions, we mapped all the reviewed papers using a parallel coordinate view (Figure 2). Such a view is extensible and can add new dimensions, as the framework evolves over time.

In the plot, each line represents one of the 62 papers we surveyed. Each line traces through the points in the various dimensions as per our synthesis. In a few special cases, projects possess multiple values. This is common in design strategies, because some strategies are non-orthogonal and can be used together (e.g., feedback strategy and education strategy in [49]). In these cases, only the primary strategy applied in the project has been selected as the value to identify major trends. Furthermore, a few projects do not yield any specific values in dimensions such as time and frequency. For example, there is no requirement on when and how often users should play a game [36]. In such cases, the value was set to "not specific" on the time dimension and the frequency dimension.

5.1 Design Trends

We investigate the parallel plot to see the design patterns from the current projects. Based on parallel coordinates, we discovered that there are no clear trends in the field. Thus, we investigated each dimension independently. To categorize existing designs, we summarize patterns that are reflected in the parallel coordinates (Figure 2). Here, patterns reflect multiple projects in one cluster.

5.1.1 Advice and reminder to a single user. Five projects [33, 51, 81, 96, 118] leveraged an "advice and reminder" strategy, which targets a single stage process and single users. Four of them (80%) used personalization to induce higher persuasiveness. Personalization was particularly common, given that 11 of the 62 projects (18%) employed it.

5.1.2 Real-Time Intake Monitoring. Five projects were designed to monitor dietary intake (i.e., tracking food consumption) targeted at single users in a single process [19, 29, 31, 51, 115]. Somewhat unexpectedly, only two of the five projects adopted a personalized approach in their design, despite their potential to employ personalization [31, 51]. All of these self-monitoring applications are deployed on mobile devices (e.g. a smartphone), due to their ubiquity and convenience. This eating tracking design has been largely applied to commercial apps such as MyPlate [3] and MyFitnessPal [4] and LoseIt![5] or commercial devices such as the SmartPlate [6] (Intervention tools of this sort were excluded from the literature review in favor of focusing on academic outcomes and prototypes).

5.1.3 Educational gaming and websites. Eleven out of the 62 reviewed projects applied the education strategy on gaming platform

[3]https://www.livestrong.com/myplate/
[4]https://www.myfitnesspal.com/
[5]https://www.loseit.com/
[6]https://www.getsmartplate.com/

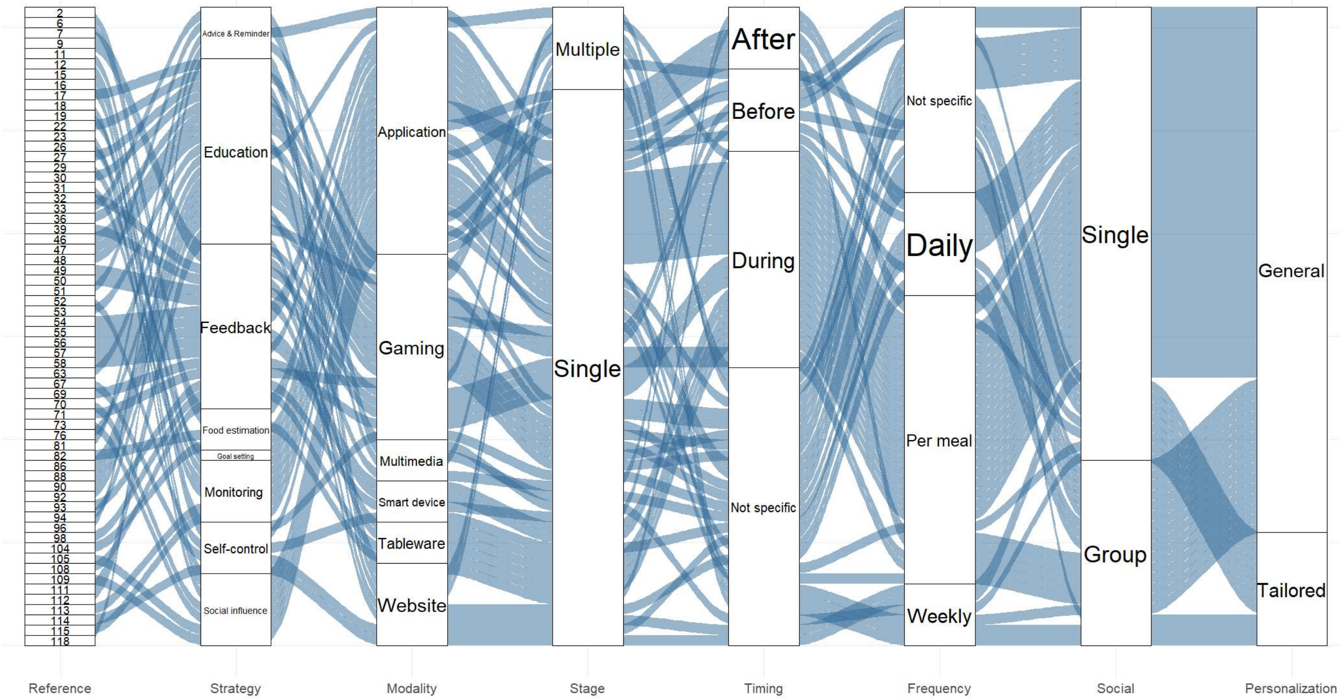

Figure 2: Parallel coordinates of the papers surveyed and categorized using design dimensions of the framework (N = 62).

(i.e., serious games with educational/training purposes). While the goal of education is to provide nutrition information, the gaming modality can transform this experience into a pleasant one, while reducing boredom caused by the repetition. Moreover, five of the reviewed projects used websites to educate healthy eating. Interestingly, most of the educational gaming approaches target a single stage (i.e., nine out of eleven projects) rather than multiple stages.

5.1.4 Real-time feedback. This design delivers, in real-time (during-meal), feedback to the users (14 projects). Real-time feedback can influence eating directly but requires accurately identifying improper eating behavior. Therefore, real-time feedback depends on sophisticated eating recognition systems on tableware (e.g., trays, and utensils) or wearable devices (e.g., wrist bands [54, 55]).

5.1.5 Training for healthy eating. We found designs which train individuals to be cognizant of healthier eating patterns.

Single user's food estimation control in real-time. Four solutions applied the food estimation control strategy from a single process perspective, which fell into the during-meal category in the timing dimension with per-meal frequency; each was designed for single users in the social dimension. These projects leverage and manipulate users' perception of food estimation in a real-time eating setting. Mindless Plate designed by Adams *et al.* [2] is one of such design, in which the the plate's color changes according to the color of the food on it, to create an illusion of there being more food. This perceptual effect aims to modify food serving size. Their intuition is that users may serve less, since small portions seem large enough, due to the perceptual manipulation.

Self-control facilitation for single users. Five projects employed the self-control strategy from a single process perspective, which targeted single users without limitation in the time dimension (e.g., an online training program with implementation intentions and go/no-go tasks [114]). Designers of such interventions need to be adequately familiar with the training methods in psychology.

5.1.6 Promoting healthy eating behaviors to a group. Interventions which target a group of users often leverage social interactions to impact eating habits.

Social influence via social media applications. Seven projects employed a social influence strategy and leveraged application modalities to a group of users. Social media applications can nudge mobile device users to post pictures of meals, make comments, and interact with other users' eating-related posts. This trend can be further expanded due to the proliferation of social media platforms.

Family-based digital interventions. Of the 62 projects, two induced family-based social support to regulate food intake (one focused on healthy snacking [105] while the other focused on general healthy eating [73]). The results from these two research studies firmly supports that family-based interventions can indeed produce positive changes in eating habits [73, 105] because family members care about each other's well-being, and can influence each other greatly with regards to their eating habits.

5.2 Potential future directions and challenges

Potential design directions emerged based on the above summary of our analysis from the parallel coordinates plot visualization.

5.2.1 *Tailored solutions.*

User-tailored solutions (11 out of the 62) seems to be an area that has not been fully explored among the reviewed projects. Given that individuals have unique eating habits, personalization could be effective to support individuals’ eating regulation. One potential direction is tailored feedback, which is based on each individual’s preference and characteristics. Naturally, target users would accept tailored solutions more easily than non-tailored solutions. Personalization could also present challenges, because additional data is required from users to make adjustments. While the tailoring procedure might be complex technologically, it is promising and beneficial for future interventions.

5.2.2 *Applied feedback to a group.*

One project applied feedback strategies to a group of users [7], using gamification in an engaging way. A potential direction could be providing feedback for a group of people while using other modalities, such as mobile apps.

5.2.3 *Multiple-stage design.*

Eight projects applied a multi-process approach; seven out of them leveraged the education strategy and the other applied the feedback strategy [71]. This significant overlap (7 out of 8) exists presumably because the education strategy includes multiple processes. The infrequent use of the multiple process design could be attributed to difficulties associated with the investigation that are needed over the long-term with various stages. Multiple process designs, or the combination of various, single process designs could help improve eating behaviors at various stages longitudinally. Expanding focus from a single process (e.g., real time eating feedback) into multiple stages for eating habit intervention (e.g., healthy eating education) is promising but relatively complex, and thus requires careful investigation.

6 DESIGN STUDY

To see whether our framework can actually contribute in design practice by inspiring novel ideas, we conducted a series of design sessions to explore the framework’s generative aspects. We aimed to qualitatively explore our fundamental question: "Can our framework guide designers’ idea generation process?"

6.1 Design brainstorming sessions

Two brainstorm sessions were conducted with seven participants (n = 3 in the first and n = 4 in the second session) with design background. Participants with some design background were recruited to enhance the brainstorming sessions. All of them were recruited through posters at a local university. A 30 CAD gift card was provided to each participant as compensation. This study protocol was reviewed and approved by the local university review board.

The participants’ demographic information was collected prior to the design session. Each participant indeed had a design background (F = 5, M = 2; M_{age} = 22.9). Most of the participants were beginner student designers or amateur designers except for one participant who was a professional designer. More specifically, three participants were art school students, while two participants already had a degree from a design-related program (e.g., decorative design and graphic design; note one of them worked as a designer). The other two had experience in graphic design (e.g., posters and tickets). In the first half-hour, the research assistant provided participants our framework Fig 1, which was thoroughly explained

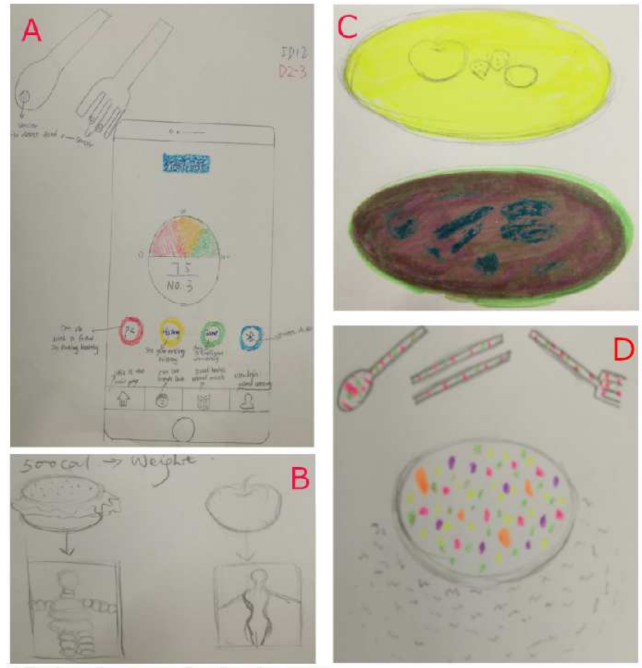

Figure 3: Designs generated by the participants. (A) from Participant 2’s 3rd design (i.e. D2-3) is an application to monitor eating quantity. (B) D5-1 is an app that can display body images based on the detection of food. (C) D5-2 is a plate which can display various colors and shapes based on the food it holds, to provide visual feedback about food. (D) D5-4 is a plate with numerous lights which can flash and shake in order to provide visual feedback about eating rate.

along with pertinent examples found in the literature. In the next step, participants were asked to collaboratively design and draw solution ideas for the following issues:

- High food intake rate for fast eaters;
- Unhealthy food consumption and low consumption of fruits and vegetables

The participants were informed to assume that any eating detection technologies would be available to achieve their design. Thus, their idea generation is not hindered by the lacking technologies.

The participants had one hour to brainstorm and sketch new designs. Then, participants were asked to explain and discuss each of their designs with other participants. Finally, participants separately answered open ended questions (e.g., "How did the design framework support your design in this study?") on a sheet. Thus, the participants’ experience of using the framework was explored qualitatively. Each design session lasted two hours in total.

6.2 Design discussions

From the design session, 22 design ideas were generated (see Figure 3). 21 of them targeted the two design objectives as instructed on the design sheets. One design (D1-4, or the fourth design from participant 1), a smart water bottle, focused on monitoring water intake. This design was included in discussion since healthy liquids

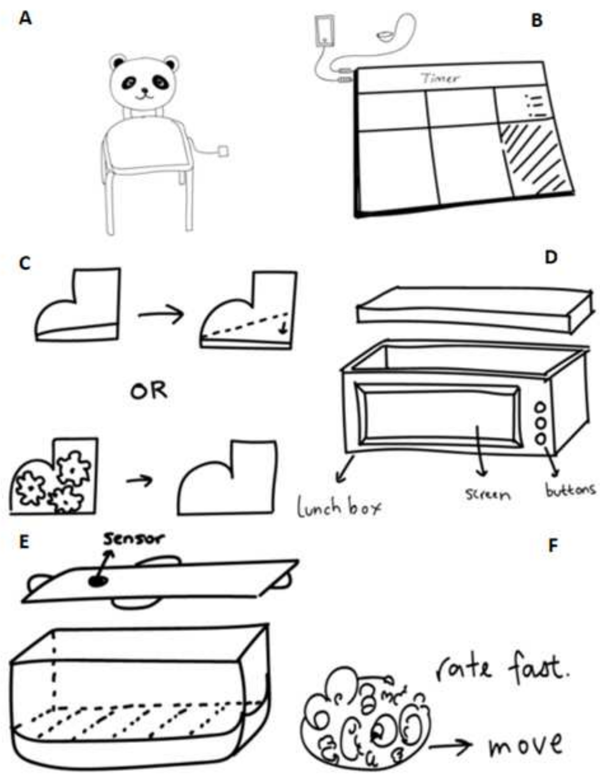

Figure 4: Six designs that were generated based on our framework. (A) is a child chair which can provide music in order to influence children's eating habits (D7-2). (B) is a smart table cloth which can measure food consumption by connecting tableware and has a screen to show nutritional data and support video chat (D6-1). (C) are smart shoes which can change the height of the bottom and shape on the outer layer to provide feedback (D3-4). (D) is a lunchbox with a screen which can display eating rate and provide guidance according to user's goals (D1-1). (E) is a lunchbox with two levels which can lock the second level to decrease food itaken when it detects unhealthy food (D2-2). (F) a movable plate which can move away from the user to slow down eating rate (D5-3).

intake is indeed related to food intake habits and could be combined with other designs to provide healthy eating regulation (e.g., [50]). After the design session, the generated designs were investigated, which are illustrated in Figure 4. Through another visual analysis (Figure 5), we explore and describe how the patterns in these newly generated designs build off our framework.

6.2.1 Leveraging persuasive strategies. Participants leveraged five types of persuasive strategies in their designs. The most frequently used types were feedback and monitoring, which are commonly applied in commercial fitness and wellness monitoring applications. In contrast, neither the food estimation nor the self-control strategies were employed. This is in line with the limited use of such strategies in existing works (Figure 2). These omissions may be due to the participants' lack of knowledge and experiences with such strategies in comparison to feedback and monitoring.

Not surprisingly, the goal setting strategy was jointly implemented with the monitoring strategy. One example is a diet monitoring lunchbox with a goal setting feature, to track food intake based on the goals set by users (D1-1). The lunchbox provides clear goals to allow users to see the tasks needed to be completed. Participants also applied social influence strategy in their designs, such as a diet monitoring tablecloth with a screen which can support video chat (D6-1). The reason social interaction features were included could be related to the fact that participants are continuously exposed to various types of online social interactions (i.e., higher familiarity). Applying social influence strategy into a design benefits target users in gaining support from peers to regulate eating habits. The trend of combining various persuasive strategies to design interventions for eating habits also exists in the related literature.

6.2.2 Implement practical design factors. Most designs from the brainstorming sessions focused on modalities that included application, smart device, and tableware. One tableware uses lights with various colors, which can flash to provide visual feedback to influence the user's eating rate (D5-4). This design is similar to the Kooijman Dish, a prototype which utilizes a light attached to a dish to influence eating [62]. Note, this Kooijman Dish was not provided as an example to the participants, which indicates our participants were able to generate novel devices with our framework. Additionally, one design was an earphone (D3-1) which can provide auditory intervention; another idea focused on smart shoes (D3-4,C in Figure 4) to provide feedback based on the user's eating behavior. These novel designs show that our framework can facilitate participants' design activity, at least partially. Interestingly, gamification and website modalities were not employed by participants. This could be due to the perceived complexity in designing games and websites (hence, not suitable to discuss in a brainstorm session), but also a reflection of the participants' backgrounds, as none of the participants had experience with game or web development.

Most of the designs applied the single-process, within the stage dimension. Furthermore, there were only two designs that emphasized personalization. The lack of the multiple process and tailored approaches shows that incorporating these strategies could be a challenge or simply undesirable, at least for these participants. The multiple-process design is also rarely apparent in the literature (only eight out of 62 applied multiple-process), which reflects how most designers prefer to focus on single process solutions.

6.3 Participants' experiences

The experiences of participants experiences in using the design framework was explored qualitatively, using the questionnaire.

6.3.1 Efficacy of the framework. All the participants commented on the framework's usefulness (e.g., P3 or participant 3:"guided me to know more information"; P2: "This framework gave me a lot of ideas"). These responses are encouraging as they also indicate that the framework is comprehensible. Furthermore, participants' responses implied that they explored beyond the boundary of the framework (e.g., P1: âĂIJthink through each theory and see what you can findâĂİ; P2: "use the theory first to determine what kind

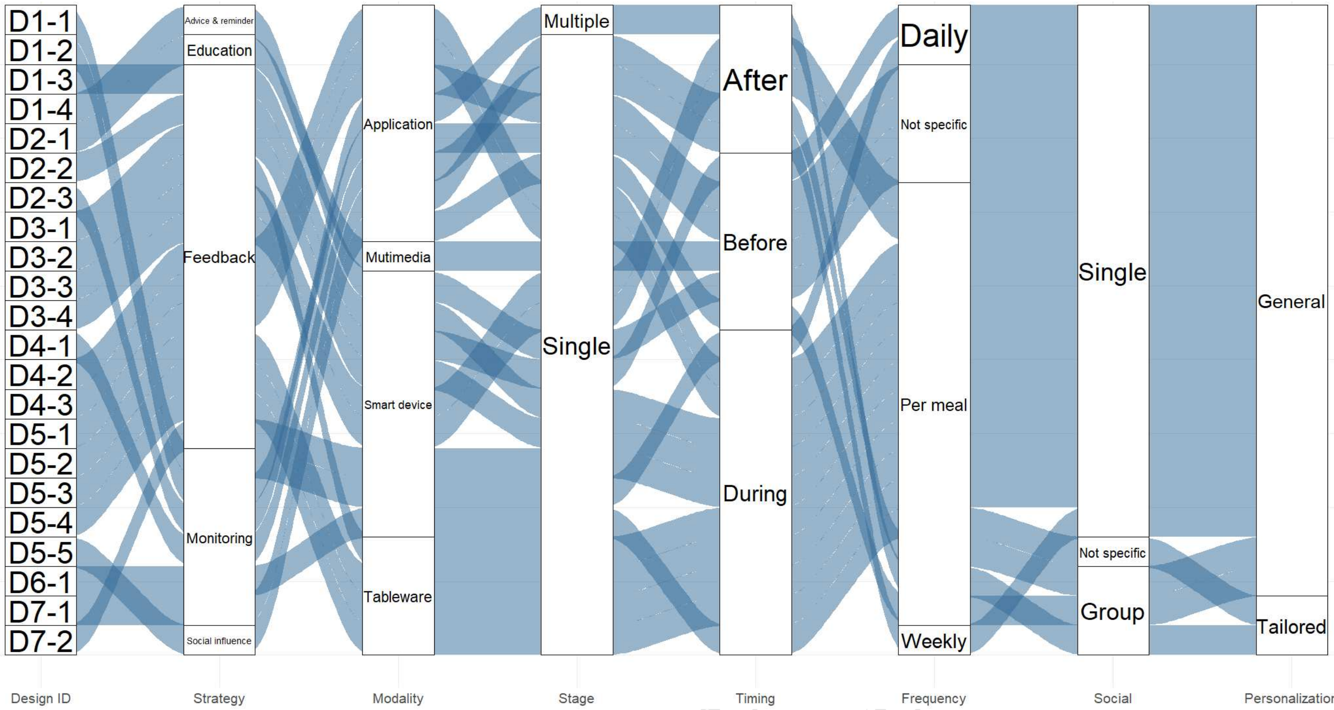

Figure 5: Parallel coordinates based on the designs generated by participants in the study using our proposed framework

of strategy would you like to apply"). Moreover, P2 was concerned about the feasibility of implementing design ideas in practice, even though we asked them to disregard the limitations of the technologies.

6.3.2 Amount of information: Providing examples. The importance of providing examples in design practice has already been investigated in previous studies [41]. Thus, design examples taken from our literature review were provided to facilitate participants' understanding of the framework. As expected, participants valued these examples and noted that these examples guided them in understanding what to design. Further, P3 suggested that adding descriptive images of the examples could be useful when introducing the framework. Making the framework available online, with example images linked to it, could be one approach to offering more detailed information. While providing images of examples may make improve a user's ability to imagine these sample technologies more readily, it may implicitly limit a user's imagination at the same time (i.e., I should design something like the example I saw). Further investigation is needed to understand how much information, especially images, should be provided in order to enhance creativity.

6.3.3 Complexity vs. Simplicity: Cost and benefit. Three participants found the framework somewhat confusing at first. P4 mentioned "it took some time to understand it . . . could be simpler". P7 mentioned the necessity to clarify the intent of the framework when introducing it. One reason for this perceived complexity might be due to the multiple dimensions and values of the framework. Furthermore, none of the participants had used this kind of framework for their design activities. The framework may benefit from further simplification, especially if used by designers who have never used a design framework. Although a simplified framework may become easier to understand, it might not provide enough information. Thus, alternatively, the users should have more time to understand the framework with clearer instructions, prior to the design activity, in order to maintain the efficacy of the framework.

7 DISCUSSION AND LIMITATION

The review, as expected, does not cover the entire field. The narrowed down literature search strategy did not detect potentially valuable papers such as food journaling [21, 119], improving snacking [44], dietary sharing interventions [35, 91] or design of persuasive technology on user interfaces [68]. Along with developments in the field, more recent works are emerging on topics such as different types of food trackers [75] and photo-based diary meal tracking [13]. The goal of our review was not to provide exhaustive information, but to offer a set of primary design dimensions to aid in the beginning stage of the design process. We believe our review still offers significant coverage in terms of unique attributes.

For practical design practice, the goals and target users are important to consider. Here, healthy eating is a broad term, which has various meanings to different target users. In a study with dietitians, Luo *et al.* found each individual has different needs for healthy eating (e.g., increasing or decreasing calorie intake, adding a variety of food , getting more protein, avoiding sugar), depending on their age, gender, health conditions, activity levels, etc [75]. Without understanding who the target users are and what "healthy eating" means to them, it is unlikely to make an impact on target users' eating habits. Here, it is assumed the design goal and target is clear, and we aim to focus on the design parameters for health eating intervention. We believe a target user investigation is another important study area, which is not the scope for this project.

We acknowledge that the current version of the framework, with multiple dimensions, might appear somewhat complex at a glance. This complexity may be challenging, especially for designers who have never employed a design framework. One solution to this perceived complexity could be to present the design framework in a hierarchical structure (see ordered sequences of the thematic tree in [117]). A hierarchy logic might be needed for the designers to follow. Such a hierarchy might assist in deciding/determining the order in which to consider design factors (e.g., strategy, modality, stage, timing, personalization). For now, such logic was not generated, to avoid misleading and limiting the designers' creativity. Alternatively, specific subgroup frameworks could be developed based on independent design descriptions (e.g., real time feedback eating intervention), possibly simplifying our descriptive framework.

Our parallel coordinates attempted to encapsulate the current trends. The visual identification of the trends is challenging, reflecting the lack of major trends in the field. Another explanation could be the sheer number of projects reviewed (since the area is rather new). Attempts to cover as many design considerations (design dimensions in the framework) as possible led to the inclusion of more dimensions, making the trend identification task in the static visualization more complex. The usability and interpretability problem raised regarding using parallel coordinate plots to investigate such a complex framework. Alternatively, it may be possible to instead use a multidimensional matrix to map out various existing designs, to identify the gaps in the design space [8, 78]. However, this alternative can only represent the interrelations between two dimensions at a time. Perhaps, interactive features could be added to our parallel coordinates, to represent even minor trends for smoother interpretation [25, 45]. Since the current plot limits each design to a single value within each dimension, a novel visualization is needed to accommodate multiple, jointly designed parameters in each dimension, which would be useful to improve the interpretation of the design patterns.

In the design study, we did not quantitatively investigate the appearance of the framework on the design generation (i.e., can designers benefit from our framework?). A future experiment comparing the quality of generated design ideas may be fruitful (i.e., With Design Framework vs. Without Design Framework while controlling participants' design experience level and capability specifically in the field). Inviting another group of experts to evaluate the designs from participants, with a single standard on the design quality is also necessary to investigate the design ideas [100]. Additionally, most of our participants were beginners and the generalizability of our results to experienced designers is unclear [100]. While beginners appreciated the framework, this may not be the case for more experienced designers. Studies with experts who work in healthy eating design domains will also increase our knowledge of the framework's usability, and support the discussion of the potential pros and cons of different choices within the various design dimensions.

Evaluations of the interventions we reviewed are not included in the current project. A future evaluation matrix is needed to evaluate the quality of the interventions in promoting healthy eating with actual users. Even though the framework presented in this paper prompts valuable design thinking and may inspire useful future designs, lacking the considerations of quality might be a problem for technology design in the health domain, where there are significant concerns around safety and efficacy. Researchers need to evaluate interventions according to efficacy (does a design cause health behavior change in users), usability (can people use it), acceptability and engagement (will people use it), and safety (does a design harm the user or lead to inappropriate behavior change). To establish ways of designing and evaluating health interventions, Mckay *et al.* created a scale to measure the quality of potential behavior change, used in mobile phone applications [77]. Validating the outcomes of the design study with actual users would also be an option if we were to have higher fidelity prototypes. In this project, the design quality was not the focus and instead, we focused on summarizing previous work, to identify under explored areas. We admit the omission of the quality considerations and believe this could be addressed in the future work.

8 CONCLUSION AND FUTURE WORK

In this project, a review of digital intervention and persuasive technologies for eating habits were conducted. Based on a review of the related literature, a design framework for digital interventions was developed, which gives a top-down view of intervention design. To explore the utility of this framework, we visually summarized reviewed projects into parallel coordinates to probe current trends. Finally, to show the feasibility of using our framework in practice, two design sessions on generating eating improvement design ideas were conducted. Overall, the framework was found to be helpful in guiding (mostly beginner) designers to generate new ideas.

Although participants recognized the value of our framework in guiding their design activity, a minor complexity issue emerged. In future, interactive features could be implemented into our framework to better facilitate understanding. The development of an interactive web application with animations could highlight relevant aspects of the design framework (i.e., an interactive design framework website [7]). Guidelines for understanding the design framework could also be provided to assist learning and using the framework (as Lundgren *et al.* did in [74]). To tackle eating habit concerns faced by society, new intervention technologies are rapidly emerging. As the field evolves, the addition of new design consideration and dimensions should be considered. Since the goal of the study was to explore the utility of a framework, the generated design ideas were not immediately evaluated. A future study focusing on the evaluation of the generated ideas, based on formalized design criteria could be valuable [see [100] as an example].

Eating habits can lead to serious health issues. We hope our framework will support future investigation and contribute to the design of eating habit intervention technologies.

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