Exploring and designing for multisensory interactions with 3D printed food

Tom Gayler

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School of Computing and Communications
Lancaster University

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Declaration

This thesis has not been submitted in support of an application for another degree at this or any other university. It is the result of my own work and includes nothing that is the outcome of work done in collaboration except where specifically indicated. Many of the ideas in this thesis are a result of discussion with my supervisor Professor Corina Sas.

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List of Publications

Gayler, T., Sas, C., Kalnikaite, V., (2021). The Design of a Multisensory Visual Probe Kit to Support Personalised Flavour Design, *Proceedings of the 2021 on Designing Interactive Systems Conference*.

Gayler, T., Sas, C., Kalnikaite, V., (2021). Framing the Design Space for Food-Human-Technology Interaction. *Under 2nd revision for ToCHI.*

Gayler, T., Sas, C., Kalnikaite, V., (2021). "It took me back 25 years in one bound": Self-Generated Flavour-based Cues for Self-defining Memories in Later Life, in: *Manuscript Submitted to International Journal of Human-Computer Interaction.*

Gayler, T. (2020). Inbodied interaction design example: Smell. *Interactions*, *27*(2), 38–39. https://doi.org/10.1145/3380870

Gayler, T., Sas, C., & Kalnikaite, V. (2020). Material Food Probe: Personalized 3D Printed Flavours for Emotional Communication in Intimate Relationships. *Proceedings of the 2020 on Designing Interactive Systems Conference*. https://doi.org/10.1145/3357236.3395533

Gayler, T., Sas, C., & Kalnikaite, V. (2020). Co-Designing Flavor-Based Memory Cues with Older Adults. *Companion Publication of the 2020 International Conference on Multimodal Interaction*, 287–291. https://doi.org/10.1145/3395035.3425644

Gayler, T., Sas, C., & Kalnikaite, V. (2019). Taste Your Emotions: An Exploration of the Relationship Between Taste and Emotional Experience for HCI. *Proceedings of the 2019 on Designing Interactive Systems Conference*, 1279–1291. https://doi.org/10.1145/3322276.3322336

Gayler, T., Sas, C., & Kalnikaitė, V. (2018). User Perceptions of 3D Food Printing Technologies. *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, LBW621:1–LBW621:6. https://doi.org/10.1145/3170427.318852

Exploring and designing for multisensory interactions with 3D printed food

Abstract

Experience of food is as varied as it is widespread, part of mundane activities but also embedded in rituals and celebrations. Despite its pervasive richness it has yet to be fully exploited to support embodied and multisensory experiences within Human-Computer Interaction. This thesis addresses this shortcoming, drawing on the unique qualities of food experience in combination with novel technology to design rich, affective, and embodied interactions through food.

This work approaches *3D printed food* as a *material* to design emotion- and memory-based experiences with food, and *3D printing of food* as a *technology* for crafting multisensory user experiences in everyday contexts. These perspectives are integrated through the design and evaluation of novel interactions with 3D printed food, following a Research through Design approach combined with material approaches. Through this enquiry, novel research tools for HCI were also created for working with food, flavour, and taste.

The thesis comprises seven studies that advance knowledge, based on gaps identified, and novel theoretical framings in a systematic literature review. Through a survey of user perceptions of 3D printed food, opportunities for user experience-based applications were highlighted. An identified opportunity for affective interactions through taste was considered through lab-based studies and interviews with chefs and food designers on using 3D printed food. This was extended through a co-design study with couples in romantic relationships to create flavours of 3D printed food to support emotional expression and coregulation. The use of flavours to cue experience was then explored in relation to self-defining memories with older adults. Through both co-design studies, a multisensory probe kit was built and evaluated to support designing with the senses in HCI and to further explore ideas from the study into food and memory and an app prototype designed for creating personalised flavour-based memory cues.

Collectively, these studies support applications of the 3D printing of food for emotional and memory-based applications in HCI, as well as theoretical and methodological contributions to multisensory design and design with food and the body in HCI.

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1 Introduction

1.1 Research Motivations

Food is as varied as it is pervasive across societies and supports a wide variety of sensory and embodied experiences, subject to increased interest in Human-Computer Interaction (HCI) research during the last decade. Particularly as novel technologies and a sensory turn drive exploration of new ways in which humans and their bodies can interact with digital technology. This thesis is motivated to promote 3D printed food as a material for designing multisensory user experience within HCI.

The research presented aligns with a recent interest in Human-Food Interaction (HFI). Thus far, the field has largely been focused on designing *around* food experience, with only an emerging set of work that directly engages *with* food experience. The following research attempts to bring together the design *around* and the design *with* food experience, to uncover the potential for rich, multisensory user experience. A key difference with most prior work is that this thesis does not see food solely from a single perspective. Instead, it collects and combines a range of perspectives on food experience, considering them in different contexts, taking existing experience potentials (such as mappings between basic tastes and emotions) and applying them to interactive experiences between humans and computers.

HFI is not a sub-discipline of HCI but has significant overlap with HCI, for example some HFI does not engage with human-computer interactions, instead only focussing on the human and food. HFI is strongly associated with design, itself a field of knowledge that overlaps but is not wholly coincidental with HCI. Design approaches and design knowledge are common in HFI research, explore the materiality of food, proposing and exploring alternative ways of experiencing and creatin with food. This thesis sits within an area of HFI that can also be seen as HCI work, it is interested in interactions between humans, food, and technology. It draws on design knowledge and approaches to engage with experience, food, and interactive technology, contributing knowledge that is of interest to researchers and professionals in HCI, HFI and design.

If food can be effectively combined with interactive digital technology it can be used to better support how humans and their bodies to interact with, and experience technology.

However, food is difficult to work with, as it relies on chemical stimuli and safe-to-eat materials, making it significantly more difficult to design with than audio-visual or haptic stimuli. To overcome this challenge, this project applies a novel technology - an innovative 3D liquid food printer developed by Dovetailed Ltd called *nūfood*. The printer allows the delivery of food stimuli as part of interactions with technology and supports customization of flavour according to user's desires. The intention is that through food, rich forms of experience may be made possible with technology. This work leverages experience with a material (food) that is highly sensory and enters the body to create opportunities to reduce the estrangement between digital technology and physical, bodily experiences.

Most prior HCI research has focused on visual and audio interfaces, with a more recent acceleration of haptic interfaces. However, little is known about how taste and smell can be leveraged in novel interaction modalities. One of the key properties of the experience of food is that it affords both taste-, and smell-based experience, through a multisensory compound experience called flavour. Through research and design with the 3D printing of food this thesis can not only extend knowledge into multisensory experiences for users but also uncover new knowledge for working with food-based, and other multisensory experiences.

1.1.1 Research Funding

This PhD research is funded via a CASE studentship on which Dovetailed Ltd. are the industry partner. The company have developed a 3D liquid food printer *nūfood* (Dovetailed Ltd., n.d.), throughout the research there was a close interaction between the research undertaken with the university and Dovetailed, strengthening expertise of both in HCI, digital fabrication and design. This project's potential for innovation is substantial and underpinned by three factors: the exploration of an innovative technology for the 3D printing of food, an innovative approach for using the 3D printer food as a technology probe to explore how it can support stronger emotional user experience; and investigating ways in which the 3D printing technology can be harnessed for gustatory and olfactory experiences.

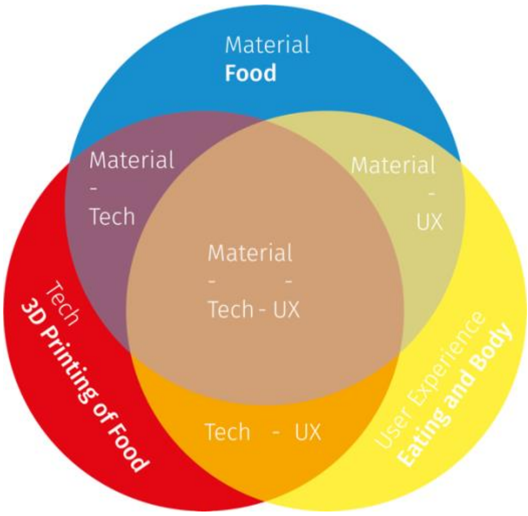

Figure 1 Diagram of thesis topics by material (food), technology (3D Printing of Food) and user experience (eating and body)

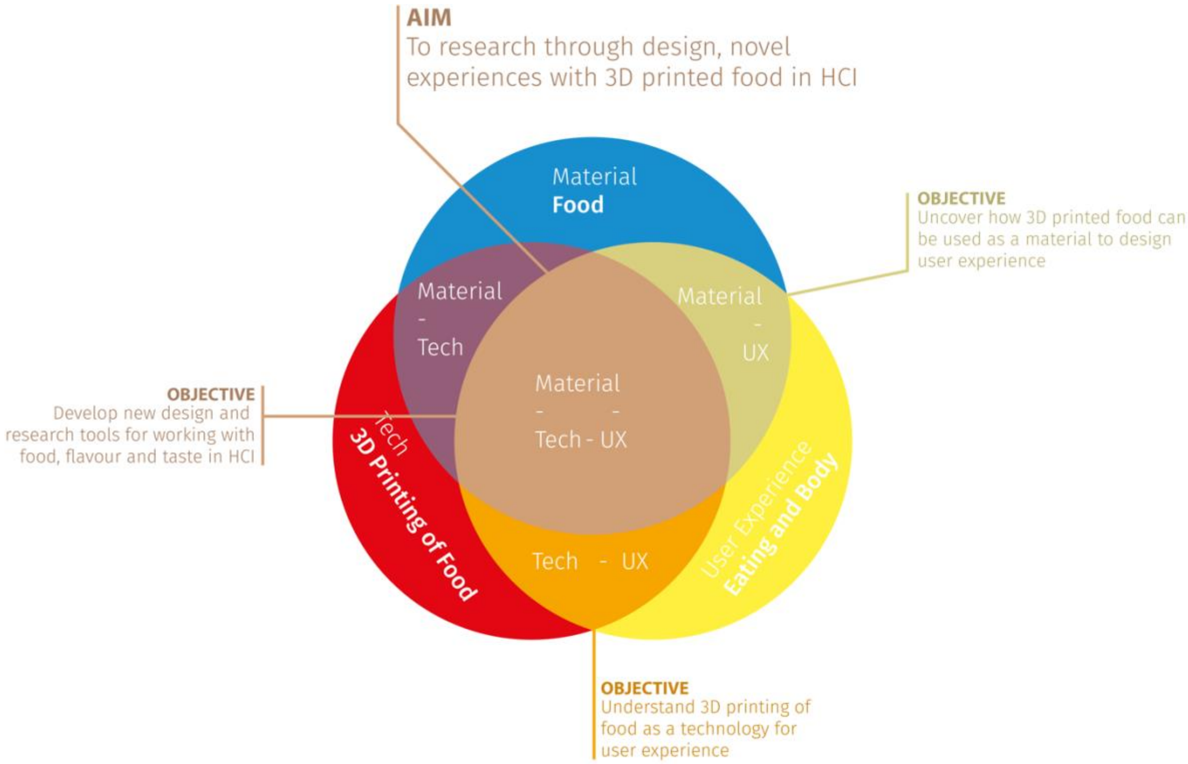

Figure 2 Diagram of thesis aims and objectives as they relate to the three concerns of the thesis: Food, 3D Printing of Food and Eating and Body

1.2 Study Objectives

The research's aims are achieved through work across three domains (Figure 1). The first domain relates to food as a *material* for design. The second is the 3D printing of food as a *technology*, the format and function of 3D printing of food and how it integrates within pre-existing interaction contexts. The third and final is the *user experience* associated with eating and its bodily experience.

The first objective aims to uncover how 3D printed food can be used as a material to design user experience (Figure 2). It aims to identify qualities of 3D printed food that allow it to be designed with in ways not possible with traditional food materials, using these to argue for the value of this technology to advancing HCI. This objective involves collating previous research from HCI as well as from sensory science, psychology and directly from chefs and food designers to identify opportunities for design. These opportunities are then explored through the design and research with 3D printed food to explore multisensory experiences for emotional and memory-based experience.

The second objective is understanding 3D printing of food as a *technology* for user experience (Figure 2). Through this understanding 3D printing of food can be more successfully leveraged by HCI in the design and research of user experiences, in particular those experiences related to emotions and memory. This involves identifying what groups are the early adopters of 3D printing of food and surveying their attitudes. This will be followed by exploring how designed interactions with technology could be through the 3D printing of food for a range of users, using interviews to record their impressions and speculations.

The third objective is to develop design and research tools for working with food, flavour and taste in HCI (Figure 2). Such methods overcome challenges of working with food, such as the personalised nature of flavour experience promoting food's adoption by designers across wider HCI work. These will be developed to bridge the gap between HCI's current limited knowledge of designing with food, and fields and practices which have greater insight. This involves interviews with chefs and food designers and the synthesis of design tools to support sensitizing users to food experience to include them in the co-design of food-based experiences.

1.3 Research Questions

To achieve the study aims the following questions have been devised for the overall thesis (Figure 3) and the individual studies (Table 1).

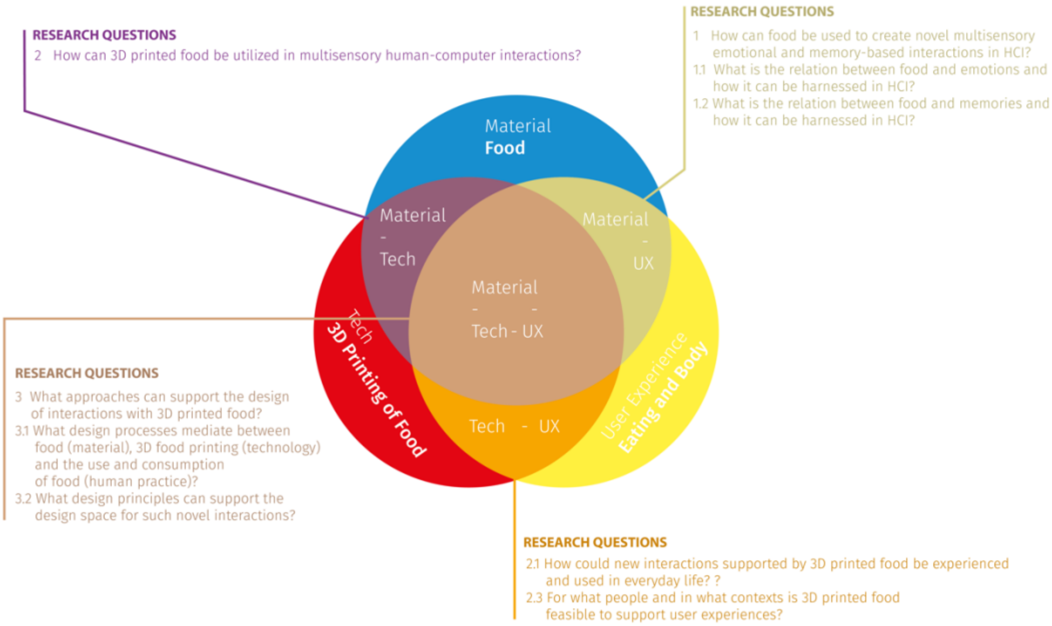

Figure 3 Diagram of overall research questions as they relate to the three concerns of the thesis: Food, 3D Printing of Food and Eating and Body

Overall

RQ1 - How can food be used to create novel multisensory emotional and memory-based interactions in HCI?

> 1.1 What is the relation between food and emotions and how it can be harnessed in HCI?
>
> 1.2 What is the relation between food and memories and how it can be harnessed in HCI?

RQ2 - How can 3D printed food be utilized in multisensory human-computer interactions?

> 2.1 How could new interactions supported by 3D printed food be experienced and used in everyday life?
>
> 2.2 For what people and in what contexts is 3D printed food feasible to support user experiences?

RQ3 - What approaches can support the design of multisensory interactions with 3D printed food?

3.1 What design processes mediate between food (material), 3D printing of food (technology) and the use and consumption of food (human practice)?

3.2 What design principles can support the design space for such novel interactions?

Objectives	To uncover how food can be used as a material to design user experience	To exploit 3D printed food as a technology to design user experience	To develop new design and research tools for working with food, flavour and taste in HCI
Thesis RQ's	RQ1 - How can food be used to create novel multisensory emotional and memory-based interactions in HCI?	RQ2 - How can 3D printed food be utilized in multisensory human-computer interactions?	RQ3 - What approaches can support the design of interactions with 3D printed food?
Systematic Literature Review	What food qualities are relevant to the design of novel human-food interactions?	How has food been used to design experiences in HCI research? How food qualities can be used to design novel human-food-technology interactions?	
Study 1 User Perceptions of 3D Food Printing Technology		Who are the early adopters (EA) of 3D food printing? What attitudes do EA have towards 3D food printing? What do EA perceive as risks of 3D food printing? What envisaged uses are there for 3D food printing?	
Study 2 Taste-Emotion Mappings and Food Experience Design Strategies from the Perspective of Chefs and Food Design Practitioners	Is sweet taste predominantly mapped to positive emotions as suggested by psychology of taste? Are sour, bitter and salty tastes predominantly mapped to negative emotions? How does the intensity of the taste link to emotional responses? How has food been used to design experiences by chefs and food designers?		
Study 3 Taste Your Emotion : An Exploration of the Relationship between Taste and Emotional Experience for HCI	What are the relationships between taste and emotions in real-life inspired scenarios?	What is the feasibility of 3D printing food technologies for leveraging taste-emotion mappings in HCI? What scenarios are most relevant to HCI research for mediating novel user experience through 3D printed food?	
Study 4 Material Food Probe Personalized 3D Printed Flavours for Emotional Communication in Intimate Relationships	What personalized flavours for intimate communication do people co-design?	How do people engage in 3D printing of such flavours in everyday lives? How does the 3D printed food support intimacy?	How can experiences with 3D printed food be prototyped?
Study 5 "It took me back 25 years in one bound" Self-Generated Flavour-based Cues for Self-defining Memories in Later Life	What self-defining memories are selected to be cued with a flavour-based cue? What flavour-based cues are designed for self-defining memories which include food and do not include food? What is the role of food in self-defining memories? Can food-based memory cues be designed for food-related and non-food related memories?	What is the value of 3D printed flavour cues for older adults' self-defining memories?	How do older adults codesign flavour-based cues?

Objectives	To uncover how food can be used as a material to design user experience	To exploit 3D printed food as a technology to design user experience	To develop new design and research tools for working with food, flavour and taste in HCI
Thesis RQ's	RQ1 - How can food be used to create novel experiences in HCI?	RQ2 - How can 3D printed food be utilized in multisensory human-computer interactions?	RQ3 - What approaches can support the design of interactions with 3D printed food?
Study 6 The Design of a Multisensory Visual Probe Kit to Support Personalised Flavour Design			How can people be supported to understand and express their experience with food? How can non-specialists participate in the design of personalised food-based interactions?
Study 7 The Design of a Mobile App for Capturing Multisensory Experience and Designing Personalized Flavor Cues			Via a digital design tool: How can multisensory experience be captured? How can flavours be reproduced? How can flavours be creatively designed?

Table 1 Study research questions as they relate to each of the thesis research objectives and questions

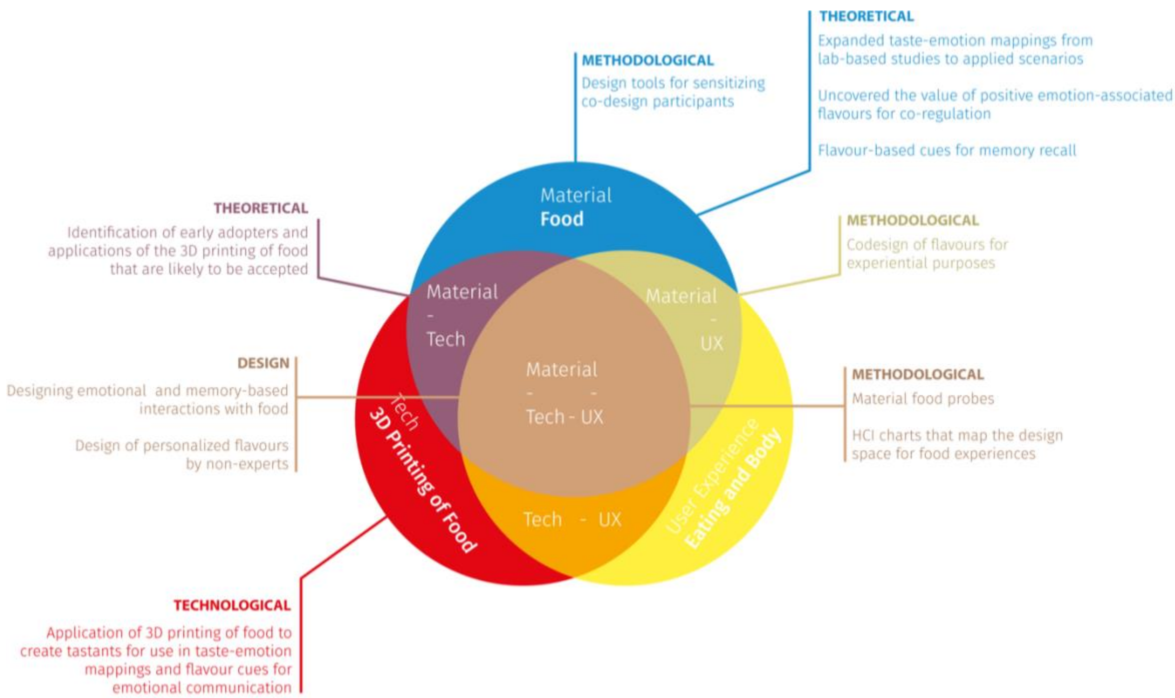

Figure 4 Diagram of thesis contributions as they relate to the three concerns of the thesis: Food, 3D Printing of Food and Eating and Body

1.4 Contributions

This thesis offers a range of contributions (Figure 4), including design knowledge for creating experiences through food, technological, methodological and theoretical contributions. They result from explorations into food, technology and experience, design work on emotion and memory-related contexts and the development of methods and technology design for creating personalised flavour experiences. The main contributions are the design of emotion and memory-based interactions through eating 3D printed food and the related development of design methods and processes to support the creation of personalised flavours with non-expert users.

1.4.1 Design Contributions

The design and co-design studies in this thesis build on identified opportunities for emotional experiences (based on both taste and flavour) and memory-based experiences (based on flavour alone).

Designing emotional and memory-based interactions with food

Through two published studies reported in this thesis (Gayler et al., 2019a, 2020), contributions support the design of emotional communication and regulation with food. Design implications arise from the application of taste-emotion mappings used for the expression and comprehensions of affective communication (Gayler et al., 2019a) and the use of flavour to support emotional expression and co-regulation (Gayler et al., 2020). Through taste and flavour, two novel ways are offered to support designing interactions with technology. These studies show both how taste can be isolated and used as a single sensory input to form the output or input into digital systems as well as how flavour can be used to craft personalised expressions of emotions that be created and used interpersonally. They support further exploration of multisensory experience with food in affective computing or interactive contexts in which emotional or embodied experiences can be usefully leveraged. Another study extends work in HCI on forms of multisensory memory cues through the use of food as an aid for memory (Gayler et al., 2021b). It details how cues can be designed for memories that both do and do not have pre-existing food connections. The memory cues are personalised and then eaten to support richer and more emotional and visceral memory recall when compared to words cues alone. Flavour-based memory cues are proposed to be used to support memory recall ability which can decline with age, offering a strategy for further exploration.

Design of personalized flavours by non-experts

App wireframes are designed and evaluated for user created personalised flavour experiences (Gayler et al., 2021c) building on previously developed co-design methods.

The digital mobile application replaces the facilitator and supports the user to undertake their own design process. It supports the progressive capture and description of sensory experience and then the curation of cues based on the selection of salient aspects of the sensory experience of the memory. It also allows for creative cue construction in which users are supported to connect sensory experience to aspects of memory. This app design supports a move towards wider adoption of the design strategies and approaches in this thesis.

1.4.2 Technological Contribution

The contribution is delivered through design work that aims to exploit the potential of 3D printing food, both for taste-based and flavour-based interactions. They indicate the value of 3D printed food to support the design of multisensory interactions.

Application of the 3D printing of food to create tastants for use in taste-emotion mappings and flavour cues for emotional communication.

3D liquid food printing was used to create foods which were controlled for aspects of their multisensory experience such as texture, temperature, colour and odour whilst varying taste. This allowed design with taste-emotion mappings as part of interactions with computers (Gayler et al., 2019b). The technology was also used with personalised flavours to support the emotional communication of couples in romantic relationships (Gayler et al., 2020).

1.4.3 Methodological Contributions

Due to the ongoing emergence of food as a field of interest in HCI, new methods are needed to support designing with it. This thesis in particular considers how to co-design flavour for personalised experiences which are key to the success of emotion and memory-based contexts explored in this thesis. It does this through proposing and evaluating co-creation and sensitizing approaches. It also offers sensitizing materials for designers, aimed at opening up the design space for food in HCI.

Design tools for sensitizing co-design participants

A multisensory probe kit design was developed as an extension of cultural probes offering insights in multisensory experience (Gayler et al., 2021d). It was deployed and iterated through two of the studies (Gayler et al., 2021b, 2020).

Material Food probes

This novel food-based probe represents a design tool that combines ideas from Material Probes (Jung & Stolterman, 2011) and Technology Probes (Hutchinson et al., 2003). It provides a unique tool for generating and evaluating interaction concepts with food. It emphasises the potential of the 3D printing of food to open up spaces for interaction design, both *with* and *around* food.

Co-design of flavours for experiential purposes

As part of designing and evaluating emotional and memory-based experiences with food (Gayler et al., 2021b, 2020) a novel co-design approach was created. This co-design approach is built around a process of sensitization towards *taste worlds* (Beauchamp & Bartoshuk, 1997) and supports the participation of non-experts in the design of personalized multisensory experiences.

HCI charts that map the design space for food experiences

Combing insights from a survey of literature and interviews with chefs and food designers, charts are presented that detail how food can be used to create emotional, temporal, narrative, communicative and embodied experiences (Gayler et al., 2021a). Design implications and sensitizing questions are provided for each experience chart to enable designers and researchers to use them in future work.

1.4.4 Theoretical Contributions

Through the exploration and design activities that resulted in the above contributions this thesis also offers theoretical contributions, that deepen the understanding of 3D printed food, taste in support of emotion-based interactions and flavour in support of emotion and memory-based interactions.

Identification of early adopters and applications of the 3D printing of food that are likely to be accepted

Tech-literacy and low food technology neophobia were suggested as characteristics of early adopters of the 3D printing of food (Gayler et al., 2018). Applications most readily accepted by this user group centre on the experiential potential of the technology.

Expanded taste-emotion mappings from lab-based studies to applied scenarios

Through interviews (Gayler & Sas, 2017a) and the design of interactive scenarios (Gayler, Sas and Kalnikaite, 2019) with 3D printed food, taste-emotion mappings understandings in applied contexts were consolidated. Research also supports the role of intensity in modulating mappings.

Uncovered the value of positive emotion-associated flavours for co-regulation

In a study into personalised flavours for emotional communication for couples (Gayler et al., 2020), the value of positively associated flavours to support co-regulation of emotions was reported.

Flavour-based cues for memory recall

Flavour-based memory cues were found to support both non-food and food related memory recall and were most suitable for positive memories (Gayler et al., 2021b). The study on cues also highlights common associations for pairing flavour-cues and non-food memories.

Having detailed the motivations, objectives, research questions and contributions of this thesis, the work now turns to related literature, to consider how this work draws from and extends the state-of-the-art with and beyond HCI.

2 Literature Review

This thesis starts by identifying opportunities for food based HCI, reviewing work from a broad range of areas. At the centre is prior work within HCI using food. Experiences with food in HCI have been examined through a systematic review of existing literature (Chapter 2.1). To inform specific studies, prior work in HCI has been reviewed (Chapter 2.3) on emotion-based interactive systems, intimacy and memory supporting applications and consideration is given to the design of multisensory experiences and interactions. And to aid general understanding of food and food experience (Chapter 2.4) there are sections on taste and flavour, taste-emotion mapping, food in intimate relationships and flavour as a memory cue.

Work with food in HCI sits within a wider, but similarly emerging field of multisensory HCI. Multisensory HCI covers interactions with technology that engage more than one sense, in particular moving beyond traditional audio-visual interfaces. Research in this area seeks new knowledge to exploit tactile, gustatory and olfactory sensation. It is searching for richer interactive experiences by building on the concepts of multisensory and crossmodal psychology (Spence, 2003). Multisensory HCI is focused on scoping out design spaces for, and identifying the challenges of, multisensory interactive media. It is concerned not with traditional problem-solving, but with the creation of possibilities and opportunities for experience in interaction design (Obrist et al., 2016b). Multisensory HCI focuses on the following goals: developing sensorial forms of experience, deepening the interaction between humans and computers, and supporting the use of extra bandwidth. With previous work has been limited by the following factors to challenges of working with chemical senses, and the complexity of food-based interactions (Obrist et al., 2016b). Through a systematic review of existing literature and an appreciation of novel application domains this literature review grounds the following studies and discussion.

2.1 Designing experiences with food

HCI interest in food has been diverse, driven by range of perspectives, from the creation of 'effective' diet apps (Hakobyan et al., 2016) to tracking and reducing food waste (Farr-Wharton et al., 2013). Recently, more attention has been paid to the sensory (Nijholt et al., 2016), playful, and cultural experiences with food (Altarriba Bertran, Duval, et al., 2019), helping to answer the call for a greater emphasis on celebratory practices around food (Grimes & Harper, 2008). Particularly as a result of technological advances that have allowed further design engagement with food, including the 3D printing of food (Gayler et al., 2019a; Khot et al., 2017) and digital taste stimulation which does not require any chemical stimuli (Aoyama et al., 2018). However, there still remains much more to be understood about the experience of eating food and it may inspire novel user experiences. This research gap is the focus of this systematic literature review, namely the experience of user's eating food and how eating is woven into the way we interact with each other and technology.

To address this aim, this chapter answers:

- How has food been used to design experiences in HCI research?
- What food qualities are relevant to the design of novel human-food interactions?
- How can food be used to design novel human-food-technology interactions?

HCI scholars have developed various models and frameworks to conceptualize user experience. Forlizzi and Battarbee (Forlizzi & Battarbee, 2004) described an 'interaction-centric' approach, through which interaction and experience types are defined. Extending previous work (Forlizzi & Ford, 2000), they propose a framework that centres on "interactions between individuals and products and the experiences that result" (Forlizzi & Battarbee, 2004). The framework describes user-product interactions as "fluent, cognitive and expressive", *fluent* being the most ingrained ones which do not require much attention, *cognitive* as interactions which can teach the user something or cause them confusion and *expressive* detail interactions that form a relationship between user and product. The framework also identifies three dimensions of experience as "Experience, An Experience, Co-Experience". *Experience* is a commentary or "self-talk" during product use, *An Experience* has a beginning and end and can be named, *Co-Experience* is product use that creates meaning or emotion. Through-out this thesis, different aspects of interaction and experience are apparent, with an emphasis on the potential for food to support *Expressive* interactions that result in *An Experience* or a *Co-Experience.*

2.1.1 Approach to systematic literature review

The aim of the systemic review of HCI literature on eating experiences was to reflect on this emerging yet disparate body of work prioritizing first the bodily aspects of eating experience and the types of technology and socio-cultural context supporting them. Inspired by approaches that consider both food and technology as resources for experience design (Wiberg et al., 2013), this review highlights the eating experience of as a lens for understanding experiences with food, drawing attention to the importance of the body as space for experience. Food has a unique relationship to the body, being experienced by a person both outside the body (smell, sound and vision), on the body (taste, texture and temperature), and within the body (digestion and metabolization). Whilst there is extensive work that exists within HCI related to food, this has often focused on contexts 'around' food rather than experiences directly 'with' food. This has a two-fold impact on the fields understanding of possibilities. The first is to limit the use of food within HCI to the introduction of technology into existing contexts, this means rather than creating novel types of experience, it is more about augmenting existing experiences. Whilst this is important, ignoring the food itself closes down many possibilities for future work. The second impact is to negate the importance of the body within experiences of food. The eating phase is intimately linked to the individual bodies doing the eating, and by focusing on it, more can be understood about how to design with the body. This will have benefits for work with food but also all interaction design where sensory and bodily experiences are important.

2.1.1.1 Method

Here is reported the method for the systematic literature review, detailing the choice and rationale of sources for gathering the papers, the search terms within the broader inclusion and exclusion criteria, as well as the development of the coding scheme.

2.1.1.1.1 Sources Used

For this review papers were sourced from the ACM Digital Library, in line with similar HCI reviews (Bopp & Voida, 2020). The review focused on papers published between January 2007 and September 2019, and consisted of the following stages outlined by Jesson and colleagues (Jesson et al., 2011).

Step	Method	No. of papers remaining	No. of papers removed
Collect papers	ACM Digital Library searches as described	912	-
Remove duplicates	Read titles	910	2
Remove workshops, proceedings, SIGs and panels	Read titles, searching for SIG, workshop, panel in abstracts	887	23
Remove papers out of scope of eating experiences	Read title and abstract	132	755
Code papers	Read full text	109	23 (15 Agenda setting + 8 outside of scope of criteria)

Table 2 Corpus collection and analysis steps detailing numbers of papers collected and then numbers which met the progressive application of criteria to identify the final 109 papers for analysis

2.1.1.2 Exclusion and Inclusion Criteria

Different search terms were used for the full text and for papers' keywords or abstracts. For full text search three main root words were used: "food", "interact*" and "design" to ensure sufficiently large breadth of papers, which was narrowed down through the following seven root words to search the papers' keywords or abstracts: "food*", "eat*", "tast*", "flavo*", "din*", "edibil*" or "tableware", which were considered relevant in the context of eating experiences and practices. This search returned 912 papers, from which 910 were unique.

By reading titles and searching abstracts for the terms: workshop, SIG, panel, proceedings, 23 papers were removed that did not report on new research, such as workshop proposals, SIGs or panels. This step resulted in 887 papers for. Then, through reading their titles and abstracts, further papers were kept mentioning the experience of eating food or food-like stimuli, and excluded papers mentioning experiences about food albeit without any direct consumption such as grocery shopping applications) or diet tracking apps, food journaling or eating disorders where the experiences of the eating food have not been considered. At this step, 755 papers were removed leaving 132. Then, the full text of these 132 papers was read by the first author, resulting in 23 further papers removed. From these, 8 papers did not fit the inclusion criteria of involving eating experiences and 15 papers were identified as agenda setting without user study or system design.

The outcomes of each of these steps were carefully between by the first and second author to ensure consistent use of the criteria. While previous reviews of Human-Food Interaction (HFI) research (Altarriba Bertran, Jhaveri, et al., 2019; Min et al., 2019) have used categories related to the interaction with food from sourcing and preparing, to waste disposal, this review focuses on papers that mention interaction involving eating experiences.

2.1.1.3 Development of a coding scheme

The coding scheme was iteratively developed through independent coding and extensive conversations between the first two authors. They also independently coded 10 papers which highlighted the need for more clarity in the definition of the following codes: those on body related to touch and flavour experience, the codes on the purpose of the system or eating experiences related to dining, sensitizing tools, and the codes on types of technology related to moving food and automated dispensing. These codes were further revised until complete agreement was reached, while aiming to produce as mutually exclusive groups as possible, each with internal cohesion.

As this review focuses on the experience of food in this writing it is useful to define two terms that have related but distinct meanings in the literature and are often confused in common usage: *taste* and *flavour*. Taste is the sensation of bitter, sweet, salty, sour or umami tastes by the tongue. Flavour is a complex multisensory experience of eating food that combines taste alongside smell, texture and other sensory inputs into a singular experience (such as 'chocolatey' or 'burnt').

The final scheme included three main families of codes capturing the relationship between food and human body ("Body code"), the purpose of the system or type of eating experience being designed for ("Purpose code") and the type of technology supporting these eating experience ("Technology code"). The rationale for these codes relates to the aim of the systematic review, namely, to uncover design knowledge around how the body and technology could be brought together through the experience of eating food. In particular, of these three families of codes were identified as the key elements of human-food-interaction, thus the focus on bodily aspects of human users, eating experience of food, and technology mediating the interaction between users and food. The specific codes under each family were identified and iteratively revised. For the body family, we identified two main groups of codes: a larger one reflecting food-based stimulation of external senses, traditionally used in HCI, alongside a smaller group indicating food-based stimulation of internal senses reflecting promising novel research directions. The purpose family contains four groups describing aspects of experience as well as four application domains. The third family includes two broader groups, those related to sensory augmentation and general technologies, respectively.

2.1.2 Systematic Literature Review Findings

This review starts by describing the relationship between the body and food, continue with the purposes of interacting with food in HCI, and conclude with the role of technology in leveraging bodily-based food experience for the each of these purposes. It starts with the body and the sensory experiences related to eating, followed by descriptions of each purpose code, reflecting on how the sensory experience is leveraged by designers. Finally, the findings turn to technologies and their use to leverage bodily experiences of eating for the specific purposes reported here.

2.1.2.1 Bodily Experiences of Eating

Code group	Body codes
External unimodal senses from eating experience	Taste (26)
	Smell (3)
	Visual (27)
	Audio (3)
	Touch, Mouth (8)
	Touch, Hand (4)
	Deprivation (0)
Senses integrated - external multisensory experience	Flavor, Food (13)
	Flavor, Drink (5)
	Flavor, Multisensory interfaces (8)
Internal senses	Digestion, metabolization (12)

Table 3 Body family codes and the weighting by papers (number of papers in brackets)

The systematic review outcomes highlight that human-food interaction experiences are sensory rich. However, their focus is not only on external senses of taste, smell, touch, sight and hearing, with the latter three being predominantly used in interaction design, but more importantly, also on internal senses related to digestion and metabolization which have been less explored in HCI research.

Findings indicate that human-food interactions support both unimodal and multisensory flavour experiences. Unimodal experiences include those where stimuli trigger single sensory pathways, i.e., taste stimulation through electric current applied to tongue (Hiromi Nakamura & Homei Miyashita, 2011) which in turn can be further used to impact other aspects of eating experience, i.e., manipulation of visual qualities of a cookie to increase satiety (Narumi et al., 2012). The most common stimuli used to design for unimodal external experiences of food were visual (n = 27 papers) and taste stimuli (n = 26). Taste sensation is relatively novel in HCI and is stimulated through two distinct pathways: food or drinks (n=16) and electronic stimulation (n=10). Interestingly, among the 5 basic tastes (bitter, salty, sour, sweet and umami), the reviewed work has focused on interactive systems leveraging only a few rather than each of the 5 tastes. For instance, sweet and sour were the most common tastes, explored in 20 and 19 papers respectively, bitter in 17, salty in 14 and umami in just 7. In contrast, only 6 papers considered experiences with all 5 tastes (Gayler & Sas, 2017a; Obrist et al., 2014a; Ranasinghe et al., 2013; Velasco et al., 2018; Vi, Ablart, et al., 2017; Vi et al., 2018), while 4 papers included them all except for umami (Huisman et al., 2016; Ranasinghe et al., 2012; Ranasinghe & Do, 2017; Velasco, Carvalho, et al., 2016). Moreover, sweet – sour, and sweet – bitter pairings were considered by only 4 (Bruijnes et al., 2016a; Moser & Tscheligi, 2013; Murer et al., 2013b; Q. J. Wang et al., 2017) and 3 (Carvalho et al., 2016; Gayler et al., 2019a; Mathiesen et al., 2019) papers, respectively, where they were often used to support contrasting experiences. The remaining 9 taste papers considered other combinations (Mesz et al., 2017; Nakamura & Miyashita, 2012; Ooba et al., 2018; Ranasinghe, Cheok, et al., 2011; Vi, Marzo, et al., 2017) or single tastes (Hiromi Nakamura & Homei Miyashita, 2011; Nakamura & Miyashita, 2011, 2013; Samshir et al., 2016).

Alongside taste the other chemical sense is smell (n=3) which has been more commonly used alongside taste and visual stimuli to stimulate multisensory rather than unimodal experiences, like for instance in VR systems showing mediated visualizations of food (Narumi, 2016; Narumi et al., 2011; Tuanquin, 2017). Visual (n=26) and audio (n=3) modalities of interaction are more common in HCI. Systems employing visual modality related to the shape of the food (n=16), or on subtly altering (n=11) its apparent size or colour in order to influence perception of satiety or flavour. Auditory systems often leveraged sound stimuli during eating, or their manipulation in order to influence the perception of flavour (Koizumi et al., 2011; Velasco, Carvalho, et al., 2016; Yan Wang et al., 2018). Haptic stimuli related to systems exploring haptic sensations in the mouth (n=8) and the hand (n=5). Mouth based haptic experiences relate not only to the perception of textural aspects of the food (Y. Lee et al., 2019), but also to its exploration through licking (Brueggemann et al., 2018) or thermal stimulation of the mouth through Peltier elements (Ranasinghe et al., 2012, 2013; Samshir et al., 2016; C. Suzuki et al., 2014). Hand-based food-body experiences involved manipulation of food while exploring novel forms of food (Hamanishi et al., 2018; Zhaochen, Ding Ting, 2017) and thermal stimulation of the mouth and lips while eating (Wei et al., 2012; Wei, Peiris, et al., 2011; Wei, Wang, et al., 2011).

In contrast with unimodal experiences, most of the papers on multisensory ones focus on *flavour*. Such papers involve the simultaneous stimulation of multiple sensory pathways, more often as taste and visual stimuli to create for instance lemony flavour from pure water colour using LED lights of yellow colour (Ranasinghe, Lee, & Do, 2014), or taste and thermal stimuli to create sweet tasting flavours (Samshir et al., 2016). Indeed, taste and visual stimuli were used together in 4 systems (Ranasinghe, Jain, et al., 2017; Ranasinghe, Lee, & Do, 2014; Ranasinghe, Lee, Suthokumar, et al., 2014a, 2014b) and then with smell in a further system (Ranasinghe, Nguyen, et al., 2017). Moreover, 2 systems paired taste with thermal stimuli (Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011) and only 1 integrated taste, thermal and smell stimuli together (Ranasinghe et al., 2015).

Within these multisensory interfaces taste, visual and thermal stimuli were predominantly digital such as electronic taste, lighting to manipulate colour, and Peltier modules; smell stimuli were predominantly chemical, i.e., volatile scents. Taste was stimulated in all 8 interactive systems (Ranasinghe et al., 2015; Ranasinghe, Jain, et al., 2017; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011; Ranasinghe, Lee, & Do, 2014; Ranasinghe, Lee, Suthokumar, et al., 2014a, 2014b;

Ranasinghe, Nguyen, et al., 2017), visual appearance in 5 (Ranasinghe, Jain, et al., 2017; Ranasinghe, Lee, & Do, 2014; Ranasinghe, Lee, Suthokumar, et al., 2014a, 2014b; Ranasinghe, Nguyen, et al., 2017), smell in 4 (Ranasinghe et al., 2015; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011; Ranasinghe, Nguyen, et al., 2017) and touch via thermal stimulation in 3 (Ranasinghe et al., 2015; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011).

Both unimodal and multisensory food-based experiences were predominantly triggered through chemical stimuli (food, n=10; drink, n=5), and to a lesser extent through a mix of chemical and electrical stimuli (n= 8). When food itself was used as stimuli, it consisted of a wide range of solid and semi-solid foodstuffs such as chocolate (Kehr et al., 2012; Y. Lee et al., 2019), ice-cream (Yan Wang et al., 2019), cotton candy (Hamanishi et al., 2018), carrots with sauce (Markéta Dolejšová & Lišková, 2015) and non-food materials such as concrete and fabrics (Brueggemann et al., 2018).

When drinks were used as stimuli, they consisted usually of concentrated sweet-flavoured drinks, such as energy drinks (Harley et al., 2018; Khot et al., 2015, 2015, 2014; Velasco, Carvalho, et al., 2016). For both the unimodal sensory and multisensory experiences, the interactive systems have focused mostly on augmenting them by increasing the intensity of the stimuli and its perception. Interestingly, no papers reported sensory deprivation of while interacting with food, although this has been shown as a valid avenue for intensifying the non-deprived senses, i.e., taste in the absence of sight (Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011). However, there have been attempts to stimulate sensory experience in the absence of chemical stimuli (i.e. without actually consuming food or drink) like in the case of electronic taste (Ranasinghe et al., 2015; Ranasinghe, Jain, et al., 2017; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011; Ranasinghe, Lee, & Do, 2014; Ranasinghe, Lee, Suthokumar, et al., 2014a, 2014b; Ranasinghe, Nguyen, et al., 2017).

Beside the predominant focus on external senses, fewer papers have explored internal ones pertaining to eating such as digestion and metabolization and associated sensations arising from chewing or licking. Internal senses have been explored by 13 papers, with 6 focusing on metabolization of food and how it is impacted by eating. The latter explored the provision of energy drinks in response to physical activity (Khot et al., 2015, 2015, 2014), experimental approaches that used bodily response to hack diets through soylent-type products (Marketa Dolejšová, 2016; Markéta Dolejšová & Kera, 2017) and the impact of chocolate on cognition and mood (Hwang et al., 2018). In addition, 3 papers focused on digestion through a sensory informed experimental approach (Marketa Dolejšová, 2016; Markéta Dolejšová & Kera, 2017) to food allergies (Karkar et al., 2017), while the other two focused on gut as a space for gaming; one used VR to create a visualization of digestions relation to chewing (Arza et al., 2018), while the other used ingestible sensors as input devices for gameplay (Brandmueller & Li, 2017). Chewing, as a key component of digestion, was the focus of 3 papers; the previously mention VR game that prompt chewing to support digestion (Arza et al., 2018) and two further gaming experiences, one used chewing as input (Arnold et al., 2018) (echoing the digestion input approach above) and one aimed at rehabilitation for those with facial injuries (Y.-X. Wang et al., 2014). Not at least, licking as another component of digestion was explored by 2 papers. One used the tongue provocatively, to explore non-edible environments and materials (Brueggemann et al., 2018), while the other framed licking as a playful act (Yan Wang et al., 2019). These papers are provocative in framing the inside of human body as alternative site for interaction. Although less explored , such work opens up opportunities to focus on interoceptive experiences marking an emergent HCI interest related to body (Alfaras et al., 2020; Höök, 2018).

2.1.2.2 The Purposes of Human-Food-Interactions in HCI

Now described are the purposes of HFI-based systems. The findings identified 13 such purposes, including 9 related to novel design of eating experience, and 4 related to specific application domains for such experiences.

The former 9 purposes can be broadly grouped in those focusing on novel sensory, emotional, cognitive and social aspects of eating experiences. The novel sensory purposes include New *taste stimulation (n = 15), Internal flavour* which draws on the sensory experience of the food to create flavour experience *(n = 19)* and *External flavour* which combines sensory information from outside and within the food to create flavour experience *(n = 9).* The novel emotional aspects explore *Play (n = 28) and Emotion (n = 7).* The two cognitive aspects include *Data edibilization (n = 12)* and *Storytelling (n = 6), while Social* purpose is reflected in 15 papers. The four application domains are *Dining* (n = 14), *Persuasive technology for healthy eating* (n = 20), *Tools for sensitizing people towards eating experience* (n = 7) and *Assistive technologies* (n = 5). Each of these purposes is described in detail in the following sections.

Code group	Purpose codes
Sensory aspects of eating experiences	New taste stimulation (15)
	Internal flavor (19)
	External flavor (9)
Emotional aspects	Emotion—taste/flavor link (7)
	Play (28)
Cognitive aspects	Storytelling (6)
	Data edibilization (12)
Social aspects	Social (15)
Application Domains	Dining (14)
	Persuasive tech for healthy eating (20)
	Tools for sensitizing (7)
	Assistive tech (5)

Table 4 Code groups and codes for purpose family codes

2.1.2.2.1 Sensory aspects of eating – New taste stimulation

An important outcome is that many interactive systems have been designed with the explicit purpose of supporting novel taste stimulation as explored in 15 papers (Hiromi Nakamura & Homei Miyashita, 2011; Huisman et al., 2016; Mathiesen et al., 2019; Nakamura & Miyashita, 2011, 2013; Narumi et al., 2010; Obrist et al., 2014a; Ooba et al., 2018; Ranasinghe, Cheok, et al., 2011; Ranasinghe et al., 2012, 2013; Ranasinghe & Do, 2017; Samshir et al., 2016; Velasco, Carvalho, et al., 2016; Q. J. Wang et al., 2017). These systems aim to create or augment such novel taste experiences, to increase pleasure thorough novel taste or novel food forms and their texture. A large body of work in this space is on electronic taste devices which stimulate taste sensation in the absence of chemical stimuli which could significantly extend the reach of taste-based interactions. Two thirds of these papers (10/15) use electric taste stimulation which can be broadly grouped in 3 types of devices which they all work by using the flow of electric current to stimulate the taste sensation. The first and most common type uses a bespoke tongue probe to apply electric current to the tongue (Ooba et al., 2018; Ranasinghe, Cheok, et al., 2011; Ranasinghe et al., 2012, 2013; Ranasinghe & Do, 2017; Samshir et al., 2016). The second type uses a single pole apparatus, such as a fork or chopstick in which current passes through the mouth and body via a second contact point of the hand holding the implement (Hiromi Nakamura & Homei Miyashita, 2011; Nakamura & Miyashita, 2011, 2013). The third type uses a device with two opposite polarity probes for instance as part of a straw, with the tongue used to connect the circuit (Hiromi Nakamura & Homei Miyashita, 2011; Nakamura & Miyashita, 2013). The systems that use chemical stimuli for taste experience rely on manipulating taste experience of a base food or drink by through changing the colour through lighting (Huisman et al., 2016; Narumi et al., 2010) or by listening to specific music during eating (Mathiesen et al., 2019; Velasco, Carvalho, et al., 2016; Q. J. Wang et al., 2017).

While most of papers in this section focus on technical challenge of delivering or augmenting taste experiences, a few have started to consider how this might be leveraged for wider purposes including the temporal, affective and embodied aspects of taste (Obrist et al., 2014a) or how changes in taste through electric stimulation can be used at a distance to support social communication (Nakamura & Miyashita, 2011; Ranasinghe et al., 2012; Samshir et al., 2016). Whilst eating experiences are sites for social interaction, this approach uses the eating itself to support social communication in a new sensory way. The next two sections look at the integrated multisensory experience of flavour, extending the findings on new taste stimulation.

2.1.2.2.2 Sensory aspects of eating – Internal flavor

This theme relates to the flavour experience of food. Flavours are described by words like ‘chocolatey’, coffee or meaty and consists of the integration of different sensory inputs (taste, smell, sight, hearing, touch, digestion, metabolization). By augmenting one or more of the external sensory pathways when eating food, the flavour can be changed. Findings show that 20 papers support this aim (Bruijnes et al., 2016a; Carvalho et al., 2016; Koizumi et al., 2011; Y. Lee et al., 2019; Narumi, 2016; Narumi et al., 2010, 2011; Ranasinghe et al., 2013, 2015; Ranasinghe, Jain, et al., 2017; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011;

Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011; Ranasinghe, Lee, & Do, 2014; Ranasinghe, Lee, Suthokumar, et al., 2014a, 2014b; Ranasinghe, Nguyen, et al., 2017; Velasco et al., 2018; Yan Wang et al., 2018; Wei, Wang, et al., 2011; Zoran & Cohen, 2018), 16 of which aimed solely at producing flavour experiences, while the other 4 create flavour in support of a specific application such as persuasive tech for healthy eating (Narumi, 2016). 9 of these 16 papers describe systems using electric taste integrated with other senses, such as sight to manipulate the appearance of drinks' colour through LED lights (e.g. (Ranasinghe, Lee, & Do, 2014)), smell through added scents, (e.g. (Ranasinghe, Nguyen, et al., 2017)), or hearing by manipulating the sound of eating experience (Carvalho et al., 2016; Koizumi et al., 2011; Yan Wang et al., 2018) in order to influence the perception of flavour. For example, the feeling of food 'crunchiness' is augmented by amplifying the sound of chewing (Koizumi et al., 2011), or the appearance of food and thus the flavour or resulting satiety is augmented through VR (Narumi, 2016; Narumi et al., 2011), the flavour of food through lighting (Bruijnes et al., 2016a; Narumi et al., 2010) or texture of food through food printing (Wei, Wang, et al., 2011). Other approaches to designing flavour experiences came from 3D food printing focusing on novel texture and their impact on flavour (Y. Lee et al., 2019) or tailored digitally designed moulds for personalized flavour experiences (Zoran & Cohen, 2018).

The limited focus of these systems on personalization is surprising, suggesting untapped potential of future work to better support them. Although flavour was mostly used to support pleasurable user experiences, i.e., something that "tastes nice", it was also used to transgress acceptance or palatability at times to challenge the user and create more complex interactive dynamics, aiming for 'interesting experiences' not just 'happy' ones (Velasco et al., 2018). It is surprising that only two papers explicitly considered dining contexts (Bruijnes et al., 2016a; Wei, Wang, et al., 2011), where augmentation of flavour took place as part of table-based eating experiences. This perhaps indicates the challenge of designing interactive flavour augmentation systems without disrupting the dining experience itself.

2.1.2.2.3 Sensory aspects of eating – External flavor

Whilst the previous section looked at flavour experiences informed solely by foodstuff itself, the papers in this section examine how flavour experiences are informed not only by foodstuff but also by additional external stimuli within the environment in which the food is eaten.

Findings indicate 9 papers (Carvalho et al., 2016; Mathiesen et al., 2019; Mesz et al., 2017; Nakamura & Miyashita, 2012; Nishizawa et al., 2016; C. Suzuki et al., 2014; Velasco, Carvalho, et al., 2016; Wei et al., 2012; Wei, Peiris, et al., 2011) that explore how environmental stimuli impact flavour experiences, making them more enjoyable and usually in dining contexts. From the 9 identified papers, 4 papers focus on music sound to influence perception of flavour (Carvalho et al., 2016; Mathiesen et al., 2019; Mesz et al., 2017; Velasco, Carvalho, et al., 2016), exploring for example the impact of different music tracks varying in pitch and volume on the perception of chocolate's taste and texture (Carvalho et al., 2016). Two papers report on predefined audio stimuli that is created to achieve specific outcomes in relation to the appreciation of flavour qualities of the food (Carvalho et al., 2016; Velasco, Carvalho, et al., 2016). For example, a Brazilian cocoa praline eaten to the music of a Brazilian composer or a field recording of the kitchen in which the chocolate was made (Carvalho et al., 2016). All of the above applications rely on users' exposure to such ambient sound whilst eating. There are two papers however that grant greater agency to the user as they are able to generate and modulate sounds themselves through the act of drinking (Mathiesen et al., 2019; Mesz et al., 2017). However, none of these systems supports the user to deliberately construct the audio experiences themselves, merely to have a degree of control in triggering the playback of the audio. It can be imagined how audio could be selected much like a wine pairing with active engagement and consideration of the user.

Most of these papers explore sound stimuli to enhance the experience of flavour, through traditional ambient audio (Carvalho et al., 2016; Mathiesen et al., 2019; Mesz et al., 2017; Velasco, Carvalho, et al., 2016) such as music (Carvalho et al., 2016; Velasco, Carvalho, et al., 2016). Visual stimuli were used to change the visual appearance of the food itself for instance through 3D food printing alongside thermal-haptic experiences as part of multisensory remote connection interactions (Wei et al., 2012; Wei, Peiris, et al., 2011), and in particular through colour washes projected on top of 3D printed food to influence the perception of flavour by augmenting the appearance of colour of the food (Nishizawa et al., 2016). The papers in this group shown the exploration of flavour both for its own ends (Carvalho et al., 2016; Mathiesen et al., 2019; Nakamura & Miyashita, 2012; Nishizawa et al., 2016; C. Suzuki et al., 2014; Velasco, Carvalho, et al., 2016) as well as part of social dining contexts (Wei et al., 2012; Wei, Peiris, et al., 2011) and playful experiences (Mesz et al., 2017). This indicates that flavour experiences can be appreciated in isolation, but within broader social contexts. It is envisaged that as such technologies mature, there will be more systems focused on sensory aspects increasingly integrated in social contexts.

2.1.2.2.4 Sensory aspects of eating – Playfulness

This group consists of 28 papers (Arnold et al., 2018; Arza et al., 2018; Brandmueller & Li, 2017; Brueggemann et al., 2018; Bruijnes et al., 2016a; Y.-Y. Chen et al., 2018, 2019; Chia & Saakes, 2014; Döring et al., 2013; Ganesh et al., 2014; Hamanishi et al., 2018; Ibáñez, 2015; Joi et al., 2016; Kadomura et al., 2014; Kadomura, Li, et al., 2013; Khot et al., 2015, 2015, 2014; Lo et al., 2007; Mesz et al., 2017; Moser & Tscheligi, 2013; Murer et al., 2013b; Read & Sim, 2014; Vi, Ablart, et al., 2017; Vi et al., 2018; Vi, Marzo, et al., 2017; Yan Wang et al., 2019; Wei, Peiris, et al., 2011) that focus on the use of food as part of playful eating experiences from structured game-play to more open ended ones. Interestingly, many of them 12/28 take place in dining contexts where the meal rituals traditionally emphasize the civility (Elias, 1978) and aesthetics of eating rather than its playfulness or sensory aspects (Marshall, 2005). The others 16/28 focus on play while snacking in home or work contexts. These papers provide an interesting lens into how HFI contributes to more informal dining practices. Almost half of the papers focusing on playfulness (12/28) explore interactive systems for dining or particularly as persuasive technology for healthy eating (9/12), both through game-based and open-ended play for example to encourage children to eat all their food (Ganesh et al., 2014). One sensory modality that is emphasized within playfulness systems is audio. Here, 3 papers use audio outputs from eating experiences, i.e., crunching, not for the purposes of supporting the flavour experience but as separate playful experience. Each relies on electrical conductance to cue the interactive experience, and while two papers (Döring et al., 2013; Yan Wang et al., 2019) use conductance through the food material such as jelly (Döring et al., 2013) and ice-cream (Yan Wang et al., 2019), the other uses conductance via a mouthpiece of a drinking device (Mesz et al., 2017) allowing the users to 'play' music through interacting with it.

12 papers report on structured, rules-based gaming applications (Arnold et al., 2018; Arza et al., 2018; Brandmueller & Li, 2017; Ibáñez, 2015; Joi et al., 2016; Kadomura et al., 2014; Kadomura, Li, et al., 2013; Lo et al., 2007; Moser & Tscheligi, 2013; Murer et al., 2013b; Read & Sim, 2014; Vi, Ablart, et al., 2017; Vi et al., 2018) using for instance the eating of healthy food to progress in a mobile game (Arnold et al., 2018; Kadomura, Li, et al., 2013) or playing a video in which sweet or bitter tasting liquids are an output from the gameplay (Moser & Tscheligi, 2013; Murer et al., 2013b). In contrast, the open-ended games support more exploratory approaches where users have a high level of agency in the direction of the experience, such as creating music through interaction with the foodstuff or drinking device (Mesz et al., 2017; Yan Wang et al., 2019). One approach that diverges from this, requires the user to construct their own, rule-based games from food (Ibáñez, 2015). Food itself has also been used as both input and output in the playful experiences. Food is used as input in a variety of ways; through lollipop as joystick (where physical movement is captured) (Moser & Tscheligi, 2013; Murer et al., 2013b), as a capacitive material that becomes interactive when touched and licked (Yan Wang et al., 2018, 2019) and as a material to be chewed, the chewing action being captured as input control for the game (Arnold et al., 2018).

Video games are used as contexts for exploring the role of food in game-based playful experiences, both as input and output (Arnold et al., 2018; Chisik et al., 2018; Ibáñez, 2015; Moser & Tscheligi, 2013; Murer et al., 2013b; Vi et al., 2018), ranging from *Minesweeper* system using a mouthpiece for delivering tastes as feedback in play (Vi et al., 2018) to bespoke VR/AR (Arnold et al., 2018; Arza et al., 2018) game environments. Food has been also used in both physical and mixed reality gaming contexts (Ibáñez, 2015). A key technology for supporting the use of food as output in video games is the delivery of the stimuli, mostly in the form of pumped liquids into a mouthpiece (Moser & Tscheligi, 2013; Murer et al., 2013b; Vi et al., 2018). Capacitive sensing and translating into sounds output underpin three open-ended play examples (Döring, 2016; Mesz et al., 2017; Yan Wang et al., 2019).

Another interesting finding is that over a third of the papers (8/28) leveraging gamification principles focus on internal senses of digestion and metabolization. This include for instance VR based games aimed to visualize, increase awareness of slow chewing and digestion through competitive gameplay against another diner (Arnold et al., 2018; Arza et al., 2018), or ingestible sensors which score points in gameplay based on gut temperature (Brandmueller & Li, 2017). Digestion also involves the act of licking whose ludic aspect has been explored particularly with foodstuff such as ice cream (Yan Wang et al., 2019) (Brueggemann et al., 2018). With regard to metabolization of food, 3 papers focus on the relation between food as fuel and exercising is reflected in playful edibilizations of tracked fitness data through an elaborate fountain that mixes sports drinks in response to heartrate (Khot et al., 2015, 2015, 2014), to be also used for collaborative play (Khot et al., 2014). Playfulness systems usually draw on taste as shown in 7 papers (Bruijnes et al., 2016a; Mesz et al., 2017; Moser & Tscheligi, 2013; Murer et al., 2013b; Vi, Ablart, et al., 2017; Vi et al., 2018; Vi, Marzo, et al., 2017) where feedback is delivered both through the presence and absence of stimuli (Murer et al., 2013b) as well as the taste of the stimuli (Moser & Tscheligi, 2013; Murer et al., 2013b; Vi et al., 2018), drawing on the relationship between emotions and tastes explored in the following section.

2.1.2.2.5 Emotional aspects of eating – Emotion

Emotions and eating experiences are strongly connected and 7 papers explore this relationship (Gayler et al., 2019a; Gayler & Sas, 2017a; Hwang et al., 2018; Moser & Tscheligi, 2013; Murer et al., 2013b; Obrist et al., 2014a; Vi et al., 2018). Most of these (6/7) report on the emotional valence and specific taste, particularly the association of bitter tastes with negative emotions and its value in interaction design (Gayler et al., 2019a; Gayler & Sas, 2017a; Moser & Tscheligi, 2013; Murer et al., 2013b; Obrist et al., 2014a; Vi et al., 2018). The other paper focuses on the emotional experience associated with flavour such as those triggered by comfort foods and their positive impact on mood (Hwang et al., 2018). In addition, the potential of food for regulating emotions has been explored both at individual (Hwang et al., 2018) and dyadic level, i.e., co-regulation of emotions (Gayler et al., 2019a).

From the 7 papers focusing on the relationship between taste and emotional valence, 2 papers consider how taste might be better leveraged by designers of interactive systems (Gayler & Sas, 2017a; Obrist et al., 2014a). Furthermore, 2 papers build on this relationship in interactive systems such as those for communication of affective content to users (Gayler et al., 2019a) or for supporting mood boosting through food (Hwang et al., 2018). The another 3 papers explore it within gaming contexts, using for instance tastes such as sweet and bitter to provide positive and negative feedback, respectively, during gameplay (Moser & Tscheligi, 2013; Murer et al., 2013b; Vi et al., 2018). All gameplay devices that were reviewed rely on pumped liquid stimuli, with liquid stimuli used in (Obrist et al., 2014a), solid food in (Hwang et al., 2018), and 3D printed stimuli in (Gayler et al., 2019a). For instance, pumped liquids are used in LOLLio system (Murer et al., 2013b) where a lollipop-type device is both an input and output device; as a joystick in the mouth and, and as delivery tool for pumped liquid taste stimuli. While liquid stimuli have been commonly used for taste-based interactions, given their limited texture and therefore increased control over the flavour experiences, 3D printed food have also emerged as an alternative to solid form taste stimuli (Gayler et al., 2019a) allowing the exploration of other aspects of flavour besides taste such as texture and appearance.

2.1.2.2.6 Cognitive aspects of eating – Storytelling

An interesting finding is the specific focus on storytelling through eating experiences reflected in 6 papers (Abeyrathne et al., 2010; Bruijnes et al., 2016a; Markéta Dolejšová & Lišková, 2015; Harley et al., 2018; van Gennip et al., 2015; Velasco et al., 2018). Most of these papers explore how foodstuff can be used to capture (van Gennip et al., 2015), communicate (Bruijnes et al., 2016a; Harley et al., 2018; Velasco et al., 2018) or capture and communicate (Markéta Dolejšová & Lišková, 2015) both personal (Markéta Dolejšová & Lišková, 2015; van Gennip et al., 2015) and collective stories (Bruijnes et al., 2016a; Harley et al., 2018; Velasco et al., 2018). For example, *Streetsauce* is an interactive system that supports users to create recipes based on ingredients as autobiographical foodstuff matched to their personal narratives of homelessness ad, in (Markéta Dolejšová & Lišková, 2015). Other systems also emphasized the performative aspect of eating-based storytelling inspired by multi-sensorial theatre combining audio, visual and edible stimuli (Bruijnes et al., 2016a), multi-sensory film (Velasco et al., 2018) or VR experiences (Harley et al., 2018). While the work descried above target users as story tellers, 3 papers take the approach where the audience (Bruijnes et al., 2016a; Harley et al., 2018; Velasco et al., 2018) engages in eating experiences during storytelling . Three papers use food to allow a person to narrate a personal story, either to oneself (van Gennip et al., 2015) or to another (Abeyrathne et al., 2010; Markéta Dolejšová & Lišková, 2015). For instance, a remote food printing system supports remote grandparents telling culturally significant stories through food to their grandchildren (Abeyrathne et al., 2010).

2.1.2.2.7 Cognitive aspects of eating – Data edibilization

An interesting set of 12 papers focuses on *data edibilization* or data communication through food (Henze et al., 2015; Khot et al., 2017, 2015, 2015, 2014; Khot, Pennings, et al., 2015a, 2015c; F. 'Floyd' Mueller, Kari, et al., 2018; Patekar et al., 2018; Patekar & Dudeja, 2017; Rüst, 2014; Yun Wang et al., 2016) where food that is eaten is used to explicitly visualize and communicate data. Often such data is tracked data on bodily practice such as users' physical activities, taking the form of messages printed out on edible materials (e.g. in chocolate (Khot et al., 2017)). Data can also be printed in edible inks onto food (Rüst, 2014) or laser cut onto the surface of food (Henze et al., 2015). The aim of data edibilization is usually to support to support deeper user engagement or as they may eat the food on which the data is communicated and reflect on its meaning.

An illustrative example is *Edipulse* (Khot et al., 2017; Khot, Pennings, et al., 2015a, 2015c) producing chocolate to communicate data about user's completed physical activity, reward it as the same time, l indicating the potential for multiple layers of meaning within data edibilization. Several such systems [85,87–91,113] focused on tracked calory data on physical energy expenditure during exercise abstracted into digital format, reproduced in a physical, edible format, and then consumed by the originator of the data. The act of eating adds a multisensorial aspect, creating a richer, more embodied experience of data that contrasts with its traditional, limited physical form. This creates an interesting loop, particularly in the case of physical activity (Khot et al., 2017, 2015) where food or drinks such as isotonic sports drinks are used both as reward for the previous running session and as fuel for the next one (Khot et al., 2015, 2015, 2014). Beside tracked fitness data, the information being communicated also includes food-centric data such as nutritional information (Henze et al., 2015), as well as food unrelated data such as personal, CV like information (Patekar et al., 2018; Patekar & Dudeja, 2017) or data on gender inequality in tech (Rüst, 2014).

The form of food is the most important quality that is manipulated in this group of papers. Foodstuff that can be easily shaped such as chocolate (Khot et al., 2017; Khot, Pennings, et al., 2015a, 2015c) or doughs (Patekar et al., 2018; Patekar & Dudeja, 2017) are prioritized, with melting points that are not much above room temperature or that have material characteristics allowing them to flow under small amounts of pressure. As mentioned above, the foodstuff itself is selected for a particular meaning, such as chocolate as reward (Khot et al., 2017; Khot, Pennings, et al., 2015a, 2015c; F. 'Floyd' Mueller, Kari, et al., 2018) or isotonic drinks to refuel (Khot et al., 2015, 2015, 2014), albeit more often, the specific type of foodstuff is not deliberately considered (Patekar et al., 2018; Patekar & Dudeja, 2017), although more often they are sugary, much preferred foods such as chocolate (Khot et al., 2017; Khot, Pennings, et al., 2015a, 2015c) fried sweet doughs (Patekar et al., 2018; Patekar & Dudeja, 2017) or sweet pies (Rüst, 2014) likely to boost engagement rather than support specific flavour experience (Khot et al., 2017, 2015, 2015, 2014 ; Khot, Pennings, et al., 2015c, 2015a ; F. 'Floyd' Mueller, Kari, et al., 2018 ; Patekar et al., 2018 ; Patekar & Dudeja, 2017). Also related to form is the focus of 11 papers on the precise delivery of food's amount, either though through pumped liquids (Khot et al., 2015, 2015, 2014) or food printing, both 2D (Khot et al., 2017; Khot, Pennings, et al., 2015c, 2015a; F. 'Floyd' Mueller, Kari, et al., 2018; Patekar et al., 2018; Patekar & Dudeja, 2017; Rüst, 2014) and 3D (Yun Wang et al., 2016). Also in the context of form, beside whole foodstuff being used to communicate data, 11 papers explored food surfaces as spaces for communication (Henze et al., 2015). This approach maintains the foodstuff's form but uses laser cutting to inscribe visual information onto the food itself.

2.1.2.2.8 Social aspects of eating – Social

The final set of 14 papers covers the social aspects of eating experiences (Arza et al., 2018; Bruijnes et al., 2016a; Khot et al., 2019; Korsgaard et al., 2019; Mehta et al., 2018; Mitchell et al., 2015; Nakamura & Miyashita, 2011; Nawahdah & Inoue, 2013; Ranasinghe et al., 2012; Samshir et al., 2016; Wei et al., 2012, 2014a; Wei, Peiris, et al., 2011; Wei, Wang, et al., 2011). These papers cover three main social aspect namely commensal, communicative, and co-operative. Papers with commensal social aspects (Bruijnes et al., 2016a; Khot et al., 2019; Korsgaard et al., 2019; Nawahdah & Inoue, 2013; Wei et al., 2012; Wei, Peiris, et al., 2011; Wei, Wang, et al., 2011) share similarities with pre-exiting HCI work on technologies for commensality (Comber et al., 2014a; Ferdous et al., 2016a), but they particularly use technology to leverage the eating experiences for social bonding, instead of merely supporting the social contexts of eating. Here there is for instance companion robots for dining with (Khot et al., 2019), VR systems for eating together with remote strangers as dining elderly partners (Korsgaard et al., 2019), or video conference-based interactive system supporting time-shifting co-dining so that people can remotely share dinner with their loved ones, whose dining experiences have been previously recorded at an earlier time zone(Nawahdah & Inoue, 2013).

Papers supporting communicative social aspects also focus on eating together remotely by supporting co-diners to communicate via messages on 3D printed food or video links (Wei et al., 2012; Wei, Peiris, et al., 2011; Wei, Wang, et al., 2011).These papers also support social communication during eating experiences outside of the dining context, for instance through messages in workplace in the form of cookies as 3D printed food (Wei et al., 2014a), whilst other systems explored the link between emotions and taste in order to support more emotional communication during eating experiences. (Nakamura & Miyashita, 2011; Ranasinghe et al., 2012; Samshir et al., 2016). Such systems open up interesting design opportunities for public-private communication where the messaged embedded in food, while publicly visible, are privately experienced as only the receiver eats them.

Papers supporting co-operative eating (Arza et al., 2018; Mehta et al., 2018; Mitchell et al., 2015; Nawahdah & Inoue, 2013) involve at least two co-diners who have to work together so that each one can enjoy a technologically mediated eating experience. Examples include robotic arms for feeding each other (Mehta et al., 2018), VR games controlled by chewing (Arza et al., 2018) or interactive table which influences the eating speeds of two diners by tilting, to guide them towards similar speed. in which case, the table is balanced (Mitchell et al., 2015).

2.1.2.2.9 Social aspects of eating – Social

The final set of 14 papers covers the social aspects of eating experiences (Arza et al., 2018; Bruijnes et al., 2016a; Khot et al., 2019; Korsgaard et al., 2019; Mehta et al., 2018; Mitchell et al., 2015; Nakamura & Miyashita, 2011; Nawahdah & Inoue, 2013; Ranasinghe et al., 2012; Samshir et al., 2016; Wei et al., 2012, 2014a; Wei, Peiris, et al., 2011; Wei, Wang, et al., 2011). These papers cover three main social aspect namely commensal, communicative, and co-operative. Papers with commensal social aspects (Bruijnes et al., 2016a; Khot et al., 2019; Korsgaard et al., 2019; Nawahdah & Inoue, 2013; Wei et al., 2012; Wei, Peiris, et al., 2011; Wei, Wang, et al., 2011) share similarities with pre-exiting HCI work on technologies for commensality (Comber et al., 2014a; Ferdous et al., 2016a), but they particularly use technology to leverage the eating experiences for social bonding, instead of merely supporting the social contexts of eating. Here there is for instance companion robots for dining with (Khot et al., 2019), VR systems for eating together with remote strangers as dining elderly partners (Korsgaard et al., 2019), or video conference-based interactive system supporting time-shifting co-dining so that people can remotely share dinner with their loved ones, whose dining experiences have been previously recorded at an earlier time zone(Nawahdah & Inoue, 2013).

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(Mehta et al., 2018), VR games controlled by chewing (Arza et al., 2018) or interactive table which influences the eating speeds of two diners by tilting, to guide them towards similar speed. in which case, the table is balanced (Mitchell et al., 2015).

2.1.2.3 Technologies to Support Eating Experiences in HCI

Now reported are the different types of technologies designed and developed to support eating experiences in HCI research. These technologies relate to the different identified purposes for human-food interactions, so they are described for each of these purposes.

A large number of technologies (58 uses across 29 papers, with some papers use one or more sensory technology) support the sensory aspects of the eating experience, namely taste, smell, sight and hearing. The second largest group of technologies target the creation of novel forms of foodstuff in order to support emotional and communicative experiences (25) as well as play (7 papers). A third group of technologies for remote connection (10 papers) and interactive dining tools (23 papers) directly support persuasive technologies for healthy eating (16/23), while self-tracking apps support monitoring of eating experiences for healthy eating (6). Further technologies are used for a range of experiential purposes and control delivery of food or the movement of food through space as part of eating experiences (9 automated dispensing, 10 moving food). There are also a group of papers which use technology *indirectly* related to eating experiences (10 papers).

Technology codes
Electronic Taste (18)
Smell-based interfaces (4)
Thermal (7)
AR/VR (10)
Visual (9)
Audio, Ambient (7)
Audio, Internal (3)
Food as input (2)
Novel formats (25)
Remote connection (10)
Interactive dining tools (23)
Automated dispensing (9)
Moving food (10)

Table 5 Technology codes

2.1.2.3.1 Technologies augmenting sensory aspects for more pleasurable and healthier eating experiences

Technology that augments sensory experiences of eating food focus predominantly on sensory stimulation of basic tastes (Ranasinghe, Cheok, et al., 2011), although work on supporting other purposes such as communication through taste has also started to emerge (Nakamura & Miyashita, 2011). Most technologies for sensory stimulation focus on taste stimulation and in particular electronic taste (18 papers) intended to create taste experiences albeit without any chemical food stimuli (Hiromi Nakamura & Homei Miyashita, 2011; Nakamura & Miyashita, 2011, 2012, 2013; Ooba et al., 2018; Ranasinghe, Cheok, et al., 2011; Ranasinghe et al., 2012, 2013, 2015; Ranasinghe, Jain, et al., 2017; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011; Ranasinghe, Lee, & Do, 2014; Ranasinghe, Lee, Suthokumar, et al., 2014a, 2014b; Ranasinghe, Nguyen, et al., 2017; Ranasinghe & Do, 2017; Samshir et al., 2016). In contrast to chemical stimuli requiring reservoirs of tastants to be ongoingly refilled after use which raises challenges for their deployment in naturalistic settings, electronic taste stimuli are easier to deploy but they remain limited in the sensations they can create, with none being observed to support all 5 basic tastes. A range of variables are involved in the design of electronic taste, including the use of cathodic (e.g. (Nakamura & Miyashita, 2013)) and anodic (e.g. (Ranasinghe et al., 2012)) tongue probes, manipulation of current and frequency (e.g. (Ranasinghe et al., 2013)), and location of stimulation on top or below the tongue (e.g. (Ranasinghe et al., 2013)). An interesting potential of this technology is leveraging the link between taste and emotions (Gayler et al., 2019a; Obrist et al., 2014a) in order to better support taste-based emotional communication, increasing the enjoyment of multisensory experiences (Nakamura & Miyashita, 2011).

One limitation of electronic taste devices is the discomfort of using them or lingering aftertaste (Ranasinghe & Do, 2017), and that beside sweet and sour which are the most common electronic tastes, other tastes, such as salty and bitter have been less explored through such devices (Ranasinghe & Do, 2017). The assumption behind electronic taste devices is their potential to support healthier eating by swapping out sugary drinks for water drunk with augmented electronic taste (e.g. (Ranasinghe, Lee, & Do, 2014;

Ranasinghe, Lee, Suthokumar, et al., 2014a)) or reducing salt content by electronically creating salty tastes (Nakamura & Miyashita, 2013). However, such potential has been limitedly realized, given the reduced acceptability of electronic taste systems and ability to deliver the full range of taste sensations. This perhaps explains the trend towards leveraging such devices for communication purposes (Nakamura & Miyashita, 2011; Ranasinghe et al., 2012; Samshir et al., 2016) so that this added value counterbalance their limitations.

Beside taste, the sense of smell also contributes significantly to flavour experiences (Spence, 2010). However, in contrast to the emphasis on taste, technologies augmenting the sense of smell for eating experiences have been less explored. Interestingly, the limited research on smell interfaces focused on chemical-based ones, commonly used in conjunction with electronic taste (Ranasinghe et al., 2015; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011; Ranasinghe, Nguyen, et al., 2017), and occasionally with thermal and visual stimuli, with the intention of supporting the construction of flavour experiences without consumption of food, or the consumption of healthier but less flavoursome alternatives. One explanation for the limited focus on smell-based interfaces is that their chemical stimuli tend to consist of foodstuff such as chocolate ((Khot et al., 2017; Y. Lee et al., 2019)) or sports drinks (e.g. (Khot et al., 2014)) rather than actuators or delivery systems. Thermal actuators, such as Peltier modules are more common than smell stimuli, with 7 papers using them to deliver warmth or coolness to the area around the mouth in order to influence the perception of flavour (Ranasinghe et al., 2012, 2013, 2015; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011; Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Ponnampalam, 2011; Samshir et al., 2016; C. Suzuki et al., 2014). The exploration of thermal actuators in our reviewed work tends to be coupled with that of taste, and future work can focus on its potential to support emotional and communication purposes (Wilson & Brewster, 2017).

The visual stimuli for augmenting eating experiences involved mostly Virtual or Augmented Reality (VR/AR) as shown in 10 papers (Arnold et al., 2018; Arza et al., 2018; Harley et al., 2018; Korsgaard et al., 2019; Narumi, 2016; Narumi et al., 2012, 2011; E. Suzuki et al., 2014; Tuanquin, 2017; Y.-X. Wang et al., 2014). The input into most of these systems consisted of photos of food (8/10) and less so images of objects such as plates (E. Suzuki et al., 2014) or people physically chewing virtual images of food (Y.-X. Wang et al., 2014). The output of these system consists of manipulated images of food through the VR/AR technology, either by themselves or in combination with smell stimuli. This suggests similarities between how AR/VR technologies and electronic taste systems are used, the former drawing on the visual, the latter on the taste modality, with both being extended by integrating also smell stimuli. More traditional visual augmentation through images on 2D screens is reported in 8 papers (Huisman et al., 2016; Narumi et al., 2010; Nishizawa et al., 2016; Ranasinghe, Jain, et al., 2017; Ranasinghe, Lee, & Do, 2014; Ranasinghe, Lee, Suthokumar, et al., 2014a, 2014b; Ranasinghe, Nguyen, et al., 2017). Most of these papers manipulate the appearance of food colour to influence the flavour perception. For instance, they use yellow, green and white lights to simulate different lemonade flavours (Ranasinghe, Jain, et al., 2017), multicolour RGB LED modules controlled by the users (Narumi et al., 2010; Ranasinghe, Lee, & Do, 2014; Ranasinghe, Lee, Suthokumar, et al., 2014a, 2014b; Ranasinghe, Nguyen, et al., 2017) to select the colour lights for colouring drinks as part of systems supporting electronic taste (Narumi et al., 2010; Ranasinghe, Jain, et al., 2017; Ranasinghe, Lee, & Do, 2014; Ranasinghe, Lee, Suthokumar, et al., 2014a, 2014b; Ranasinghe, Nguyen, et al., 2017), whilst others use projection of red, green, grey (Huisman et al., 2016) and brown, green purple colour as well as hue and chroma (Nishizawa et al., 2016) to manipulate lighting onto solid foods (Huisman et al., 2016; Nishizawa et al., 2016). The intention is to manipulate flavour experiences to become more pleasurable (e.g. (Nishizawa et al., 2016)) or to allow swapping to healthier foods whilst maintaining the flavour experience (e.g. (Ranasinghe, Lee, & Do, 2014)).

Audio stimuli for augmenting eating experiences included both ambient sounds and more tailored sound such as the one generated by the mouth while eating. 7 papers focused on ambient audio stimuli (Carvalho et al., 2016; Döring et al., 2013; Mathiesen et al., 2019; Mesz et al., 2017; Velasco, Carvalho, et al., 2016; Q. J. Wang et al., 2017; Yan Wang et al., 2019) such as specific designed musical soundscapes in order to alter the perception of food taste towards sweeter or more bitter (Carvalho et al., 2016). Two of these systems generated adaptive ambient sound triggered by the foodstuff itself, leveraging the capacitive sensing of food materials such as jelly and ice-cream that when touched or licked trigger electrical signals resulting in pleasurable playful eating experiences (Döring et al., 2013; Yan Wang et al., 2019). Fewer papers focused on audio stimuli generated while eating (Koizumi et al., 2011; Velasco, Carvalho, et al., 2016; Yan Wang et al., 2018). These systems record the audio of eating such as the crunching noise of eating crisps (Koizumi et al., 2011),and augment it by varying the volume so when played back it influences the flavour perception towards more crunchy (higher volume) and less crunchy (lower volume), supporting both more and less pleasurable experiences respectively. Of course the desired crunchiness is relative to the context in which the food is consumed, so challenging or surprising sensory information (e.g. a crunchy soup) could be further explored, in order to extend beyond pleasure towards uncomfortable experiences (Benford et al., 2013). Two of these papers use food such as ice-cream and jelly as input, therefore leverage capacitive sensing of food materials while transforming food into an hybrid organic-conductive component of interactive systems (Döring et al., 2013; Yan Wang et al., 2019).

2.1.2.3.2 Technologies creating novel food forms for emotional, ludic and cognitive purposes

Beyond the sensory experiences with food, technology is applied to create food in a range of novel forms (25 papers). Most such systems rely on food printing either in the form of 2D low relief (9 papers) or 3D structures (5 papers). 2D printing is often used to draw messages on food such as toast or as standalone jelly-type foods by remote dining partners (Abeyrathne et al., 2010; Wei et al., 2014a; Wei, Peiris, et al., 2011; Wei, Wang, et al., 2011), or to create visualizations of bodily data such as physical activity (Khot et al., 2017; Khot, Pennings, et al., 2015a, 2015c; F. 'Floyd' Mueller, Kari, et al., 2018)). Similarly, 3D food printing was also used for communication of data such as a person's CV or physical activity (Patekar et al., 2018; Patekar & Dudeja, 2017; Yun Wang et al., 2016) in foodstuffs as jalebi (Indian fried batter sweet) and marzipan (European almond-paste sweet). 3D food printing technology explored variations in taste experiences in solid foods whilst controlling other aspects of flavour experience such as appearance, smell and texture (Gayler et al., 2019a), thus moving away from the traditional use of liquid tastants for taste-based interactions.

Liquids were also presented in novel forms in 3 papers which explored how the performative mixing of different liquids could be used to communicate data about user's physical activity such as heartrate (Khot et al., 2015, 2015, 2014). Acoustic levitation was also explored as a way to 'float' food in space, as novel forms that are not necessarily static but dynamically changing in response to user's interaction. A common theme reflected in 3 papers explored the use of magnetic fields and foodstuffs to create performative experiences with food forms where food appears to move in space, either on the plate on in mid-air which in turn adds a ludic, entertaining dimension to eating experiences (Abd Rahman, Azhar, Johar, et al., 2016; Abd Rahman, Azhar, Karunanayaka, et al., 2016; Rahman et al., 2016). Further exploration of novel forms rely on accessible Computer Numerical Control (CNC) technology such as laser cutting to draw messages onto food surfaces for communication purposes (Henze et al., 2015), 3D printing of moulds to create personalized recipes (Zoran & Cohen, 2018), or digitally controlled cotton candy machines for rapid prototyping in food (Hamanishi et al., 2018). It is clear that exploration of new ways of making food draws on accessible manufacturing technologies such as laser cutting and 3D printing which are democratizing access through lower prices and ease of use. Perhaps more can be done to explore mass food manufacturing techniques as they could be democratized through maker movement adoption, combining both the knowledge about food and eating experience with the tools to further explore and design in this space.

2.1.2.3.3 Technologies supporting remote connection during eating for social purposes

An important finding is that most of the systems supporting the social aspects of eating experiences do so by supporting remote connection (10 papers). Such technologies include video conferencing with food printing, multisensorial environments, and camera tracking of food consumption with the aim to facilitate commensal experiences. In this respect, these papers relate to the broader HCI body of work on commensality technologies (Comber et al., 2014a; Ferdous et al., 2016a) where video conferencing tools have been commonly used to share sensory experiences of remote co-diners. The distinction is that the 10 papers identified in our review focus primarily on eating experience so that the technologies they employ are not (only) video conferencing tools but rather technologies supporting the delivery of novel food forms or food messaging during remote dining in order to share augmented multisensory experiences of flavours as shown in 5 papers. Such technologies involve 3D food printers (Abeyrathne et al., 2010; Wei et al., 2012, 2014a; Wei, Peiris, et al., 2011; Wei, Wang, et al., 2011) , as well as haptic/thermal actuators triggering thermochromic ink in a special tablecloth to change appearance, allowing the drawing of images and text between dining partners (Abeyrathne et al., 2010; Wei et al., 2012, 2014a; Wei, Peiris, et al., 2011; Wei, Wang, et al., 2011). The remaining five papers draw on electronic taste for sensory connection between co-diners through eating (Ranasinghe et al., 2012; Ranasinghe, Jain, et al., 2017; Samshir et al., 2016) or extend video conferencing with VR technology for more immersive experiences of co-dining (Korsgaard et al., 2019).

2.1.2.3.4 Technologies for interactive dining tools to support persuasive technology for healthy eating purposes

An important finding is that the predominant technology across application domains consist of interactive dining tools (23), used mostly as persuasive technologies for healthy eating (16/23). The latter technologies cover a range of augmented plates (Y.-Y. Chen et al., 2018, 2019; GalOz et al., 2014; Ganesh et al., 2014; Han & Kang, 2017; Joi et al., 2016; Jaejeung Kim et al., 2016; Lo et al., 2007; Randall et al., 2018; Sakurai et al., 2015), cutlery (Bruijnes et al., 2016a; Chia & Saakes, 2014; Hirose et al., 2015; Joi et al., 2016; Kadomura et al., 2014; Kadomura, Li, et al., 2013; Kadomura, Tsukada, et al., 2013; Joohee Kim et al., 2016) and cups (Han & Kang, 2017; Kadomura, Tsukada, et al., 2013) as well other more specialized systems such as gaming (Brandmueller & Li, 2017; Ibáñez, 2015), apps for self-tracking (GalOz et al., 2014; Ganesh et al., 2014; Han & Kang, 2017; Hirose et al., 2015; Joi et al., 2016; Kadomura et al., 2014; Kadomura, Li, et al., 2013; Kadomura, Tsukada, et al., 2013; Jaejeung Kim et al., 2016; Joohee Kim et al., 2016; Randall et al., 2018), social dining robots to support commensality for solitary diners (Khot et al., 2019) and the use of audio to improve the taste and flavour experiences of food (Velasco, Carvalho, et al., 2016). The augmented plates, cutlery and cups track the eating interactions in order to provide feedback in two main forms; either via haptic- and light-based systems which are triggered by eating too quickly or too much (e.g. (Joohee Kim et al., 2016)), or by using the eating experience as input via sensors in the forks or plates that measure the consumption of food through a video game played at a collocated tablet computer (e.g. (Chia & Saakes, 2014)). Other interactive dining tools augment tables to regulate eating speed (Mitchell et al., 2015), sounds to create engaging and fun dining (Velasco, Carvalho, et al., 2016), toasters to remind users to eat (Burneleit et al., 2009) or use ingestible sensors as part of a game controlled by gut temperature (Brandmueller & Li, 2017) embedding such novel technology into the spaces where food is created, eaten, and digested.

2.1.2.3.5 Technologies for automated dispensing to support emotional, ludic and cognitive purposes

Technologies for automated dispensing are described in 9 papers (Kehr et al., 2012; Khot et al., 2015, 2015, 2014; Moser & Tscheligi, 2013; Murer et al., 2013b; Velasco et al., 2018; Vi, Ablart, et al., 2017; Vi et al., 2018) addressing the purposes of ludic (7 papers) and emotional eating experiences (3 papers), data edibilization (3 papers), storytelling, tools for sensitizing, dining and internal flavour purposes (1 paper each). Some papers addressed more than one purpose.

Most commonly, such technologies involved pumping liquids such as tastant solutions (e.g. sugar dissolved in water (Vi et al., 2018)), or drinks (e.g. isotonic sports drinks (Khot et al., 2014)), with one paper reporting dispensing of solids such as chocolate balls (Kehr et al., 2012). One of the advantages of liquid foodstuffs is that they can be pumped through a controlled delivery, i.e., measured and small volumes. This allows systems to use 5 different stimuli; one for each basic taste of bitter, salty, sour, sweet and umami (Vi, Ablart, et al., 2017; Vi et al., 2018). The most common purpose of these technologies is using food as part of output of interactive systems supporting ludic eating experiences through gaming (Moser & Tscheligi, 2013; Murer et al., 2013b; Vi, Ablart, et al., 2017; Vi et al., 2018), entertainment through films (Velasco et al., 2018) or to edibilize heartrate data (Khot et al., 2015, 2015, 2014). Pumped liquids such as tastant solutions or drinks are either delivered directly in the mouth while allowing the hands to be used for another activity like gaming (Moser & Tscheligi, 2013; Murer et al., 2013b; Vi, Ablart, et al., 2017; Vi et al., 2018), or into a cup (Khot et al., 2015, 2015, 2014). The pumping into a cup also allows a performative element to be designed into the experience via a fountain-like device which mixed the drink for the user (Khot et al., 2015, 2015, 2014). The use of taste for augmenting user experience is interesting, albeit more work is needed to understand how it can be effectively leveraged to support users to monitor or understand of multiple data sources simultaneously (i.e., audiovisual data via taste), and it remains to be seen how appropriate taste may be in this scenario.

2.1.2.3.6 Technologies for moving food to support dining and assistive purposes

Moving food is also the focus of what is termed here kinetic technologies for eating experiences (10 papers) (Abd Rahman, Azhar, Johar, et al., 2016; Abd Rahman, Azhar, Karunanayaka, et al., 2016; Jiménez Villarreal & Ljungblad, 2011; Koller et al., 2019; Latt et al., 2014; Mehta et al., 2018; F. 'Floyd' Mueller, Kari, et al., 2018; Rahman et al., 2016; Vi, Ablart, et al., 2017; Vi, Marzo, et al., 2017) intended to support purposes such as dining (7/10), assistive (3/10), social (2/10), playfulness (2/10) and data ediblization (1 paper). Some papers had more than one purpose. 5 papers use novel food forms, magnetic foods or droplets light enough to be levitated as part of these kinetic experiences, by moving food through magnetic, or acoustic fields, respectively (Abd Rahman, Azhar, Johar, et al., 2016; Abd Rahman, Azhar, Karunanayaka, et al., 2016; Rahman et al., 2016; Vi, Ablart, et al., 2017; Vi, Marzo, et al., 2017). Other systems relate to assistive domain, consisting of robotic arms that move food from the table to the mouth (Jiménez Villarreal & Ljungblad, 2011; Koller et al., 2019; Latt et al., 2014), or playful applications of the same technology for collaborative eating experiences where co-diners feed each other by using robotic arms (Mehta et al., 2018; F. 'Floyd' Mueller, Kari, et al., 2018).

2.1.3 Discussion of Systematic Review

The findings are now discussed, focusing on the main gaps or limitations and opportunities for future work. Within the many of the papers in the review (particularly in relation to health or flavour there is an idea of a generalized optimum experience; be it in diet, flavour experience or social behaviour. At times interventions are reacting to correct for changes in practice as part of modernity (particularly with respect to the social sphere for remotely located families and healthy eating for diet related health crises) whilst other research is interested in the application of new insights and technology to improve the existing experiences of food (flavour experience through food and environment). One major difference between this group and those creating new experience, is the rejection of personal or divergent behaviours. Each paper's 'optimum experience' relates to general principles or 'norms'; on what it means to be healthy, to have good dining manners, or to enjoy eating food. Based on these principles the aim is to refine, augment and improve practice in a singular fashion towards a goal. Technology is applied with specific and defined outcomes in mind meaning that the user's agency is limited in how they fit their own idiosyncratic food practice into the frameworks of each. Users are also removed from the decision making around the goal setting, they adopt a one size fits all technology which may not be tailored to their bodies, practices or communities. Included here are papers aimed at specific populations that address a perceived need, this is perhaps most contentious where a defined action or relation between the user and food is made on their behalf (for children (Han & Kang, 2017; Joi et al., 2016; Kadomura et al., 2014; Lo et al., 2007; Randall et al., 2018)) or reinforces able bodied as the desired norm (for disabled users (Jiménez Villarreal & Ljungblad, 2011)).

Regardless of the suitability of the optimums set out in each context, attention should be paid to the methods by which behaviour or experience is directed, whether through informed user choice or sub-conscious influencing. Of note is the degree of invasiveness of the technology into established practices, particularly when it comes to the use of head mounted displays for VR/AR (Arza et al., 2018; Korsgaard et al., 2019; Lin et al., 2018) and the disruption to eating food. Experimental approaches to food as a material are absent from papers in this group, instead existing food practices are preserved and disconnected from the interventions. One major trend in the relation of food and technology for improving behaviour is the tracking of food material. Tracking occurs through cameras (Korsgaard et al., 2019; Lin et al., 2018), scales (Randall et al., 2018), capacitance (Han & Kang, 2017) and audio (Arza et al., 2018) reflecting the multimodal nature of food experience in so far as the way food and technology interact. One conclusion is that foodstuff is viewed as more core to the existing food practices than the existing tools or contexts. Another is that this dynamic arises as a result of the relative ease of augmenting experience through tools and environment rather than manipulating food, which as a 'living' material degrades and changes over short time spans (Obrist et al., 2016b).

One of the major limitations of works that aim to improve existing practice is their lack of criticality of the goals they are aiming for. There are no examples of systems which support the user to tailor or set goals based on their own personal needs or desires. They also don't support users to question whether the goal of the system is a desirable outcome for them personally. The issues are perhaps most obvious in health, where work on dieting apps has been critiqued for the embedded ideologies which reinforce harmful relationships between people and food (Eikey & Reddy, 2017). However, there is also an issue with respect to flavour, each of the systems is predicated on generalized principles as to what is a desirable flavour experience, neglecting the role of personal differences in perception and sensitivity (J. A. Williams et al., 2016). The scientific insight behind the flavour enhancing principles derive from attempts to improve mass produced food, but the interaction contexts in this review are often individuals or small groups (e.g., families) eating food. For these contexts more tailored and personal experiences should be provided, supporting difference in practice rather than imposing homogeneity. One of the major contributions of the work on improving existing practice is the engagement with existing practice, but this needs to be aligned with an open-ended and user-centric approach to deliver positive impact. Research is required that improves practice through user-led means, supporting individuals to create and iterate food practices autonomously, through a scaffold of knowledge and technology and a greater sensitivity towards their own experience.

Another theme within the review considers novel forms of engagement between people and food, moving away from the predominance of the dining context for food experience design. The interactive technologies in these papers allow new methods for groups or individuals to understand and experience food, supporting personal and open-ended experiences of discovery. Key to their approaches is supporting user choice and agency around food, reflecting both variance in food practices as well as the personal, bodily nature of food-based experiences. The process of creating novel practices with food, requires users to be sensitized to new forms of engagement, for instance through surprising food formats or eating contexts that disrupt familiar consumption and that emphasize the relationships between the three actors: food, technology and body.

Interestingly, by connecting technology and body, the food performs a variety of roles: meaningful data object (Khot et al., 2017, 2015; Patekar et al., 2018; Yun Wang et al., 2016), emotion (Gayler et al., 2019a; Gayler & Sas, 2017; Hwang et al., 2018) or narrative (Bruijnes et al., 2016b; Markéta Dolejšová & Lišková, 2015; Harley et al., 2018; Velasco et al., 2018). It does so flexibly with at times the flavour (Gayler et al., 2019a; Gayler & Sas, 2017; Murer et al., 2013; Vi et al., 2018), the shape (Khot et al., 2017; Patekar et al., 2018) or the structure (Döring et al., 2013; Hamanishi et al., 2018) taking on the role of meaning carrier. In order to ensure this flexibility, technology is employed to digitally control food production and delivery. In addition, findings indicate that the multisensory nature of food supports its integration within multimodal experiences in which multiple sensory channels are simultaneously stimulated. However, this also poses challenges for designers in terms of how to direct attention to specific sense within a rich multisensory experience. Within HCI and research-led work, food is often only manipulated from a single aspect and the richness of the material becomes somewhat limited. Both the technology used, and the design approaches may benefit from richer interactive experiences with food. This will also mean further work should explore new practices in the contexts of everyday lives, understanding how they can become adapted and adopted as well as shared across cultures.

A key limitation of previous work highlighted in this systematic review is the insufficient attention paid to the eating of food, food qualities that bear relevance to the act of eating, and how they may be used to inform novel user experience intersecting food and technology. To further explore this, attention was also paid to expert designers of food-human interactions in Study 2 (Chapter 5).

2.2 Human-Food Interaction beyond eating

In the above review eating-based Human-Food Interaction (HFI) work was reported on. To connect wider HFI (both involving eating and not) with the 3D printing of food, two rather independent areas: "*around* food" and "*with* food" are presented and then reflected upon in light of how the 3D printing of food can bring them together.

2.2.1.1 Design around Food – Social Experiences in HCI

Work within this space has focused on the social experiences around food consumption, particularly the sharing of food in domestic spaces for both collocated (Ferdous et al., 2016), and remote families (Wei, Wang, et al., 2011), as well as broader community settings (Gross et al., 2011). *Phototalk* tackles some of the disruptive impact of technology around the dining table through a shared digital photo frame to support prosocial interactions (Ferdous et al., 2016). Technologies for remote connectedness facilitated by the sharing of meals include traditional video conferencing (Wei, Wang, et al., 2011) through overhead capture and projection on to tables (Barden et al., 2012; Comber et al., 2014b), or those for taste and smell stimulation through food outputs (Wei, Wang, et al., 2011) supporting conversations and the sense of presence (Sas, 2004). However, most such systems (excepting (Wei, Wang, et al., 2011)) tend to ignore food as a resource for design which could enable novel multisensory and embodied interactions.

2.2.1.2 Design with Food – Crafting Edible Experience

Attempts to harness the taste experience of foodstuffs have started in the context of designing for experience (Obrist, Comber, et al., 2014), and emerging HCI has focused on leveraging taste experience to support user' communication and expression of emotions (Gayler et al., 2019a). Food has also been integrated with text messaging where messages are printed onto edible biscuits (Wei et al., 2014b). However, such data representations printed on a unchanging, base foodstuff do not fundamentally change the eating experience, contrasting with taste-based experiences where the foodstuff is technologically mediated (Gayler et al., 2019a; Murer et al., 2013; Vi, Ablart, et al., 2017). Space travel presents a context where designing with food can create rich experiences within restricted conditions. Speculations are presented for the mixing of flavours through human input, 3D printing temporal experiences with food and 'earth memory bites' (Obrist et al., 2019).

2.2.1.3 The 3D printing of food – Designing 'with' and 'around' Food

Besides 2D images printed onto food, the encoding of information into food has also been explored through the 3D printing of food (Khot, Pennings, et al., 2015; Lin et al., 2018; Patekar & Dudeja, 2018), which is an application of additive manufacturing, using edible materials. This technology provides the opportunity to bring together the *design-with-food* and the *design-around-food*, creating new experiences rather than merely automating existing ones (Gayler et al., 2018). Much HCI research on the 3D printing of food could be grouped into two categories, those prioritizing form, and those prioritizing flavour.

CoDine (Wei, Wang, et al., 2011) prints images with a jam onto bread, allowing users to design their own drawings or to write messages for dining partners. A similar "2.5D" form-based approach can be found in *Edipulse* (Khot et al., 2017), which prints out various predesigned forms in chocolate, such as graph traces or emojis, in response to physical activity data. A different form of data ediblization (Yun Wang et al., 2016) can be found in *Data Jalebi Bot* (Patekar & Dudeja, 2018) that provides an edible representation of a person's CV. Each of these systems use a single flavour (chocolate (Khot et al., 2017), sugary, deep fried jalebi (Patekar & Dudeja, 2018) or jam on bread (Wei, Wang, et al., 2011)), creating mostly visual experiences that can be eaten, similar to edible messages (Wei et al., 2014b). More recently form and food structure possible through 3D printing has been explored to create different flavour perceptions (Lin et al., 2018).

All food-based experiences described above contain food whose primary mode of interaction is visual rather than edible, flavour-based experiences. In speculating on how food outputs could be crafted in HCI, e*dible interfaces* were proposed as the next step to Graphical UIs and Tangible UIs (Maynes-Aminzade, 2005). To create such interfaces researchers should exploit the 3D printing of food, to bring together design *around* and design *with* food, combining both the exploration of food for crafting new experiences such as social bonding (Ferdous et al., 2016) and for data communication (Khot et al., 2017; Patekar & Dudeja, 2018). In doing so designers could better address the challenge of designing for taste-, and flavour-based experiences (Obrist, 2017), for instance by leveraging the connection between taste and emotion (Gayler, 2017; Obrist et al., 2014a), which 3D printed foods have been already shown to support in HCI contexts (Gayler et al., 2019a).

2.3 Context related investigations (HCI)

This thesis now addresses non-food work from HCI that supports later studies on emotion and memory-based interaction, designing for those in intimate relationships and older adults. It also reviews the extent of existing multisensory design approaches.

2.3.1 Emotion-based interactive systems

Emotion is an important aspect of how people experience and interact with each other and with things (Donald A. Norman, 2007). Emotional user experiences with computers (a part of a wider field of Affective Computing) can create interactions that are playful and meaningful as well as supporting function (Picard, 2003; Saariluoma & Jokinen, 2014). Norman identifies three levels of the cognitive and emotional systems that make up the experience of things; visceral (‘natural’ aspects humans respond to, things that are cute or pretty), behavioural (functional, needs meeting aspects) and reflective (meaning- making and cultural aspects) (Donald A. Norman, 2007, p. 36) each level generating emotional experience independently and potentially in conflict. Designing with an awareness of these aspects and their emotional experience supports designers to create systems that work better. Norman’s levels indicate the extent to which emotion influences experience from the instinctual and animal, through to the educated and reflective. When users experience emotions, they can clearly feel the connection between connective and physical experience, from flushing red when angry through to nervous butterflies in the stomach. The nature of emotions exposes the indivisibility of body and mind, when designing for and with emotion therefore it is important to retain the bodily perspective, something traditionally marginalised by more cognitive approaches to experience.

Embodiment is a concept that has been explored previously in the development of affective mappings in HCI. Antle et al. (2009) used expert interviews in the derivation of mappings for bodily movements and user–centred approach that derived mappings from direct user interaction (Bakker et al., 2012). One approach for creating embodied affective experience is exploring novel multisensory approaches. This includes augmented interactions with plants for cognitively or sensorially impaired people (Angelini et al., 2016), multisensory robots that support therapy to improve emotional communication for those with autism spectrum disorders (Bevill et al., 2016), and multisensory emotional subtitles for films for those with sensory impairments (Basori et al., 2008). ‘Affective haptics’ attempts to draw together individual explorations on touch and emotion (Eid & Al Osman, 2015). Haptic interaction is claimed to be effective in increasing the level of emotional immersion during experiences (Eid & Al Osman, 2015; Gatti et al., 2013) and can be used to communicate valence and arousal. The body therefore offers some promise as a pathway for emotional experience, however, as yet taste and smell have only been of limited attention to this purpose.

2.3.2 HCI Research on Intimate Relationships

Emotions are a key part of romantic relationships and have been the attention of several studies into supporting emotional communication and experience between remote partners (Li et al., 2018). A rich body of HCI research has focused on intimate relationships and how they can be designed for to support "awareness, expressivity, physicality, gift giving, joint action, and memories" (Hassenzahl et al., 2012). Awareness of each other's presence and joint actions underpins the *Lover's cups* (Chung et al., 2006), a pair of augmented, Wi-Fi connected drinking cups that use light and haptic feedback for intimate communication. Gift-giving, expressivity, physicality, and memories were captured in *Lovers' box* (Thieme et al., 2011), a physical-digital repository for couples that required the creation and curation of multimedia content to communicate emotional experiences. Both projects aim to support connectedness, within fleeting, quotidian experiences as well as enduring ones. Another strand of work has explored emotion co-regulation, or the ability to influence partner's emotions such as calming down when stressed, or cheering-up when sad (George, 2000). *Lightweight*, *vague* and *indirect interactions* are design principles that have been proposed to support intimacy and coregulation (Pradana & Buchanan, 2017), and more reflective interpersonal experiences mediated by technology (Mols et al., 2016) supported by three principles: *re-pattern* (creating new behaviours to change engagement), *reflect* (considering past influences on the present relationship) and *re-story* (understanding the relationship from a new perspective).

Although HCI research on the value of food in designing for intimate relationships has been less explored, there can be a link drawn between the concerns. For instance, flavour experience is highly multisensory (Spence, 2013) and influenced by mood (Eskine et al., 2012), while its idiosyncratic quality allows *vagueness* in exchanges. Foods themselves be packaged as a snack experience for *lightweight interactions* (Lindley et al., 2008). By providing context for other experiences, food can also create an *indirect interaction* that contrasts with direct verbal communication. In addition, food is often *given as a gift*, and is *physical*, both in terms of the food itself and its bodily experience. Finally, *joint action* occurs in shared meals or cooking together, while the smell of food is strongly associated with emotional *memories* (Larsson et al., 2014).

2.3.3 Memory Technologies: Cue Modality, Generation and Effectiveness

Much HCI research on memory technologies has focused on digitally augmented cues for supporting recall of episodic memories. Predominantly in visual and sound modalities, cues are often photos (Dib et al., 2010), recorded sounds (Frohlich & Murphy, 2000; Isaacs et al., 2013), or videos (Le et al., 2016) capturing the situated context in which the memory event has occurred. Cues have also been captured in text format as brief self-reports tagging emotions or thoughts by self-tracking applications (Isaacs et al., 2013), and as visual-biodata showing the value of arousal for recognition and recall (Sas et al., 2013; M Umair et al., 2020; Muhammad Umair et al., 2018, 2019).

While HCI literature has looked mostly at visual and auditive cues (Le et al., 2016; Sas, Davies, et al., 2020; Sas et al., 2013; Sas & Coman, 2016), psychology research has explored a broader range of sensory cues: including chemosensory ones, such as gustatory and olfactive (Chu & Downes, 2002; de Bruijn & Bender, 2018; Herz, 1998, 2004). A wealth of lab-based findings have shown that olfactive cues, evoke more emotional (Herz, 1998, 2004; Herz & Engen, 1996) and vivid memories (Chu & Downes, 2002; de Bruijn & Bender, 2018; Herz, 2004), and stronger recollective experience of travel in time (Larsson et al., 2014) than verbal or visual cues. In both HCI and psychology research, memory cue modalities have been explored mostly in isolation, with a few exceptions pointing to the value of crossmodality, integrating for instance visual and auditory cues (Le et al., 2016), or text, photo, and music cues (Peesapati et al., 2010).

Cues can also be distinguished by how they are captured or generated. While in psychology research, most studies relied on cues prepared by researchers, HCI work tends to distinguish cues by how they are captured: automatically (Eldridge et al., 1993) or manually (Carter, 2005). HCI work comparing different forms of capture across different modalities is limited. A landmark example explores manually and automatically captured photos using SenseCam, where better recall was cued by manually captured photos which authors attributed to their saliency (Sellen et al., 2007). Manual capture of cues does require more user involvement compared to passive capture, but the additional effort for *making the cue* remains limited. Work has also emerged looking at how cues can be actively created or crafted through users' effortful input that goes beyond the mere recording of data. Such self-generated cues have been shown in psychological studies to be particularly effective in supporting memory recall (Hunt & Smith, 1996) but there has been limited HCI exploration of them. Exceptions include self-generated cues in doodle modality particularly suitable to creatively communicate emotional meaning (Sas et al., 2015) or users' crafted video summaries from photos that led to increased ability to recall memories (Le et al., 2016). Psychological memory research has also emphasized the *generation effect* (Slamecka & Graf, 1978) of cues being created by participants, with the increased mental effort required for cue generation leading to cues' stronger connection with the initial event (Bertsch et al., 2007), and personal relevance (Slamecka & Graf, 1978).

Regarding cue effectiveness, HCI work has identified the importance of being recognizable as belonging to the original experience, personally relevancy, and distinctiveness so that only one memory is prompted by a given cue (M. L. Lee & Dey, 2007; Mazzoni et al., 2014). In addition, consistent findings on episodic retrieval have shown reliance on some salient features from the content of the episodic memory that are shared with its cue (Schlagman et al., 2009). Such features reflect the sensory perceptual content of the memory event such as the smell of the sea and sound of the waves (Ball & Little, 2006). The effectiveness of these features has been explained by the *principle of encoding specificity* (Martin A. Conway, 2005) stating that retrieval is supported by increased matching of the content in the memory with that of its cue. This is commonly reflected in the complexity of the cue, derived from its content as the amount of distinct information such as colours, patterns or textures for visual cues, and modality, i.e., one or more sensory modalities. The latter is important as multimodal sensory cues and vivid episodic retrieval are underpinned by the same neural substrates, i.e., angular gyrus (Tibon et al., 2019).

To conclude, most of HCI research on memory cues has focused on traditional visual and sound modalities of automatically or manually captured cues, but less so on users' self-generated chemosensory cues and how these can be co-designed and leveraged in memory technologies. Chemosensory cues, and in particular olfactory ones are more specific, evoking more emotional (Herz, 2004; Herz & Engen, 1996) and vivid (Chu & Downes, 2002; de Bruijn & Bender, 2018; Herz, 2004) episodic memories and their recollective retrieval (Larsson et al., 2014) but gustatory ones have been much less explored, especially outside the lab and how they may be personalized through co-design.

2.3.4 HCI Research on Aging and Sense of Self

HCI research on aging has focused on key functions such as memory, personhood, and particularly the sense of self. Since *episodic memories* or memories with sensory content of personally experienced events, situated in specific time and space, are the most severely impaired type of autobiographical knowledge in both healthy aging and in dementia (Hamel et al., 2016; M. L. Lee & Dey, 2007; Lindenberger & Mayr, 2014; Piolino et al., 2006), it is not surprising that most HCI work supporting memory decline in aging has targeted them. Older people's increased reliance on external rather than internal information for memory functions (Lindenberger & Mayr, 2014), coupled with the transient, sensory content of episodic memories, makes them suitable candidates to be captured through personal and ubiquitous technologies which record the *here and now* situated content of personal events as visual or auditory cues. For instance, research on wearable cameras such as SenseCam has shown their value for supporting episodic memory recall (Harper et al., 2007), indicating also that best cues are memorable, distinctive and self-relevant (M. L. Lee & Dey, 2007).

While chemosensory memory cues (gustatory and olfactory) have been less explored in HCI, aging research has shown their benefits for older adults helping them recall more autobiographical memories compared to younger people (Zucco et al., 2012). Flavour memory has been shown to evoke autobiographical memories (Mojet & Köster, 2016), and that for people living with Alzheimer's disease, odour-based cues lead to increased number of more emotional and specific autobiographical memories from both childhood and adulthood compared to non-odour cues (Glachet et al., 2019), and improved mental time travel compared to music-based cues (EL Haj et al., 2018). HCI research has also explored older adults' engagement in co-designing personalized cues to support reminiscing (Wheeler & Gabbert, 2017). For instance, visual or audio content has been used to create digital or hybrid scrapbooks such as Memento (West et al., 2007), multimedia biographies (Frohlich & Murphy, 2000), and were integrated with physical possessions such as Memory Box (Frohlich & Murphy, 2000) to support reminiscing in old age. Crafting has been shown as beneficial due to the increased need for sensory stimulation in old age and those with dementia (Livingston et al., 2014; Reisberg et al., 2002). Such work highlights older adults' preference for physical cues

(Thiry & Rosson, 2012) that leverage haptic experiences (Huber et al., 2019) and active engagement in craft-based activities (Sas et al., 2015, 2017) or in co-designing (Wallace et al., 2012, 2013). This is not surprising, as episodic memories are intrinsically related to the sense of self: upon integration in autobiographical memory system they become stable, durable, and available for *recollective experience*: *"the sense or experience of the self in the past"* (M A Conway, 2001, p. 1375) as illustrated in the self-memory system (Martin A. Conway & Pleydell-Pearce, 2000). This system emphasizes another type of autobiographical memories, namely *self-defining memories* that are emotionally intense and vivid because they recruit those episodic memories linked to enduring concerns with the aim to support *self-coherence*, i.e., "*retrieval from the long-term self of episodic and conceptual knowledge structures that help to give meaning to experience*" (Martin A. Conway et al., 2004, p. 511). Because of their link to the sense of self, sadly, the negative impact of aging on the recall of episodic memories also extends to the diminished sense of self (EL Haj et al., 2018; Sas, 2018). Therefore, efforts to support self-defining memories can be beneficial to the sense of self, by tapping into the sensorial richness of the episodic memories underpinning them.

In contrast to episodic memory cues, the exploration of cues for self-defining memories has been limited. A few exceptions include findings that music-based cues lead to better recall of self-defining memories of people living with Alzheimer's disease, when listening to their own chosen music rather than music provide by researchers (Haj et al., 2015, p. 263). HCI work on self-defining memories has started to emerge showing the benefit of craft-based projects to support older people to elicit such memories around key events (Sas, Whittaker, et al., 2016; Sas & Whittaker, 2013) or employ craft to design no longer accessible cues (Sas et al., 2017). Another study showed the positive affect of self-defining memories, their link with identities, predominantly achievement and relational self, and how these may be evocatively cued by predominantly crafted objects (Sas, 2018).

To conclude, aging is associated with impoverished retrieval of contextual details so that episodic memories become increasingly generic or semanticized, negatively impacting on the recollective experience of the sense of self in the past, that is essential for both episodic and self-defining memories (Piolino et al., 2006). This emphasizes the value of supporting the sensorial and emotional phenomenological aspects of recollective experience (Piolino et al., 2006), for which a promising avenue is self-generated multimodal chemosensory cues.

2.3.5 Designing with Multisensory Experience

As technologies have made interaction through touch, taste and smell possible initial guidelines have been proposed to support multisensory design (De Giorgi et al., 2011; Merter, 2017; Schifferstein, 2011). These frameworks consider multisensory experience as a compound experience that can be deconstructed into individual sensory experiences each with its own implications and meanings. They apply framings such as relation to body parts (Schifferstein, 2011) or metaphors from synaesthesia (Merter, 2017) to reconstruct new arrangements of these individual sensory phenomena into a single multisensory experience. Drawing on from food and sensory science, De Giorgi et al., (2011) have adapted *sensory evaluation* approaches for use within product design. Their approach is similar to other multisensory design approaches Schifferstein, 2011) by break downing sensory experience, analysing its parts and then reassembling with an awareness of the 'harmonic' interaction between sensory experiences. The need to build on existing frameworks to create new approaches for designing multisensory experience has been identified (Obrist et al., 2016a), with technical challenges remaining a barrier. These include differences between subjects and varying experiences of taste and smell over time (i.e., becoming accustomed to a smell or developing an acquired taste). The solution proposed is to develop frameworks that combine both qualitative and quantitative parameters, combining the scalar evaluations from sensory profiling with space for the expression of personal felt experience. An example of this can be seen in work on taste experience, where a novel interview technique was combined with physical objects applied to support the verbalisation of taste experience (Obrist, Comber, et al., 2014). One of the further outstanding issues is apparent with existing design frameworks is how they can be applied to individual users. It is known that perceptual thresholds differ between people (Bartoshuk, 1978). No existing model currently considers the perspective of the individual who will experience it in a meaningful way. A more recent approach to designing multisensory experience (Velasco & Obrist, 2020, pp. 84–87) highlights 6 aspects for consideration; the background to the experience (why?), impressions that are intended (what?), the event it becomes (when?), sensory elements that it is comprised of (how?), concepts that support the experience and enabling technologies. This framework is presented in the form of *xSense cards* to inspire design. Whilst encompassing some of the deconstruction of previous approaches, this tool focuses more on the holistic experience attempting to connect more to the specific receiver and the context within which an experience occurs.

A key challenge for work with bodily and multisensory experience, is the ability to understand and articulate idiosyncratic personal experience (De Giorgi et al., 2011). Co-designing with users can support better representation of an individual's personal experience (Branco et al., 2016), however it can be difficult for novices to be aware of, and articulate the nuances of sensory and embodied experience. Finding ways to support participation in the design process has resulted in approaches ranging from artifact-based to bodily-based. Artifact-based interventions include the *Sensual Evaluation Instrument* (Isbister et al., 2006), a set of physical 3D objects with abstract but distinct forms that are not designed to represent explicit meaning instead representing a range of possible expressions. Users handle them whilst describing an experience to support explication. The objects provide an external reference point for emotional or cognitive experience through their visual appearance as well as through touching and manipulating the forms.

Sat between artifact and bodily-based are Aesthetic Laborations (A-labs), a sensitizing approach developed as part of a S*omaesthic* design which treats cognitive and bodily experience as entwined (Höök, 2018). A-labs augment sensory information through blindfolding to explore materials through different senses and body parts, for example exploring touch on the back of the hand vs. touch on the lips. A bodily-based is 'Sensory bodystorming' (Turmo Vidal et al., 2018), in which attention is paid to each sensory pathway in turn and used for seeding ideation processes. The intention of all approaches is to better understand sensory and bodily experience to inform the design of interactions. Each one attempts to support awareness, understanding and communication about personal sensory experiences that maybe otherwise unnoticed or inexplicable. The strategies of each can be seen in a multisensory probe kit for researching Technostress (Behzad Behbahani et al., 2019) that draws on smell, haptic and audio stimuli in the kit to open up multisensory experience as a design space and mixes artifact and bodily focused interventions.

2.4 Food experience (non-HCI)

This thesis finally reviews previous work on food experience, detailing the nature of taste and flavour experience, detailing the relationship between tastes and emotions and reporting on the role of food and flavour in intimate relationships.

2.4.1 Taste and Flavour Experience

For terminological clarity, in this thesis, the term *flavour* is used for the complex multisensory experience combing taste, smell, touch and temperature (Spence, 2010); *taste* is a single sensory experience on the tongue of sweet, sour, bitter, salty, and umami (Beauchamp & Bartoshuk, 1997); and *tastants* as stimuli designed to control for the non-taste parts of flavour experience, so that the differences in the experience of taste can be used to create specific modes of experience.

Taste and smell are distinct senses but are both tightly connected in the experience of food. Whilst taste is the result of stimulation of the tongue and smell, the nose when we eat something the combination of taste and smell appears as if it occurs in the mouth only, this is known as oral referral (Spence, 2016). The experience of flavour is multisensory, this means it integrates not only taste and smell, but somatosensory experiences in the mouth (texture, temperature and more), sounds from the food, visual appearance and environmental factors as well (Spence, 2010). These sensations are not only operational in a strictly additive manner, but combinations between different sensory stimuli can be super-additive and the function of these relationships can vary from person to person (Spence, 2010). This provides individuals working with flavour experiences both challenges as well as opportunities, whilst extra attention needs to be paid to unintended influences on an eating experience, the same connections can be utilised to emphasise or reinforce any intended sensory experience.

2.4.2 Taste-Emotion Mappings

Much previous work on taste and emotions has shown their relationship, often described in terms of mappings identified by both emotional responses to tastes (Bredie et al., 2014; Park et al., 2011; Rousmans et al., 2000; Yamaguchi & Takahashi, 1984) and as tastes' influence on the perception of affective stimuli (Eskine et al., 2011; Ritter &

Preston, 2011). These studies often rely on pure tastants (chemical stimuli that solely triggers taste receptors) as their stimulus and occur in controlled environments. Often these findings lack the ecologically validity required to support their use into an applied field such as HCI.

Sweet has largely been shown to map to positive emotions (Park et al., 2011; Q. J. Wang et al., 2016; Wendin et al., 2011; Yamaguchi & Takahashi, 1984) as well as influencing mood and enhancing positive and limiting negative responses to affective stimulus (Eskine et al., 2011; Greimel et al., 2006). Negative affective response has been linked to bitter (Herbert et al., 2014; Kashima & Hayashi, 2011; Macht & Mueller, 2007; Rousmans et al., 2000; Q. J. Wang et al., 2016), sour (Rousmans et al., 2000; Wendin et al., 2011; Yamaguchi & Takahashi, 1984) and salty tastes (Park et al., 2011; Rousmans et al., 2000; Q. J. Wang et al., 2016; Wendin et al., 2011; Yamaguchi & Takahashi, 1984). Disgust specifically has been mapped to bitter (Bredie et al., 2014; Eskine et al., 2011; Wicker et al., 2003), sour and salty (Bredie et al., 2014; Robin et al., 2003). Out of these three tastes, bitterness is reported as having the strongest connection to negative response, it has also been used to explored the influence of embodied cognition via its association with disgust response (B.-B. Chen & Chang, 2012).

The above research indicates the connection between taste and emotion as bidirectional, with taste stimuli influencing affective experience and emotional stimuli impacting on taste perception. Embodiment has been cited as a mediator in connecting taste and emotional experience (Eskine et al., 2012). If mappings are shown to be useful in the design of affective interactions, the bodily aspect of experience provides an additional layer and an enticing direction for exploration. The extent to which taste-emotion mappings identified in lab-based experiments, also hold true in real world contexts has been previously questioned (Desmet & Schifferstein, 2008) . A challenge of moving from lab to real-world setting, is the creation of specially designed taste-only stimuli (known as tastants) as part of robust tools for interaction. To address this challenge an exploration of the optimum method for delivery of taste stimuli is needed which would allow the identification of mappings by users, while controlling for other confounding variables such as smell and visual appearance.

The correlation between emotion and taste has also been associated with both action and personality by Meier et al. (Meier et al., 2012). They found that preference for sweet foods could be used as a predictor of prosocial personalities, intentions and actions. This observation combines conceptual metaphor ("*She's a sweetie"* to describe someone with a nice personality) with embodiment, creating an embodied metaphor (showing that sweetness, as metaphor, indicates prosociality on a cognitive level as well as sweet tastes from an embodied perspective increasing the perception of prosociality). However this idea is challenged by the findings of Chan et al. (2013) in their work on love and jealousy. They found that while there was an influence of emotion on perception, not all metaphors relating food and affective response were valid in predicting mappings.

Among the few studies of taste-emotion mapping in real life settings, Noel and Dando's (Noel & Dando, 2015) work has explored the relationships between taste and emotion following hockey matches where participants rated the tasted of a sweet and sour ice-cream. The key finding from their study was that sweetness was promoted in positive situations (after a win) and supressed in negative ones (following a loss), whilst the reverse was true for sourness. The study design used controlled flavour samples of food representative of tastes rather than pure tastants. This is perhaps closest to how HCI applications would work and highlights the value of pursuing taste-emotion mapping for designing experience in-the-wild (Y. Rogers, 2011b).

2.4.3 Flavour and Food in Intimate relationships

Boxes of chocolates, oysters and, for the ancient Greeks, prunes. There is a long and storied relationship between food and romance, from foods seen as aphrodisiacs to the 'dinner date' as a courtship archetype. Previous work has shown the value of food for enhancing communication in romantic relationships by ensuring both increased awareness of one's own and partner's emotions (Croyle & Waltz, 2002), as well as impacting upon emotional responses (Evers et al., 2010). The instinctive understanding of the connection between food and emotions is also reflected in everyday metaphors such as 'sweet love', 'bitter jealousy' (Chan et al., 2013), 'eating your feelings' and 'comfort foods' (Evers et al., 2010). Evidence for the broader connections between food and emotions have been provided by research on the meaning of food in religious celebrations (Feeley-Harnik, 1995), fasting and feasts (Insoll, 2011). The bodily aspect of food, has been used to draw connections with sex (Goody, 2005; Korsmeyer, 2005a). This connection is played out through shared ideas of indulgence and abstinence in these bodily pleasures (Korsmeyer, 2005b). These connections between ideas, actions and the semiotics of sex and relationships underpin a design exploration in the L.O.V.E. FOODBOOK (Baltz & Boisseau, 2012) which uses ingredients as metaphors for aspects of romance, love and desire.

Food therefore can be said to have two roles within romantic relationships. The first relates to the meaning-making with food, both arising from the character or cultural perception of individual ingredients (oysters and prunes) as well as from the bodily act of consumption and the related embodied pleasures. The second is a cultural imprint of the first and relates to how food forms part of the structures of romantic relationships and acts of care. Following feminist critique of how this has undervalued women's labour to these ends, (Arlene Voski Avakian & Barbara Haber, 2005) there is an opportunity to reconsider the way food and its use in acts of care can be designed with to extract the value whilst also promoting equality and liberty.

2.5 Conclusion

Having explored the work with HCI on food and eating experiences and identifying approaches to designing *with* and *around* food as part of HFI, this chapter grounds the research in the frontiers of the field. By further considering the qualities of the food material and contexts in which those qualities can be exploited it has laid the groundwork for exploration and design of multisensory interactions with 3D printed food that generate new design knowledge. To enable the research to successfully achieve this, a methodology was followed set-out in the next chapter which mixes Research through Design with Material Approaches.

3 Methodology

3.1 Introduction

This thesis aims to explore and design multisensory interactions with food in HCI, to do this its draws on a constructive design approach of Research through Design (Koskinen et al., 2011; Zimmerman & Forlizzi, 2014) informed also by a Material Approach (Wiberg, 2014). The aim of the research requires a methodology that supports the understanding of the relationship between food (as a material), 3D printing of food (as a technology) and eating and the body (as user experience). Figure 5 demonstrates how the approaches, individual methods and studies in this thesis relate to these three interconnecting terrains. The research commenced by identifying the opportunities for food-based HCI, this was done by drawing on existing literature in HCI as well as work from sciences that engage with food experience, such as psychology and sensory science. This research took a particular type of material (food) as the focus of attention

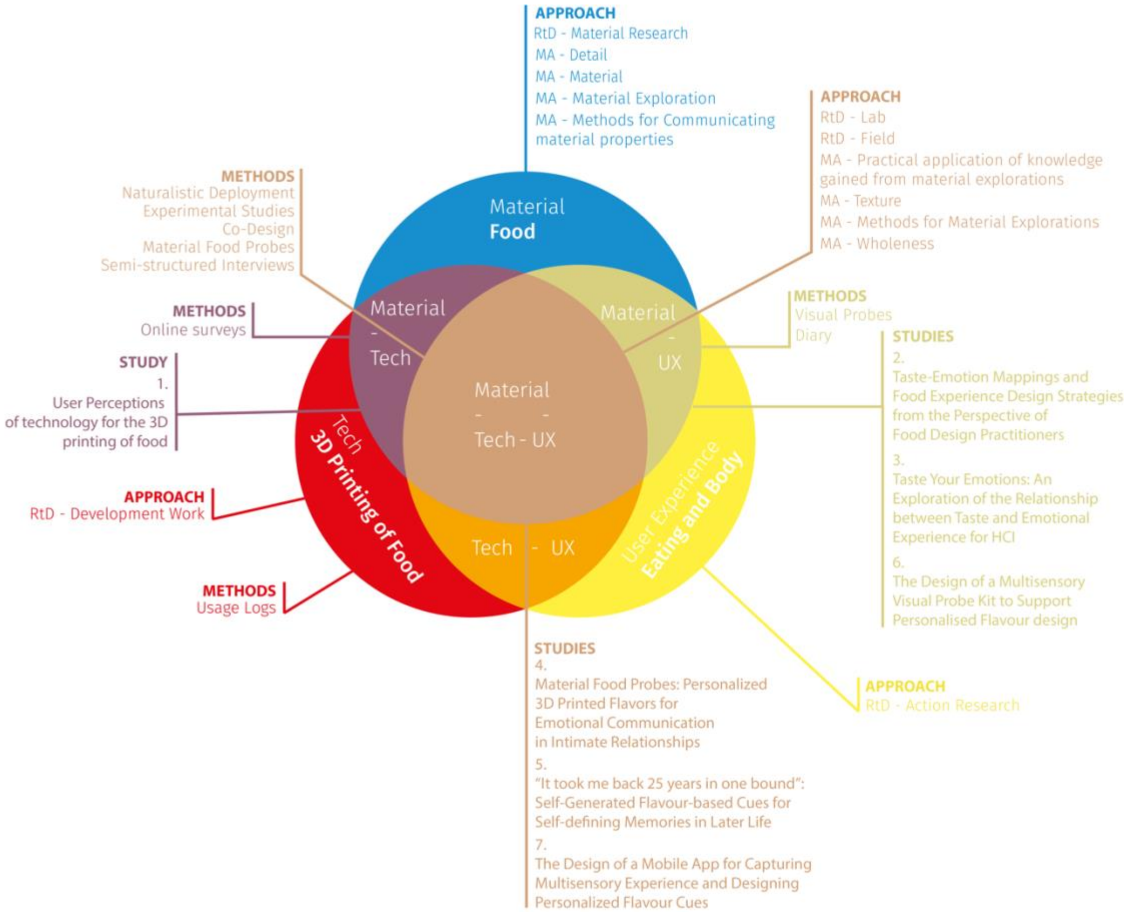


Figure 5 Diagram showing methodological approach, methods and studies as they relate to the three concerns of the thesis; Food, 3D printing of food and Eating and Body

and as such the methodology developed is informed by discussion in the wake of the *material turn* in HCI (Robles & Wiberg, 2010).

3.2 Overall Approach: Research through Design

Although originating in a publication by Frayling (1994), *Research through Design* has only latterly been adopted by the HCI community (Zimmerman et al., 2007, 2010). As set out by Forlizzi and Zimmerman (2014, p176-7) "*Research through Design (RtD) is an approach to conducting scholarly research that employs the methods, practices, and processes of design practice with the intention of generating new knowledge*. [… In] *RtD, design researchers focus on how design actions produce new and valuable knowledge. […I]ncluding: novel perspectives that advances understanding of a problematic situation; insights and implications with respect to how specific theory can best be operationalized in a thing; new design methods that advance the ability of designers to handle new types of challenges; and artefacts that both sensitize the community and broaden the space for design action*". This statement makes clear the diversity of what is constructed through *constructive design research* and is reflected through the different contributions made in this thesis. In *Design Research through Practice* (Koskinen et al., 2011), the authors identify three distinct practices of 'constructive design research': *Lab, Field* and *Showroom.* Two of these practices (*Lab* and *Field*) relate to the work in this thesis and are outlined in further detail.

3.2.1 Lab

In their description of the 'Lab', (Koskinen et al., 2011) identify the notion of *Rich Interaction,* which was developed at TU Delft in the Netherlands and is exemplified in work by (Frens, 2006). The basis of this approach was to draw on 'theories from perceptual psychology, ecological psychology, and phenomenology' as a move away from a singular focus on cognition and to more fully engage human's bodies in designing technology (Zimmerman & Forlizzi, 2014). The name for this approach arose from user experience labs where the research took place, which were used to focus on specific phenomena and understand how they work. In Labs, research is conducted via an experimental approach, through manipulating specific variables whilst controlling for other aspects of experience (Koskinen et al., 2011). Whilst this approach offers a way to understand the potential of an interaction or material, it remains distant from knowledge about use in context and the development of knowledge into applications for the real world.

3.2.2 Field

In contrast *Field* places a focus on design as responding to and changing realities of users lives, practices and environments. As described by Koskinen et al. (2011), "*The lab decontextualizes; the field contextualizes."* Research through Design in the Field aims to gain knowledge on how and what to design by becoming embedded in the user's systems of meanings. Whilst Field draws heavily on the practice of ethnography in the anthropological tradition, a distinction is made with respect to the practice for RtD. Designers study the material world, not only as it, but also as it might be, by introducing imagination the aim is to create and explore new possible worlds. Designers do this through the making of 'things' that help create a new reality. Part of the Field approach relies on designers' ability to engage their users in the design process. To this end, co-design methods have been developed that allow participation and ownership of the design process to be shared between the designers and users.

3.2.3 Defining Research through Design (RtD)

- RtD is designing new things (e.g., objects, experiences, services) in the pursuit of knowledge
    - This sets it apart from traditional design (the creation of something new or better) and the research into designed things (research that occurs independently from the design action).
- RtD articulates propositions for 'how things could be' through design artefacts, the design artefacts are used to enact and understand the proposition
    - RtD is concerned with imagination through design artefacts, experiences or objects that are crafted to create an alternative reality that can be researched.
- RtD consists of (Frayling, 1994):
    - Material Research – exploring the potential of materials, both new and existing
    - Development Work – Exploitation of new technology to create design artefacts, translating technology into experience

- Action Research – The engagement with the design context and direct enactment within the research

3.2.4 The relationship between Theory and RtD

The history of RtD begins with Frayling (1994) but was given limited theoretical background. Later, Gaver provided discussion of this (Gaver, 2012) by outlining the various forms of theory that are applied, or implied, through design approaches:

1. Conceptual perspectives that move to theory through practice
2. Borrowing and appropriation of theory from other fields
3. Manifestos as reflection on practice
4. Frameworks for design
5. Theory on RtD itself - how and why

Having made links between RtD and theory, Gaver remains sceptical as to a singular theory that can describe any form of design research. In his argument, Gaver takes the philosophy of scientific theories to explore the application theory for design and design research. He draws on two conflicting perspectives of knowledge within science to emphasise that design can thrive as a discipline despite not having a core theoretical foundation. His contrast of Popper's falsifiability principle of scientific theory (Grim, 1982, pp. 87–93) is juxtaposed against Lakatos's theory of scientific research programmes (Lakatos, 1978). Drawing from these two points of contrast Gaver reflects that design theory is unfalsifiable due to two important characteristics:

1. "*theory underspecifies design - decisions are taken about many factors at the same time, design theory is only ever a 'sometimes' thing.*
2. *Design is generative - not what is, but what might be. Design, and research through design, is generative. Rather than making statements about what is, design is concerned with creating what might be, and moreover, in Zimmerman et al.'s (2007) formulation, on making the 'right thing'.*"

"*I have suggested that the theory produced from design practice tends to underspecify practice and to be generative in nature, and thus that it is provisional, contingent, and aspirational*" (W. Gaver, 2012).

This ‘provisional’ relationship between design and theory is further explored by Koskinen & Krogh (2015), who state: "*the crux of practice-based design research is that […it] is characterized by balancing numerous concerns in a heterogeneous and occasionally paradoxical product*". In considering theory as part of their argument for design accountability they claim that various theories "*from other disciplines can give partial answers to design problems, but cannot give answers to everything designers need to know*" (Koskinen & Krogh, 2015). In this thesis, the research borrows from various theories as part of a building of a rich picture of food experience through multiple perspectives.

3.2.5 Material Approaches in HCI

Material Approaches for HCI calls for engagement with all available perspectives to understand and design with a material’s qualities and possibilities. It is rooted in considering and mixing together insights, both broad knowledge about whole things and micro understandings of material composition and potential. It directly connects to *Material Research* as one of the activities identified by Frayling (1994) in his original description of RtD. In this thesis, its application aims to reconcile food and food experiences with technology and technological experiences, allowing the research to identify, design and reflect on food as material and as part of an interactive system.

Material and Materiality is a growing topic of HCI research, developed in response to emerging materials and technologies that require alternative approaches. Wiberg (2014) proposes a framework to work with materials in HCI “*back and forth between details and wholeness, materials and textures*”. Each level is defined via two characteristics and are presented below.

Material

Material Properties - understand the properties to envision new design and to reimagine the material itself

Material Character - the sum of the material properties, how it can be used, what it expresses and its logic

Wholeness

Composition – consider the social and cultural context the experience of the designed artefact

Meaning – The ways the object is perceived or understood

Texture

Appearance – how a material is "manifested, presented, and perceived", this is not only visual

Authenticity – how much does the appearance match reality

Detail

Aesthetics – how the details are arranged as part of wholes

Quality – how well does the material perform the given purpose

(Wiberg, 2014)

Each level and characteristic offers a different lens to approach questions of materials and user experience. The hierarchical arrangement allows researchers to abstract down to fine 'details', whilst still insisting on the value of relationship between each level of the hierarchy. In this way, the approach prevents material science or semiotics of material to become the sole consideration.

The value of a material approach to RtD has been argued by (Fernaeus & Sundström, 2012) who call for the "*appropriate use of the experiential qualities of the design materials available*". With regard to approaches, they recommend four areas of focus, each defined by a series of questions:

1. Material Explorations – *"What are the limits, possibilities, and properties of specific materials, compositions and resources in terms of making interactive artefacts? What experiences can the materials trigger? What potential applications do we see?"*
2. Methods for Materials Explorations – "*How do we achieve understanding and knowledge of a new material, composition and/or resource's specific qualities and affordances? What methods and measurements are needed?"*

3. Methods for communicating material properties, and possibilities – *"How can the material properties be communicated to, and understood by various stakeholders? What forms of representation can be used to in a meaningful way share this knowledge? (demonstrators, video, diagrams, what else?)"*
4. Practical application of knowledge gained from material explorations – *"How may deep understandings of material properties be used concretely as a resource in interaction design? How may material explorations spur and potentially direct, inspire, and allow for new user-centred innovations?"*

Adding to these approaches (Fuchsberger et al., 2013) draw on McLuhan (McLuhan, 2011) for definitions of *sensory impressions* (what the material can provide) and *sensory effects* (what sense is experienced by a user). They argue that sensitivity to the distinction between these two definitions is important for design, as it is not simply enough to design with sensory impressions and potential experiences, but attention must be paid to how sensory impressions become sensory effects, or actual experiences for each and every one of the users of a design outcome. They propose a sensitivity to sensory experience as key to material appreciation, as well as to the creation of '*rich sensory effects'*.

3.2.6 Defining Material Approaches

Now set-out are definitions for material approaches as used in this thesis, drawing the discussed proposals by Wiberg (2014):

- Material approaches can sit alongside a range of HCI approaches.
- Material approaches propose that research and design draw from as many perspectives as possible to understand the material from micro-level (e.g., material science) to macro-level understandings (e.g., material semiotics)
- These perspectives can be taken in turn but must be reconciled and connected through the design practice
- Material approaches reject singular lenses as sufficient to support a research program into design with a material

3.3 Rationale

The selection of the above methodologies is now justified with reference to the research questions. Figure 6 isolates the approaches relevant to the methodology.

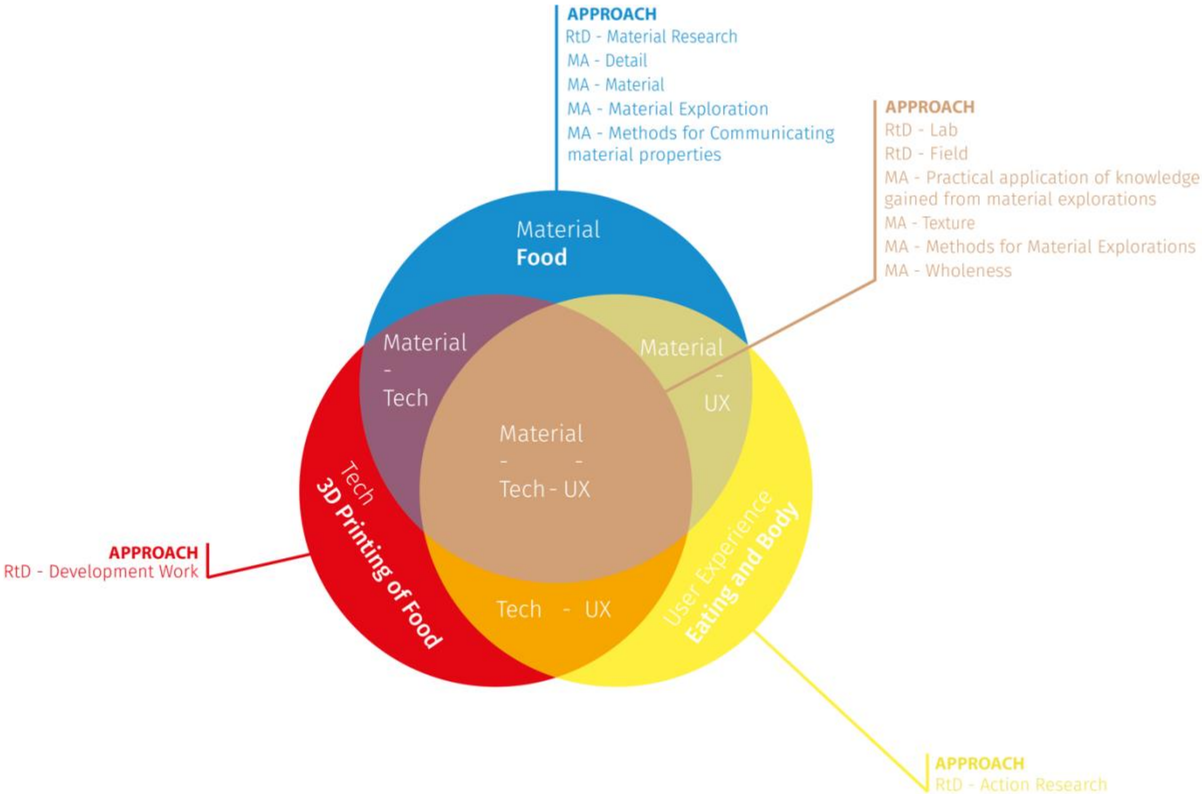


Figure 6 Diagram showing methodological approaches as they relate to the three concerns of the thesis: Food, 3D printing of food and Eating and Body

RQ1 - How can food be used to create novel multisensory emotional and memory-based interactions in HCI?

This question aims to uncover the qualities of food as a material for experience and practice. Material approaches are particularly suitable to understand aspects of food experience from details to wholeness (Wiberg, 2014). This approach supports the mapping of existing knowledge about food experience and asking what this means for HCI. This thesis' findings include examples of *material characteristics* (Fernaeus & Sundström, 2012) such as taste, which have been examined for their role in emotional experiences, *meaning* explored through individual's personal relationship with flavours, as well as *working back and forth between details and wholeness* (Wiberg, 2014). Part of answering this question is exploring gaps between *sensory impressions* and *sensory effects* (Fuchsberger et al., 2013), particularly as they are understood in real-life scenarios.

This first question is also partly answered through the RtD methodology. Food is a relatively new material to design with in HCI (Altarriba Bertran et al., 2018), but has been extensively studied and analysed within different disciplines, including Sensory science and Psychology. Key for this is the emphasis on the people as sensual beings (Zimmerman & Forlizzi, 2014), and their interaction with food as a highly sensorial and multimodal experience (Spence, 2010). By leaning into a design approach that aims to explore the sensorial aspect of food experience, this research aims to extract the full value of existing knowledge on food experience beyond HCI for applications in HCI, starting with *Lab* approaches (Koskinen et al., 2011). This research borrows insights from Psychology to seed potentials for interaction design in HCI to *"more fully engage people's bodies to richly express themselves"* (Koskinen et al., 2011).

RQ2 - How can 3D printed food be utilized in multisensory human-computer interactions?

This second question focuses on the qualities of technology that support delivery of food experience in HCI. To understand the capabilities of 3D printing technology, a RtD approach allows progressive enquiry, *'probing on what the world could and should be'* (Zimmerman & Forlizzi, 2014, p. 168), it is perhaps mostly closely related to *'Developmental Work'* (Frayling, 1994). Both *Lab* and *Field* approaches (Koskinen et al., 2011) are instructive in exploring the role that technology plays in delivering food experience in HCI. *Lab* provides a starting point for the enquiry, focusing on aspects of the interaction in isolation, which then can be folded back into contextual uses through *Field* based research.

This question is also concerned with the qualities of practice that arise from the experience and use of the 3D printing of food, examining how what is created as novel (e.g., 3D printed food and the experience it entails) connects with pre-existing knowledge and behaviour. In part due to the richness of the experience of food, particularly related to its experience in context, answering this question required engagement with *Field* work (Koskinen et al., 2011). Placing the technology into people's everyday lives and contexts provides a catalyst for imagination and exploration of a 'world that might be' (Koskinen et al., 2011).

RQ3 - What approaches can support the design of interactions with 3D printed food? The final question is focused on the creation of '*shared vocabularies'* and '*multifaceted understandings* […] *to extend the reach of HCI*' (Wiberg et al., 2013). In practice this means the development of design and research processes that mediate between food (material), 3D printing of food (technology) and eating and the body (user experience). In the course of answering this question the work produced corresponds with two of the four areas of focus for materials as outlined by (Fernaeus & Sundström, 2012), namely '*Methods for materials Explorations*' and '*Methods for communicating material properties, and possibilities'*. The research attempts to develop ways of understanding and designing with food, and also to create ways of communicating the knowledge of the insights and processes to a wider audience so that it can contribute to further work with food and multisensory interaction design in HCI.

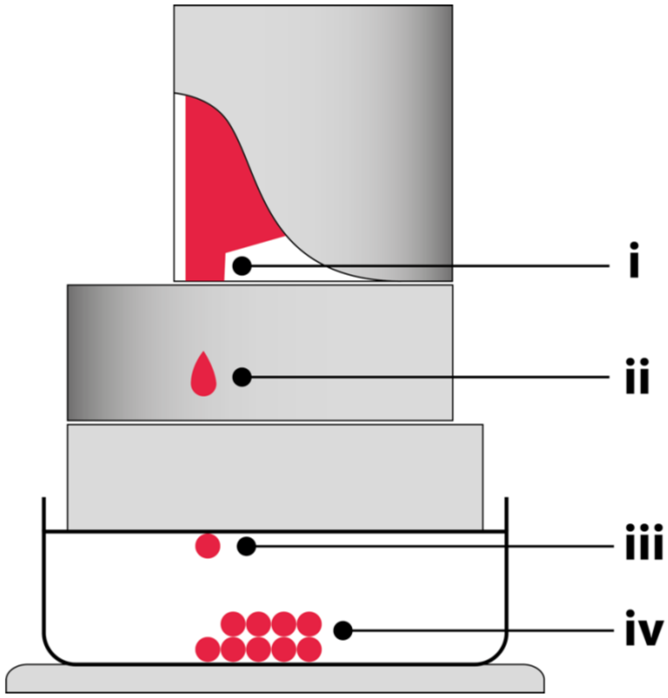
3.4 3D printing food

3D printing food is the application of additive manufacturing technology for production of edible structures. For this thesis, the nūfood 3D printer was used to support the design of multisensory experiences in HCI through the integration of food into interactive contexts. The nūfood printer uses a process of reverse spherefication of liquid phase materials and differs from extrusion type printers that use solid materials. Rather than relying on heat and pressure to undertake the printing task, a chemical reaction is used. This means nūfood can be used with a variety of flavours that are more problematic to utilise with solid food extrusion printers.

The nūfood printer is a development prototype and has been designed for consumers to 3D print food at home. The printer is about the size of a kettle and has been designed to minimise the cleaning actions necessary for safe use. The printer consists of two 'tanks', these are situated in the top section of the printer (i, Figure 7) and allow two flavours to be printed with simultaneously. The printing process relies on the mixing of two liquids; one being the 'flavour' which is added into one of the two tanks in the top of the printer, and the other being the 'bath', which is a flavourless liquid in a glass bowl at the base of the printer (iii, Figure 7). The printer functions by depositing droplets (ii, Figure 7) of the ‘flavour’ into the ‘bath’ (iii, Figure 7). The printer deposit droplets across the print area by moving the print head. Once the droplets come into contact with the bath liquid, they react and form a gelatinous skin on the droplet. This reaction continues once the droplet is at rest on the base of the bath and allows adjacent droplets to join together forming a solid structure (iv, Figure 7). This solid structure can then be removed from the printer once complete. Height can be added to the print by building layers of droplets on top of others, all prints must be widest at their base and cannot print overhangs.

The printing process is control by a mobile app, this app allows the user to start and stop the print process, design the shape of the print and select which tank each droplet should be printed from (allowing the use of two different flavours in one print). The app connects with the printer via wirelessly via Bluetooth. The design of prints by the user takes place on a canvas which displays one layer at a time, users can touch the screen to create a droplet, dragging their finger across an area to create a 2D layer. By using arrows at the edge of the screen they can navigate to the next layer to add height. Once the user is happy with the design for the print, they can press the ‘play’ button on the app to trigger the printer to create their design. Once the printing cycle is finished the print is removed from the bath via the use of a slotted spoon which allows the user to drain away excess bath water. It can be eaten straight away, or it can be kept for a few hours, however the longer it is left the print is more likely to leach out the liquid flavour from within the gelatinous skin.

The food produced by the printer is gelatinous in texture, the printer is capable of producing prints varying in size from a single 1ml droplet to a larger 150ml shapes made up of multiple droplets. When bitten into, the prints give the sensation of ‘bursting’ as the outer gelatinous skin of each droplet ruptures and the liquid contained inside the droplet is released. The strength of the gelatinous skin of each droplet can be varied through leaving prints for longer periods in the bath after printing. This produces prints which are less pleasant to eat but are more suitable for being picked up by hand. Prints removed from the bath straight after printing are best eaten from a spoon. The colour of the printed food will be dictated by the colour of the flavour used; this can be manipulated via food colourings. Prints can be refrigerated but are not suitable for normal freezing, it is possible to flash-freeze the prints with the use of liquid nitrogen and then stored in a normal freezer environment and defrosted at room temperature prior to use.



i - ‘ink’ tank containing flavour

ii – droplet deposited

iii- droplet forms a sphere as it meets the bath

iv- droplets falls in the bath and bonds together to form the shape

Figure 7 Diagram of printer, describing the printing process

3.5 Mixed Study Methods

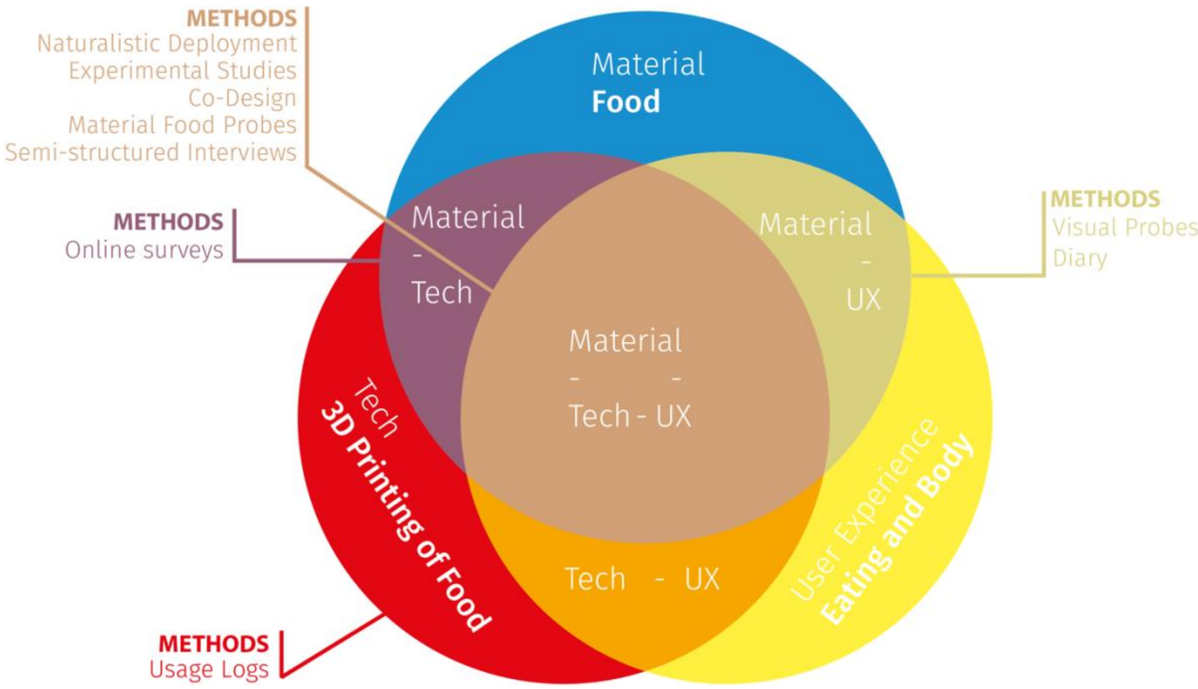


Figure 8 Diagram showing individual methods as they relate to the three concerns of the thesis: Food, 3D Printing of Food and Eating and Body

This thesis uses mixed methods for gathering data, both quantitative and qualitative data across 7 studies (Table 6). This supported the creation of a '*richer picture of the situation'* (Blandford et al., 2016, p. 72). Both quantitative and qualitative methods were employed to leverage their complementary benefits: descriptive survey data and controlled experiments for understanding of niche, specific aspects; and interviews, co-design workshops and probes for rich understandings and explorative inquiry. Figure 8 shows connections between the methods used and the aspects of the thesis (material, technology and experience). The approach to analysis both within studies and between studies involves triangulating qualitative and quantitative methods to ensure complementary findings, convergence of agreement between methods, and integration of different measures (Jick, 1979). Such triangulation of interviews and scales is not uncommon in HCI, with much cited papers on emotional experiences and memories using it (Isaacs et al., 2013; McDuff et al., 2012). In particular, the range quantitative methods provided descriptive statistics to identify themes and allowed testing of hypotheses on concepts and self-report measurements through validated scales.

RtD	-	-	Lab	Field
Method	Surveys	Interviews	Experiment Interviews	Diary Co-design Probes In-context deployment Interviews
Study	1. User Perceptions of Technology for the 3D Printing of Food	2. Taste-Emotion Mappings and Food Experience Design Strategies from the Perspective of Food Design Practitioners	3. Taste Your Emotions: An Exploration of the Relationship between Taste and Emotional Experience for HCI	4. Material Food Probes: Personalized 3D Printed Flavours for Emotional Communication in Intimate Relationships
Outcomes	User perceptions Early adopter profiles	Mappings in context Food experience design strategies	Mappings in HCI Applications for mappings Flavour suggestion	Material food probes Focal intimacy practices Co-design process for food
Study type	Exploratory Technology	Exploratory Food and experience	Design and co-design Taste-Universal	Design and co-design Flavour-Personal

RtD	Field	Field	Field
Method	Co-design Probes Experiment Scales Interviews	Expert workshops Surveys	Focus Groups Wireframes Wizard of Oz
Study	5. "It took me back 25 years in one bound" Self-Generated Flavour-based Cues for Self-defining Memories in Later Life	6. The Design of a Multisensory Visual Probe Kit to Support Personalised Flavour design	7. The Design of a Mobile App for Capturing Multisensory Experience and Designing Personalized Flavour Cues
Outcomes	Co-design process for food Flavour-based memory cues	Probe kit design	App wireframes
	Design and co-design Flavour-Personal	Design and co-design Flavour-Personal	Technology design and evaluation

Table 6 Table showing studies with relevant approach, methods and outcomes

3.5.1 Rationale

Mixed methods were mostly applied within the same studies to allow research to *work back and forth from details to wholeness* (Wiberg 2014) and to answer each research question in a rich and detailed way. For example, RQ1.2 asks what relation exists between emotion and food (answered through quantitative methods) and how it can be harnessed in HCI (answered through qualitative methods). As this thesis set-out to explore and design novel multisensory experiences with HCI it was important to both attest to the efficacy of any proposed interactions as well as understand the value and meaning for users. Food experience comprises aspects of universal experience (*relations* such as taste-emotion mappings) and some idiosyncratic ones (ways of *harnessing* relations such as flavour-based memory cues) and thus the research methods applied needed to be able to account for this as well. Quantitative methods allowed comparison between conditions in experimental studies but also comparison to wider populations, whilst qualitative methods could capture the peculiarities of an individual's experience in a rich and rigorous way.

3.6 Qualitative Methods

3.6.1 Semi-structured Interviews

Semi-structured interviews consist of pre-planned themes or questions that allow the researcher the freedom to follow-up on any emergent points of interest (Blandford et al., 2016, p. 40). Interviews were used to collect the perceptions, attitudes and experience of subjects, both in *Lab* and *Field* work. Whilst similar to surveys, they allow the researcher to go deeper into the 'why' and 'how' behind each answer, uncovering motivations and reasonings behind choices and attitudes. For each interview conducted in this thesis an interview guide was prepared which outlined questions and prompts for further data around the topic of interest (Y. Rogers, 2011a). Semi-structured interviews were used with different groups, from professional chefs and food designers, to study participants before and after interactions with 3D printed food and technology for the 3D printing of food.

They delivered insights for both RQ1 and RQ2, helping understand the experience of food and how 3D printed food could be used in HCI. Through semi-structured interviews, the research could be focused on a particular aspect of food experience (RQ1.1, RQ1.2) with interview guides drawing upon literature to explore points of interest but allowing data gathering that was responsive to the sensitivities and experience of the individual (Blandford et al., 2016, p. 41). This allowed the research to follow-up on emerging perceptions and practices as they were described (RQ2.1). In this way the interviews both gave insight into design spaces set by the designed intervention but also opened up opportunities for further design and research.

3.6.2 Diary study

As the attention of the research moved towards *Field*-led work it became important to gain an understanding of the peculiar nature of an individual's food experiences. The diary study is a form of retrospective analysis, that allows users to record and reflect on activity after the event (Katie A. Siek et al., 2014; Y. Rogers, 2011a). This was particularly useful for engaging with food experience through eating meals and snacking, due to their frequently occurring nature and distribution throughout the day. Therefore, by moving to a lightweight, immediate post-event reflection, the necessary data could be captured without disrupting the experience itself. In study 4, the data collection phase was made as low effort as possible to support participants to complete the task. The reflection on the behaviours observed took place after the fact with guidance and some prior analysis by the researcher to prompt a detailed reflection by the participant. This collaborative reflection was important not only for the data collected but also to support participant's engagement and awareness of behaviour (Katie A. Siek et al., 2014). Diaries helped answer RQ1.1 on the relation between food and emotion. In particular the use of mobile diary capture supported the integration of multimedia content into the diary which created an easy-to-use tool and thus there was greater compliance in completion. This was key to supporting the research to uncover the valuable yet unremarkable experiences not accessible through other methods.

3.6.3 Probes

Originally coined by B. Gaver et al. (1999), cultural probes offered a new design research method for working with remote communities. As a design tool they have been adapted and adopted widely for a range of purposes and contexts (Boehner et al., 2007). The original cultural probes were not strict tools for measurement but instead were based on a desire for uncertainty and the role that could play in design inspiration (W. W. Gaver et al., 2004). Despite the variety of applications, there are a core set of functions that probes serve, taken from (Graham et al., 2007);

- Probes humanise - create personal accounts, maintain the individual
- Probes create fragments - not whole data, but glimpses that need putting in context and work to interpret, also allows sensitivity to take place
- Probes use uncertainty - they require some working out from participants
- Probes inspire - create an indirect route to an idea

- Probes engender interpretation - they need to be made sense of
- Probes provoke - they impact on participants to shape thinking

These functions were drawn upon to create two forms of probe used in this study. The first is a *multisensory probe* kit that aimed to sensitize participants to food experience and the second, *Food material probes*, used food as a form or personalised, social experience elicitation. These are both further outlined below.

3.6.3.1 Probes - Multisensory (after Gaver)

The aim of the *multisensory probes* was to create empathy between designers and participants (subjects of design) through a mutual understanding of participants' "flavour-world" built on the description of *Taste worlds* (Beauchamp & Bartoshuk, 1997) a term for the personal perception of taste. The multisensory visual probe kit (Study 6, Chapter 9) drew on the paper-based tools used in the original Cultural Probes (B. Gaver et al., 1999) as well as novel elements. The elements were designed around different aspects of flavour experience, in particular examining embodied experiences that arise through flavour. They embraced the individuality of each participant, aiming to create 'fragments' of insights (Graham et al., 2007) that informed both the participant and designer. They were also an important part of context setting for later co-design activities as it made apparent the divergent and changeable nature of food experience. They made the participants comfortable with uncertainty (W. W. Gaver et al., 2004; Graham et al., 2007) as well as allowing them to practice interpreting their own food experience.

3.6.3.2 Probes - Material Food (Integrates Material Probes and Technological Probes)

Whilst the *multisensory probes* offered an interpretation of an existing model of probe kit design, material probes are a synthesis of two existing probe approaches reconfigured to explore food experience in HCI. It brings together *Material Probes* (Jung & Stolterman, 2011) with *Technological probes* (Hutchinson et al., 2003), drawing from both approaches to explore both food material as well as food-based interfaces in evaluating experience.

Technology probes (Hutchinson et al., 2003) consist of simple, single function novel technologies that are placed into people's homes. Participants interact with the provided technology and thus expose design potentials. *Material Probes* (Jung & Stolterman, 2011) are similarly interested in potentials, however in this case it is related to a material. The approach here marries together these two related but distinct approaches to examine three forms of interaction associated with 3D food experience:

1. The experience of printing food with a 3D printer for food
2. The experience of production and design of the foodstuff
3. The experience of use of the designed foodstuff in naturalistic contexts

A material food probe consists of specially designed flavours of 3D printed food. Each user co-designs these flavours according to specific experiential purpose (e.g., to express an emotion). These foods are provided alongside a 3D printer for food for users to use within their everyday contexts, allowing them to explore specific contextual use cases. *Material food probes* extend *Technology Probes* by not being just the technology, but also by including the food; they also differ in the co-designed flavours used within the probe. These support *autobiographical accounts* (Graham et al., 2007) through the personally meaningful flavours and are given in a context where *dialogue and conversation* (ibid.) can occur between multiple parties (user to food to printer to other user).

This novel probe method is informed by the material approach of '*working back and forth between details and wholeness'* (Wiberg, 2014). The co-designed flavours of 3D printed food represent an attention to the *material* and *detail*, whilst the use of the printer and their consumption in naturalistic context reflect insights into *texture* and *wholeness*. Their construction offers a new method for material exploration (Fernaeus & Sundström, 2012) that is embedded in the material within context (both the context of use as well as the context of technological system such as the 3D printer for food).

3.6.3.3 Rationale

RQ3 aimed to understand what approaches can support the design of interactions with 3D printed food. Probes were key to creating an empathy (B. Gaver et al., 1999) towards individuals food experience, both on behalf of the designer and the individual themselves. This was key to development of approaches for designing with food in general and 3D printed food in particular. Semi-structured interviews supported the capture of verbalised details of food experience; however, responses relied upon the individual to make sense of and explain their experience. Probes took a different approach to the explanation of experience, engaging with a range of modalities to support exploration of forms of expression that might be better suited to food experience (and doing so helped answer RQ1.1). They also combined with the diaries to create extended interactions, that supported longer term data collection that could align better with the nature of food experience. Probes were also key in disrupting and destabilising (Wilde et al., 2017) food experience in ways which opened up design possibilities and provoked (Graham et al., 2007) participants to consider how food experience *might be* in designed interactions. The use of material food probes helped answer RQ2.2 and 2.3 on how food could be experienced in everyday life and what contexts were feasible to support through 3D printed food.

3.6.4 Co-design

Co-design is an approach that proposes a different relationship to the traditional active designer/researcher and passive user. It aims to engage the 'user' so that they become an active participant in the design process (Muller & Druin, 2012; Sanders & Stappers, 2008). The intention is to support designing "*for the future experiences of people, communities and cultures who now are connected and informed in ways that were [previously] unimaginable*" and aims to move from the *designing of* things towards the *designing for* experiences (Sanders & Stappers, 2008). As a practice, it is informed by a wealth of fields and as such the diversity has not led to a single dominant process or application (Muller & Druin, 2012, p. 1130), a fact that is reflected by the two forms used within this research.

3.6.4.1 Co-design workshops – multisensory food design

A challenge of working with sensory and multisensory experience is the way each individual has a personal experience (Beauchamp & Bartoshuk, 1997; Schifferstein & Desmet, 2008), essentially the differing *sensory effects* of the same *sensory impression* (Fuchsberger et al., 2013). As part of designing flavours of 3D printed food for use within the different design applications, co-design workshops were used (Studies 4 and 5). Workshops involved the meeting of the researcher with the participant to work together to co-design flavours for specific goals. The workshops included materials to take people outside of their normal working practices and provoke creative thought (Muller & Druin, 2012, p. 1133). The use of such workshops shared similar aims to co-design activities as part of the *Lover's Box* project in which participants worked with artists to create content as part of the design outcome (Thieme et al., 2011).

3.6.4.2 Co-design workshops – Expert probe design

A different application of co-design was undertaken as part of the development of the multisensory probe kit designed through this research (Study 6). These involved experts from Design and Computer Science contributing their domain knowledge to help shape a design outcome. The workshops aimed to engender dialogue between different traditions as acknowledgement of the 'hybridity of HCI' (Muller & Druin, 2012, p. 1130).

3.6.4.3 Rationale

Co-design as a method supports each of the research questions (RQ1,2,3). Through working with individuals, it overcomes the idiosyncratic nature of food and flavour experiences (RQ1), supporting individuals to shape interactions towards their own perspectives. Through working with participants to create personalized experience co-design also supported engagement with technology, particularly where that was deployed in participants home (RQ2). Finally, co-design with experts shaped the creation of tools with knowledge of the needs of designers and HCI researchers to support wider research in future (RQ3).

3.6.5 Deployment in Naturalistic contexts

Deploying design artefacts or systems in 'real-world' or naturalistic contexts enables researchers to understand how interactions take place in-situ (Katie A. Siek et al., 2014, p. 119). It offers advantages over lab-based settings by allowing user the freedom to adopt the intervention into their everyday. Although deployment in this Study 4 stopped short of a full 'in-the-wild' deployment lasting a significant period of time (Chamberlain et al., 2012) this was largely a constraint of shorted timescales imposed by the perishable nature of food. The 'field sites' relevant for this work were users' homes, with the usage able to interact with everyday existing practices around food and communication. Data collection occurred through a mixed of methods including usage logs, user-entered data and post-implementation interviews (Blandford et al., 2016, p. 95). Deployment allowed a deeper understanding of how 3D printed food could be utilized (RQ2).

3.7 Quantitative Methods

3.7.1 Experimental Studies

Experimental studies aim to gather scientific knowledge and are common amongst a range of disciplines. In essence they take a variable of interest (e.g. the taste of food) and examine how manipulation of this variable has an impact on another measurable variable (e.g. perceived emotion) (Darren Gergle & Desney S. Tan, 2014, p. 191). This approach is often favoured as part of a *Lab* based approach. In this thesis, experimental work on the mappings of taste and emotions is undertaken in Study 3 to examine whether they are applicable to HCI-relevant contexts of use. In Study 3 hypotheses were formulated and then tested. (Robertson & Kaptein, 2016, p. 83). An advantage of the experimental approach is the ability to describe an approach that can be repeated by other researchers, as repeatability adds to the internal validity of the findings. A limitation of experimental research is that it relies on aggregate data and as such requires larger samples, thus providing a challenge to examining personal and variable experiences such as flavour. This method contributes to answering what the relationship is between emotion (RQ 1.2), memory (RQ 1.3) and food and how it can be harnessed in HCI.

3.7.2 Usage Logs

"In HCI research behavioural logs arise from the activities recorded when people interact with computer systems and services" (Susan Dumais et al., 2014, p. 350). Usage logs allow for pictures to be built up of a range of aspects of interactions, including frequency of use, time of use and duration, allowing the inference of patterns in activity which could be further explored through interviews (Barik et al., 2016). In Study 4, logs supported understanding of how the use of the 3D printer related to a user's daily activities. The use of logs and interviews together effectively demonstrates the potential for quantitative and qualitative data to be woven together to generate a

richer understanding of experience (Blandford et al., 2016). Logs were chosen to answer how 3D printed food could be experienced in everyday life (RQ 2.2) and what contexts were feasible to support through 3D printed food (RQ 2.3).

3.7.3 Online Surveys

"A survey is a method of gathering information by asking questions to a subset of people, the results of which can be generalized to the wider target population" (Müller et al., 2014). In this thesis, surveys were used to measure the attitudes and intent of potential early adopters towards technology for the 3D printing of food. These surveys comprised valid and reliable scales as well as bespoke Likert scale ratings for various purposes. Surveys were conducted remotely over the internet in order to reach a large sample with the specific characteristics (Loren Terveen et al., 2014). Surveys contributed to answering how 3D printed food could be experienced and used in everyday life (RQ2.2) by capturing data from larger samples in an efficient manner. It also allowed access to more specialized and geographically diverse populations, which was particularly useful in understanding more about early adopters of 3D printing for food. The integration of validated scales with more open-ended responses mirrors the mixed methodologies more widely applied to this thesis.

3.8 Studies overview

The following sections report on the studies that have informed this study, detailing the specific methods, findings and discussion of results. The thesis commences with 2 exploratory studies which explore technology (Study 1) and food and experience (Study 2). The thesis then details 4 design and co-design studies, the first deals with taste as a universal experience in the lab (study 3). Study 4 and 5 consider flavour as a personal experience in field settings. The final study in this group (study 6) details a method related to flavour as a personal experience in field settings. The thesis concludes with a technology design and evaluation study (study 7) reporting a method for flavour as a personal experience in field settings. Figure 9 indicates how these studies provide insight into the 3 aspects of the thesis. Whilst the first study addresses the connection between material and technology, largely studies focus on the connection between the food material and experience for the earlier studies and then move onto the combination of the three aspects for later work as insights are knitted together from earlier work.

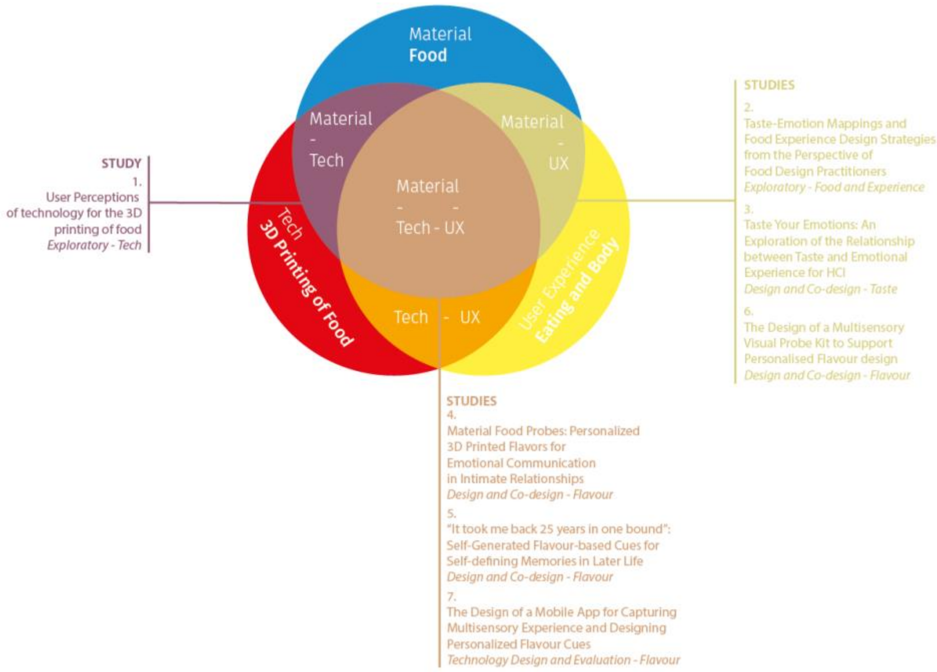


Figure 9 Diagram showing studies as they relate to the three concerns of the thesis: Food, 3D Printing of Food and Eating and Body

4 Study 1 User perceptions of Technology for the 3D Printing of Food

4.1 Aim

The first study in this thesis explores the technology of interest, 3D printing of food with potential users and draws on published work (Gayler et al., 2018).

4.2 Method

The research method consists of a survey exploring early adopters' perception, attitudes and knowledge of 3DPF (3D printing of food) technologies through three sections. First, two valid and reliable scales were used; the Food Technology Neophobia Scale (FTNS) (Cox & Evans, 2008), and Social Representations scale for novel foods (Onwezen & Bartels, 2013) developed by food science researchers for measuring consumers' perception of novel foodstuffs. These supported assessment of attitudes in comparison to the validating population to indicate the degree to which the selected groups more readily accepted novel food technology. For both scales, comparisons were made between the data collected and the validating populations using z-tests (as opposed to t-tests) as the full data for the populations were not available. Second, participants were asked to report their perceived risks for sourcing, processing, selling, preparing and eating 3D-printed food. This aimed to uncover the motivations and factors influencing adoption for the selected groups. Third, participants were also asked about direct experiences of the 3D printing of food and the envisaged contexts where they expected to see this technology used in.

4.2.1 Participants

The survey was targeted to three communities of potential early adopters' and answered by 24 members of nūfood's 3DPF Mailing List, 6 members of a 3D Printing Forum (www.3dprintboard.com), both groups were selected because of their familiarity with 3D printing, and 20 Computer Science students included to explore attitudes beyond those engaged with the 3D printing community. This study explores how well these groups do in fact represent early adopters. The groups chosen for this study were selected as potential candidates to be early adopters of 3DPF due to their familiarity with technology in general or 3D printing in particular. This aligned with literature on early adopters (E. M. Rogers, 2003) that suggests ‘Early Adopters’ as motivated by novel and rewarding experience and less concerned with the risks of technology in comparison to other population segments.

Figure 10 Photo of the nūfood 3D liquid food printer. Photo courtesy of Dovetailed Ltd.

Sample	N	Mean	s.d.	z-test	Sig. (p)
(Cox & Evans, 2008) Population	294	55.00	11.90	--	--
3DPF Mailing List	24	41.54	12.00	-5.54	<0.01*
3D Printing Forums	6	40.83	10.36	-2.92	<0.01*
Computer science students	20	48.15	8.31	-2.57	<0.01*

Table 7 Food Technology Neophobia Scores of survey groups and scale validation population. Significant difference is reported for each study group in comparison to population from (Cox & Evans, 2008)

Sample	Adherence to Technology			Adherence to Natural Food			Enjoyment			Necessity			Suspicion		
	M	s.d.	z-test	M	s.d.	z-test	M	s.d.	z-test	M	s.d.	z-test	M	s.d.	z-test
(Onwezen & Bartels, 2013)	3.11	0.80	--	3.75	0.88	--	3.70	0.84	--	2.20	0.87	--	3.01	0.73	--
3DPF Mailing List	5.21	0.87	12.86*	5.25	1.25	8.35*	6.22	0.77	14.70*	2.57	1.06	2.08	3.87	0.90	5.57*
3D Printing Forum	5.17	0.87	6.31*	3.67	1.61	3.95*	5.50	0.84	5.25*	3.00	0.87	2.25	3.67	1.48	2.21
Computer Science Students	4.77	0.85	9.28*	4.40	1.65	5.18*	5.70	1.42	10.65*	3.27	1.47	5.50*	3.90	0.95	5.45*

Table 8 This table reports the scores for the three groups on the Social Representation Scale in comparison to the population scores from the validation study. Z-tests where p<0.01 are marked with a *.

4.3 Findings

The survey findings focus on the attitudes, perceived risks and envisaged contexts of use for 3D printing technologies, alongside their comparison across the three groups.

Attitudes toward Technologies for the 3D Printing of Food

Table 7 and Table 8 show the Mean and Standard deviation for each of the three groups on the two scales, alongside the population scores from validating studies for each scale (Cox & Evans, 2008; Onwezen & Bartels, 2013). Z-tests were used to compare the samples against population means, the results indicate that all groups are less neophobic towards food technology than the population; 3DPF Mailing List (z=-5.54, p<0.01); 3D printing forum (z=-2.92, p<0.01); Computer Science students (z=-2.57, p<0.01). Z-tests for Social Representation Scale presented in Table 8 also indicate that all three groups show significantly higher adherence to technology than the validating population (Onwezen & Bartels, 2013); 3DPF Mailing List (z=-12.86, p<0.01); 3D printing forum (z=6.31, p<0.01); Computer Science students (z=9.28, p<0.01).

A comparison of these scale' scores across the three groups shows significant differences on the enjoyment dimension 3DPF Mailing List (z=14.70, p<0.01); 3D printing forum (z=5.25, p<0.01); Computer Science students (z=10.65, p<0.01). This suggests that exposure or interest in the 3D printing of food may offer a more engaging experience as opposed to 3D printing in general. Together these findings indicate that all three groups are significantly more open towards engaging with the novel 3D printing food technologies which is the marker of early adopters, with adopters of 3D printing food technology being more engaged than other groups.

Perceived Risks of the 3D printing of food

Food technologies bring a new set of considerations for consumers deciding to try a novel foodstuff (Cox & Evans, 2008). To better understand how such risks of the 3D printing of food differ from other food technologies, participants were prompted to describe perceived risks at five stages of food production (sourcing raw materials, processing materials into products, selling products, preparing products for consumption and eating the product). Findings indicate that perceived risks of sourcing 3D printed food are centred on environmental concerns, in line with the environmental impact of production for other food technologies (n=9): "w*ill [it] require the same land as non-printed food? No environmental benefit would make this more of a fad*" (Participant 18, Student). When asked to consider the processing of this food, the major risks were adulteration and additives included in the final food product: "*I imagine a number of non-nutritional preservatives will possibly have to be added to the food"* (P12, Student) In contrast to product-focused risks for the sourcing and processing, the perceived risk for selling related to consumers' lack of awareness and bias against this technology: "*consumer bias against trying new things and the stigma of 'artificial' food*" (P8, Student).

Perceived risks related to the preparation had the most prominent divergence from traditional foodstuff concerns. The major issue was the misuse or malfunction of the printer (n=20). Unlike most other food technologies (GM, Mass Production) the technology of 3D printed food is located much closer to the consumer. The potential for more creative use of the foodstuff is placed in the hands of the consumer but it also shifts the risk of malfunction closer to the consumer as well. The most prominent eating risk related to health and diet (n=14) however it was more nuanced with a focus on *"long term negative effects [that] are unknown, and untestable*" (P7, Student). This uncertainty suggests a challenge in moving the 3D printing of food technology from a one-off experience into a tool for every-day use in domestic contexts. While the risks reported at each stage echo the commonly perceived risks for all food technologies (Bearth & Siegrist, 2016) they also focus on technology's common myths. In the selling of food, the major concerns related to its opacity, limiting people's ability to understand how it works. There is no existing mental model for making sense of this technology which if not addressed, could hinder adoption.

Envisaged Uses of the 3D printing of food

The most commonly known 3D printed foodstuffs are predominantly sweet tasting, chocolate being the most used (Khot et al., 2017). Sugar was another commonly mentioned foodstuff also used in 3D System's Culinary Lab (2015). When asked if they had actually tried 3D printed food (3DPF Mailing list n=10, 3D Printing Forum n=1, Computer Science Students n=1) participants reported trying it at exhibitions or dining events. In line with this being an emerging technology it is expected to be seen at exhibitions but its use in dining events suggests the technology may first mature as a tool whose primary purpose is provision of experience, rather than the provision of nourishment. When asked about the envisaged uses for the 3D printing of food technology most participants mentioned research (n=22), this suggests a non-domestic application for 3DPF. The second most envisaged use was for creative purposes (n=21), here the ability of 3DPF to create *"novel shapes for confectionary"* (P18, Mailing List) was understood to offer potential for applications in the decoration and presentation of food. A more surprising use for the technology was in the provision of food aid in emergency situations (n=7). None of the participants provided a reasoning for this, although it is possible the technology is perceived as being able to construct satisfying meals from limited resources, there is some evidence for this claim in participant 19's (Student) potential use of the technology to *"convert rotten food to edible foods"*. A perhaps more feasible expectation for 3DPF is in assisting healthcare and healthy eating (n=6). Expectations ranged from portion control (recognizing the influence of digital control) to preparation of personalized diets (recognizing the model of micro-manufacture offered by 3D printing).

Speculative responses were also prompted from participants to imagine more unusual applications for 3DPF. Personalization (n=6) was the most often mentioned context, suggesting consumers' desire to tailor meals or dining experiences to their tastes. This also prompted responses that looked beyond the dinner plate with edible packaging (P15, Student), edible tattoos (P11, Student) and even sex toys (P14, Mailing List).

4.4 Discussion

Findings indicate that 3DPF is understood mostly as a non-domestic technology raising concerns over the long-term health effects of the foodstuff produced. Early adopters experience enjoyment from the food technology which as previously suggested (Rödel et al., 2014) places the focus on creating contexts of use where user experience is prioritized. In their speculations, participants reported personalization of meals and utilizing the technology to create bespoke foodstuffs in the home. This offers an exciting opportunity to engage users in the design of their own food experiences, parameters such as taste and form can be guided through digital tools and production handled by the printing technology.

It is clear that early adopters are inspired by 3DPF's potential to be used in emergency aid contexts. Whilst there remain questions over the usefulness of 3DPF to this end, exploration in this area will be welcomed and supported by early adopters. Findings suggest that such a humanitarian or entertainment value should be added to 3DPF in order to drive awareness and familiarity with the technology. 3DPF robots allow the production of food to take place in front of user's eyes. There is an opportunity to consider how the movements and process of printing can be designed into rituals of 3D printed food consumption.

Lack of user awareness towards the technology is a key barrier to adoption. The associated cost to the benefit of moving the ability to make and create foodstuffs towards the user is that they feel a burden to ensure its safety. This provides an insight for the wider HCI community, such as healthcare interventions where technology is empowering users and at the same time passing a burden of responsibility onto the users. Solutions may not only be about education but designing systems that inform user understanding, delivering ways of working that are supportive of creative and safe practice.

This study uncovered more about the early adopters of the 3D printing of food and in particular their interest in novel experiential uses for the technology. The next study draws on an experiential quality of food, namely the relationship between tastes and emotions to consider how chefs and food designers make use of this to create experiences for their diners and audiences. It attempts to highlight how experience designers can draw upon taste-emotion mappings specifically as well as food as a material more generally. Further study 3 continues this exploration by proposing and experimenting with a designer interaction based on taste-emotion mappings.

5 Study 2 Taste-Emotion Mappings and Food Experience Design Strategies from the Perspective of Chefs and Food Design Practitioners

5.1 Aim and Rationale

Study 1 indicated the desire for novel experiences to be delivered through the 3D printing of food. This study explores food and experience by considering one potential use of the 3D printing of food to support user experience. Specifically, how taste-emotion mappings can be utilised in applied design contexts is explored from the perspectives of chefs and food designers. As noted above taste is only part of flavour experience, taste stimuli used in lab studies is often very far from food that might be consumed in everyday life and as such it is unclear how taste-emotion mappings may function within more sensorially rich contexts in real life settings. This study also explores key food qualities imparting rich human-food experiences. To date, little attempt has been made to integrate the expert knowledge of crafts people working with food through their everyday practice into HCI. A specific focus on the design process that underlies the creation and crafting builds a bridge towards a more thorough understanding of food as a resource for design. Chefs and food designers are interviewed here not as potential end users of design solutions, but as material experts whose knowledge can support design approaches employed in HCI. Partial findings are published in (Gayler & Sas, 2017).

5.2 Method

Semi-structured interviews were run with 18 professionals: 10 chefs and 8 food designers, both groups were chosen as they are directly involved in the design and creation of experience with handmade food. The contexts in which they work are diverse including restaurants, pop-up dining events, and specific food-based exhibits or experiences. This selection was made to combine both traditional approaches to food experience from chefs with more experimental and emerging experiences by food artists and designers. These participants were not selected to be designed for as *users* as part of the further work in this thesis but instead to capture their practical knowledge as *experts* in working and designing with food. All participants were recruited from Cambridge and London, UK via mailing lists associated with Dovetailed Ltd. The average age of participants was 34.8 (SD. = 6.2, range 29-55). 8 participants identified as female, 9 as male and 1 as non-binary, representing a gender-balanced sample. 11 participants identified as British, and one each as Canadian-British, Czech, French-Colombian, French-South African, Greek, Icelandic and Nigerian-American.

The semi-structured interviews explored experts' approaches to creating experiences with food. They were asked whether they consider a specific experience in their design or food creation process; what qualities of food they manipulate in their creative process- is it only flavour or did environment, form of interaction or other factors come into play? Participants were also prompted to reflect on whether they only designed for positive experiences and to what degree they embraced challenging or uncomfortable experiences. Also explored were how specific tastes, and other food qualities beyond taste were used to elicit a desired response or experience. Finally, participants were asked to reflect on what the most important food qualities were and to outline how they considered this as part of design of food or food-based experiences. As part of this interview, participants were asked to place the 5 basic tastes onto axes of valence (renamed pleasant-unpleasant for ease of comprehension) and arousal based on the axes of the circumplex model of emotions (Russell, 2003). Participants also matched tastes to discrete emotions (Ekman, 1992) by naming emotions they felt that best represented each taste (Figure 11). In both instances, participants were asked to justify the choices as they made them. Preliminary findings related exclusively to the taste-emotion mapping gathered from an initial 7 participants have been published (Gayler & Sas, 2017). This section reports on the whole interview study with 18 participants, including their taste-emotion mappings (Gayler, Sas & Kalnikaite 2021a). The aim was to uncover their experiential knowledge of how food-based experience and their philosophies towards food experience.

5.2.1 Data Analysis

The interviews lasted around 45 minutes, were audio recorded and fully transcribed. These were analysed on Atlas.ti software through a hybrid approach including both deductive and inductive coding (Fereday & Muir-Cochrane, 2006) leading to a final set of 210 codes. The deductive codes were identified from theory-informed conceptual framework inspired from previous work on taste-emotion mappings (Bredie et al., 2014; Robin et al., 2003) to highlight tastes and emotional responses, including how language and metaphor are built from these mappings (Chan et al., 2013), the multisensory nature of flavour perception (Spence, 2010) to help uncover both the sensory cues arising from the food as well as the context in which the food was consumed, uncomfortable experience (Benford et al., 2013) and trajectories (Benford et al., 2009) to examine both negative or challenging food experiences as well as approaches to mapping out

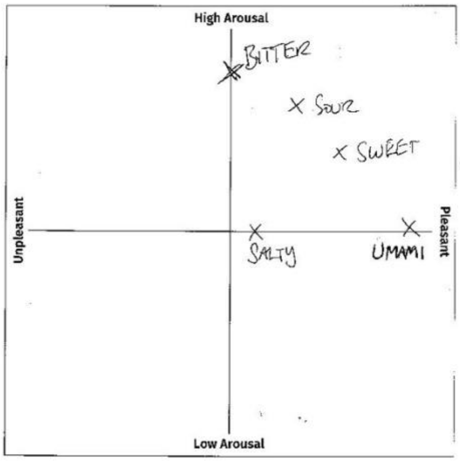


Figure 11 A taste emotion map from P14, a chef.

experience over a period of time or series of interactions. Then this framework was revised on the basis of interview data as new codes emerged around chefs' and designers' process to design food experiences such as *balance, complexity, ambiguity, transformation, ideation, iteration,* and movement metaphors for in-mouth sensations such as *kick, burst, kick, lift, pop.* The codes and emerging themes were iteratively refined through extensive discussions over 3 months between myself and my supervisor until consensus has been reached.

5.3 Findings

Now reported are five identified themes describing sensory experiences, narrative memory-based experiences, comfortable and uncomfortable experiences, balance and contrast, and the theme of design processes highlighting the comparison between chefs' and designers' approaches to food design.

5.3.1 Sensory Experience: Taste, Smell and Colour

The connection between taste and emotion has been consistently shown (Greimel et al., 2006; Kashima & Hayashi, 2011; Robin et al., 2003). Through interviews and taste-emotion mapping exercises, some nuances were discovered that add to the understanding of these mappings in ecologically valid contexts.

The key findings from the previous work (Gayler & Sas, 2017) have been confirmed in this extended study: for the mappings on valence-arousal axes all tastes were rated with positive valence, with the exception of bitter which had a mean negative rating for valence. Sweet and umami resulted in most positive and the highest arousal experiences on average, whilst salty taste received the lowest average arousal (Figure 12).

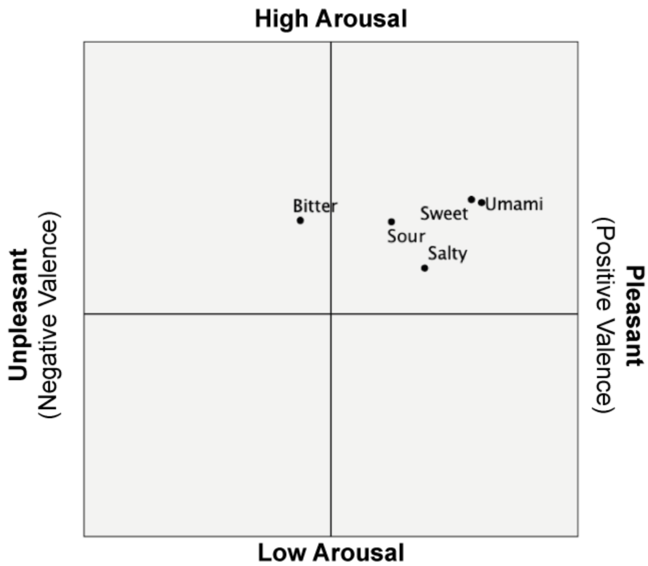


Figure 12 Mean ratings by 18 chefs and food designers for valence and arousal of the 5 basic tastes as part of taste-emotion mapping activity

Salty tastes were mapped to both positive (n=9) and negative emotions (n=8). Also confirmed is the negative perception of extremely low and high intensities for all basic tastes, and the positive perception of medium intensities (n=8). Too much sweetness was described as negative as, *'there is definitely an upper limit to what you can consume because it will very quickly start to make you sick'* (P6). Here the physical consequence informs a wariness towards very sweet tasting foods. Findings also indicate how non-taste characteristics such as trigeminal stimulation from spicy foods (n=13), burnt materials (n=7), or very sharp textures such as dry puffed pork rind (n=6), can also be mapped to discrete emotional responses such as happiness, sadness, and anger, respectively. Enjoyment of bitter tastes is known to be a learnt response (Breslin, 2013) and findings agree with this: *'there is a sort of desire to attain that level of maturity with bitterness'* (P1). Sour sweet treats were a common example of a food stuff in which the sour taste was enjoyed. Often this response was linked to early childhood memories: *'it reminds me of sour sweeties like really sour stuff, reminds me of childhood'* (P5).

For bitter and sour, respondents often pointed to prototypical food stuffs, such as sour sweets or coffee, that were enjoyed.

Aside from emotion-mappings, sour was reported as having an impact on the chemistry of the oral experience as a palate cleanser (n=5): *"we use sour or bitter flavours as a palate cleanser, to create a kind of a space before a major sweet or salty flavour"* (Participant 13). In a similarly functional capacity, fat was reported by 4 participants as *"carrying the flavour so then other elements [of taste] can come in"* (P16). Umami was reported as a complex taste (n=3) and led to experiences that were uncertain and intriguing, however this is perhaps due to the western bias of the group who saw umami as *"from cultures and cuisines that we don't know much about"* (P9, British).

Smell was a widely discussed element of food experience by 11 participants. Largely, smell was considered part of the total experience through its role as aroma in a flavour experience both complimenting and contrasting with the taste experience (n=4). For instance, P9 describes creating a dish in relation to a scene at *"a rotten fish market"* in which they *"wanted to evoke some of those [rotten, fishy] aromas whilst still making it taste good"*. It can be seen how smell is being manipulated to create a tension between the mouth and nose, delivering pleasure to one and disgust to the other. Smell also interacts with the body at a greater distance than taste, P7 reported considering whether to cover a soup with a biscuit to delay the smell delivery, or to perhaps waft a smell in prior to serving, to play with the diner's sense of anticipation.

Colour has been shown to be able to influence taste perception (Spence et al., 2010) something appreciated by participants. At a more abstract level, colour played a role in associations of tastes and emotions (n=8): *"I associate anger and rage with the colour red and chilies, [they] are very hot and fiery"* (P5). Participants also discussed the role of colour in expectation, with particular reference to the use of black foodstuffs: *"They feed you this sticky, oozy, beautiful, black syrup, liquid thing and then you eat a jelly thing, and it tastes like fish but you're like, 'what is it? Is it squid ink?' Like you have no idea and in conjunction with that they are kind of putting you through emotions of surrender and fear and anger and these feelings of survival. It's not food like you've ever experienced but it is food and you're tasting it and your taste buds are aware that it is food, and it is kind of not in any kind of human relationship to food as you know it"*

(P17). Here colour is used to negate visual identification as well as misdirect it when it comes to food experience. This could be used to create an estrangement between the consumer and food that may be useful in capturing attention during otherwise mundane eating situations.

5.3.2 Narrative and Memory-based Experiences

Previous work (Gayler & Sas, 2017) on taste-emotion mappings suggested the role played by narrative and memory for the appreciation of bitter and sour tastes. However, it was found that narrative and memory extended beyond just mappings, to impact upon the eating experience more broadly. Memory was found to be a key part of the construction and interpretation of food experiences. Childhood memories were by far the most prominently reported (n=11). Sour sweets were a common theme in these early life memories. Both positive experiences such as *"Sunday mornings as a child, going to the sweet shop with Dad"* (P16), and negative experiences with bitter tastes or eating bad seafood were encoded for triggering such memories. Within all reports of memories, it is often specific events that were recalled. Communication of such experiences, through recreating *"that feeling again is the fun part of being a chef, trying to get the customer to understand what you are expressing with that flavour"* (P14). Although these taste-based memories are personal, there are some emerging patterns such as the connection between positive experience and sour sweets. The influence of nostalgia (n=5) was reported as a *"secret, powerful influence [of] food"* (P6) and it is clear that this quality of food experience has an impact on how practitioners choose to work with it.

There were further examples of the importance of shared experience on the impact of culture. Participants with Nordic ancestry described *"rotten shark and puffin"* (P1) as delicacies to them but disgusting to others. Liquorice was another food which was highlighted as having a similar dynamic, which offers interesting possibilities for designing social interactions. Culture was also seen to impact on experience in shaping boundaries between pleasant and uncomfortable experiences. For example, participant 9 details the tension in experimenting with these frontiers: *"How far can you push it? I suppose sometimes you want to make something that is a provocation and then how far is it acceptable to go beyond something that is straightforwardly tasty and that is a real* *grey area that is really interesting”*. Both memory and culture point towards perceptions of food as a constructed, but malleable space arising from both personal and shared experiences that can be experienced on both personal and shared (Kray et al., 2006; Sas & Dix, 2008).

Findings indicate that food experiences are often designed in terms of trajectories with their related expectations, climax and temporal dimension. The term trajectory relates to food experience through the construction of various narrative arcs and journeys mediated by food: *“A meal for me is a journey, you want to start with something which is going to inspire your palate and evolve into and go on to building up to a richer, heartier main course and winding down, taking your palate on a journey from savoury and bitters flavours and finishing off with more sweet than sour at the end”* (P3). This build up to climax echoes the typical Western concept as outlined by Watz (2008). It contrasts with a narrative built on the interactions between parts of the meal, using counterpoints of taste, texture or temperature to create interest within the experience as reported by P16: *“One dish is kind of veering towards the sweet, salty, umami side, you kind of go to another dish which ends up on the more bitter, fattier side if that makes sense. So, it is all about trying to create total balance from beginning to end with what people have and how they consume food”.*

Literature indicates that expectation has an impact on actual experience (Delwiche, 2012; Dijksterhuis et al., 2014; Spence et al., 2010; Yeomans et al., 2008) and detail can be added to the understanding how this is achieved by chefs and designers. Expectations based in familiar and existing practice are used to set the context for experiences: *“I mainly work with desserts [...] they are an optional extra, no one expects to be made full from sweets so you can be very playful with them”* (P6). The notion of expectation was strongly connected to the curation of surprisingly elements within a food experience, from the use of *“miracle berries”* (P11) (*Miracle Berry Tablets UK*) able to transform raw lemon into a sweet tasting delight, to uncovering flavours in unexpected contexts, such as the fruity flavour of *“the flesh of the cacao”* (P12). Several techniques were identified for designing climatic moments within a food experience. Umami and bitter tastes were both reported as offering these moments of high tension. P13 explained how the *“umami can be a fitting high point to a meal, so we probably work up our taste, flavours and dishes around that main kind of high point”*.

Aside from the ability to curate narrative experiences from dish to dish, participants also recognized the potential for specific tastes to create narratives at different levels. Sour and salty tastes were both reported as having initially negative responses but as you tasted them that changed to positive. *"Sourness has that thing where first of all it repels you but then you want more so it's a kind of naughty but nice kind of sensation"* (P10). The opposite was observed for sweet tastes, P9 reflected on *"crashing"* after consumption. A similar time-based response to caffeine was also highlighted.

An interesting finding is that the purposefully designed new experiences are aimed to elicit not only positive but also negative emotions, and to particularly highlight contrast. It is not surprising that such experiences are underpinned by bodily experiences. Substances such as caffeine, alcohol and sugar all impact the body beyond the flavour experience, with sugar being specifically cited by P8 as causing sickness after consuming large quantities. However, it is not just the gut where the bodily response to food was reported, the sense of touch in the mouth was equally mentioned as a site for physical reaction. *"[A] really quite dry puffed pork rind, it's sort of a savoury honeycomb texture and it is quite sharp and if you try and eat that it will scratch your gums up a bit which is quite unpleasant"* (P8). The physical interaction between texture and the mouth opens up new perspectives on food design, adding to the spiciness that *"sets your tongue alive"* (P17) and sourness where the face *"all crunches up"* (P17). Descriptions of the movement of taste within the mouth were particularly prominent for sour (n=4) with burst, kicks and pops all reported.

Meaning was reported as not only arising from past experiences with metaphor proposed as alternative method of meaning construction. Linguistically, the connection between bitter tastes and bitter emotional state has been seen in prior work (B.-B. Chen & Chang, 2012) and was referenced in the interviews. Metaphor was also used to associate sadness with salty taste: *"sadness, tears, they're salty"* (P3) or with the description of fear as *"really nasty cold coffee not the nice drip stuff, something that has been sat around for too long, that has maybe had a bit of fag (cigarette) ash in it"* (P8). This descriptive construction was used both to interpret meaning, and to communicate it, with food designers in particular creating dishes to accompany moments in films or performances using associations in texture, colour, and temperature to place food as *"exploded toad"* or *"burning human flesh"* (both P8).

5.3.3 Comfortable and Uncomfortable Experiences

When reflecting on whether or not they created solely wholly positive experiences for their diners or audiences, there was a marked split between chefs and food designers. Chefs are typically dedicated to satisfying customers and this was consistently reflected in participants' answers, *"Our customers that come in here have an expectation for delivery and we have to deliver that otherwise we are not going to survive as a business"* (P3). For one chef this related to the core principle of their work, *"The first thing, it needs to be pleasant to myself, like I have to find joy whilst I am eating it. So, if it is something I don't like then I am not going to serve it"* (P14). However, food designers and some more experimental chefs were willing to consider how uncomfortable or challenging experience can be *"if you break the rules a little bit with what you can do with food then it opens the door to all those other emotions"* (P17). Predominately, participants reported pairing unpleasant smells with tasty food as a way of creating a challenging but ultimately enjoyable experience: *"I think there is something about giving something to someone to eat that is not nice, that seems very cruel, whereas smell is something that you can't control how much you smell things, it invades your nostrils. I suppose there is something quite a bit softer about that"* (P6). Uncomfortable experiences were often mentioned as tools to create divisive experiences within groups, stimulating conversation and debate as a by-product of the mixed response. There was a strong trend amongst designers to explore food in challenging contexts from zombie smells (P6) to BDSM-inspired, blindfolded feeding (P11).

5.3.4 Balance and Contrast

When discussing uncomfortable experiences, balance was highlighted as a key consideration (n=8), most often related to the taste composition of a dish. For example: *"adding in a very bitter element somewhere in a nice creamy mayonnaise or something to give you a nice range of sensations*" (P1). Acidity, sourness, and umami were all reported as important in creating dishes with balanced flavour. The idea of balance was also applied to the overall experience of the meal, often through the trajectory concept previously discussed. Contrast was important to creating balance when it came to elements within a dish or between courses: *"[When] I am trying to explain this concept, I use a meal that everyone is familiar with so fish and chips is a really good one because that has contrasts of taste and temperature and texture [… the] contrast with the crispy batter of the fish, the soft flesh of the fish, the comforting texture of the chips and I try and use that as a model for my own dishes"* (P3). For both balance and contrast there is a recognition of the need to pair together differences to create interest within the dish and work across multiple sensory pathways. Through the consideration of interactions between elements at one level, the intention is to create a coherent overall experience.

5.3.5 Design Process

As part of the interview, participants were asked to describe their approach to designing experience using food. Within this, two perspectives were notable; that of the free creativity where the chefs can create whatever they would like, and that of a designer working to a brief with a client. In reporting the process of design, both groups started from a focal point, either an ingredient or a theme, that the rest of the experience would be built from. Participant 7 and 12 both reported checklists used to support their design, aimed at considering the total experience from *"as many senses as I can"* (P7) and the who?, what?, why? and where? of the experience (P12). Prototyping (n=5) and research (n=5) were both mentioned as part of the creative process, research in particular was key to understanding cultural contexts for food. Participant 1 described developing a dish in a middle eastern country and struggling to get the taste of the meat right: *"we were walking through the cheaper sort of areas and […] we saw all the markets and little butchers and the meat and mutton and lamb hanging out in the sun, so it was getting a bit rancid out in the sun. So, we bought some […] and the feedback was 'yeah, it's great, what did you do? It's perfect!'"*. Research is used here to help uncover the differences in cultural preference. Interestingly, this preference is detailed in terms of the influence of the local climate and food retail practices upon the food's flavour. This perhaps demonstrates how designers of food experiences need to be sensitive to the diversity of cultural experiences and contexts in which food experience exists when compared to technologies which are more recent in their evolution. In the quote, the participant describes working with the target audience in an iterative manner to achieve this outcome, demonstrating the application of user-centred design principles in his food creation practice.

Within their process, participants reflected on the tension between idea-led and flavour-led experiences: *"Mugaritz* (experimental restaurant in Spain)*, stands out, I think, as the one who has done this the most, where not everything is immediately pleasurable and actually it is all there because they feel it's a sort of emotional, psychological journey to take people on. And I think that is where the concept leads over flavour and deliciousness as it were"* (P7). For some the relationship between a specific idea or concept and the overall journey of a dining experience was a close one; *"we might have a theme we want to run all the way through. So, we start by thinking about the theme and then attach things to it. [We ask] 'what is the big thing?', the main course? And then plan the rest of the menu around that"* (P13). Findings indicate that once a chef or designer has identified a major theme within the food experience, they tend to follow an iterative process to refine the food used with respect to this, carefully considering how additional food materials could tweak or shape the experience around this focal point. This iterative addition and subtraction of elements of a designed whole shares parallels with other design disciplines and highlights how food materials can be considered via their experiential outcomes: *"I might think of the trigeminal senses, I might think actually could this do with a bit of isothiocyanate [*(compound found in cruciferous vegetables like broccoli)*], like the wasabi, pepperiness and stick a bit of horseradish in or I might taste a broth and think it is really nice and umami but it needs a bit more salt, a bit of acidity to freshen it up"* (P7). This is extended beyond just the ingredient-led approach and starts to involve a series of questions that take into consideration the colour, smell and structure of the experience through the delivery of food to, and eating by, the diner: "*Wouldn't it be nice if it was actually purple so that would build the expectation, so I might think about the smell and think actually I am serving a little cup of broth do I want to cover the broth with some kind of little biscuit or something so that it only releases the smell once it hits the table or might I want it to waft the smell before I do that, before I serve it, so there'll be anticipation"* (P7). This construction and iterative combination of differing insights around sensory experience requires a detailed knowledge of the potential of food as a material, by knowing what can be used and in which contexts.

5.4 Discussion

This chapter set out to discover the applicability of taste-emotion mappings for use in designing user experiences. The interviews helped confirmed some of the findings of lab-based research; both the sweet-positive and bitter-negative mappings were recognized by participants. However, intensity was found to not be simply correlated with affective response, and new understandings of mappings for sour and umami tastes in applied contexts adding to previous work (Obrist, Comber, et al., 2014).

Indications from lab based findings had pointed to a positive correlation between intensity of taste and strength of affective response (Herbert et al., 2014). This is challenged by findings here, which suggest that tastes which are too intense create a negative valence response. This is supported by the findings of Yamaguchi and Takahashi (Yamaguchi & Takahashi, 1984) who explored intensity in relation to various foodstuffs. Prior work has also suggested that such variance occurs over time following exposure to a specific taste. (Obrist, Comber, et al., 2014). Through consideration of intensity or the temporal aspect of the taste experience it is possible to explore more complex taste-cued emotional experiences. However, it is key to understand the perspective of the individual who is experiencing the tastes, as their thresholds will be key to informing how and at which concentration the taste stimuli will change in its perception.

Theories of embodiment have previously been used to explain taste-emotion mappings (B.-B. Chen & Chang, 2012; Eskine et al., 2011) and this was extended by the connection of caffeine to fear because of the results of the digestion of the compound. Similarly, the mapping between sour and excitement and surprise is informed by the *'tingly and exciting'* physical sensation of the taste. When designing experiences with tastes it will be important to pay attention to not just this in the moment influences of embodiment, but also the longer terms effects. The connection between highly sweet tastes and nausea could be arise due to a single intense dose or an accumulation of doses over time, both potentially intended to represent highly positive contexts but entailing different results.

For sour and bitter tastes, an emergence of prototypical natural foodstuffs was uncovered. Evidence from rat studies has shown that such foodstuffs can generate a similar but more informationally rich neurological stimulation than pure tastants (Sammons et al., 2016). Prior findings support the claims of the multisensory flavour perception (Spence, 2010, 2015) through the evidencing of the extra sensory activity experience from a food compared to a taste. However, it also shows the possibility for using certain foods to create responses akin to those achieve through pure tastants.

Narrative was highlighted as a key method that interviewees constructed experience from taste, offering insight into the methods of experience construction from design intention. This method was particularly apparent in bitter and sour tastes where the narrative described the crossing of a boundary from pleasant to unpleasant, either in the experience or over a longer period of time. This transgression of enjoying an initially unpleasant sensation offers a rich space for exploration as designers, offering a tool to create experiences of transformation and change over time. Salt offers an intriguing counter point mapping to experience in way that offers a ‘negative space’ that is meaningful in its lack of definition.

Obrist et al. (Obrist, Comber, et al., 2014) have previously highlighted the variable nature of affective response to taste over time. Temporality is an under explored quality of both food and taste experience. Tuters and Kera (2014) offer a framework for understanding temporal possibilities in their theory of *metabolic interaction*. This describes how food is involved in a long chain of interactions that form together into one complete experience. For designers this adds a depth to the way in which taste can be used, operating on several temporal scales simultaneously. This quality in particular offers a unique medium for interaction designers, affording novel forms of experience.

5.4.1 Temporally Framing Food Experiences.

As noted in the findings, narrative was a shared theme for both chefs and food designers. Implicit in this is the temporal nature of food experiences. In considering food as a tool for interaction design it is worth exploring further how food experiences are framed. The act of eating (the placing of a foodstuff into the mouth) is merely one point in time where food experience occurs and has been designed for. It is both preceded and followed by other, less explored phases of experiences, namely, anticipation, eating and digestion, that can be highly impactful in terms of the overall experience.

5.4.1.1 Temporal Design with Food

With respect to anticipations, smell and vision (through seeing colour) were two sensory modalities that findings showed to be key in shaping of the expectation phase of food experience. Smell, in particular, continues to influence the experience through the act of eating. A sensitive application of this quality can be seen in P9's reference to rotting fish market. The anticipation phase of the smell is to conjure up a dirty, fishy repulsion, however as the eating phase commences the smell instead forms part of pleasant eating experience. The smell has remained constant but changes in its experience through the provision of the context of food.

Eating represents the moment at which the experience is realised. For example, the anticipation or conditioning of the user through exposure to different sounds or colours results in an augmented flavour perception at the moment the food is placed in the mouth. Eating itself can be seen to last for a period of time, the length and intensity of different tastes has been previously explored (Obrist et al., 2014a). In the findings on uncomfortable experience, the mechanical impacts of eating (such as crunchy foods cutting up the gums) or burning the roof of the mouth whilst eating show how intensity of experience can be considered from a multisensory perspective including nociceptive and thermal experiences. Eating also represents a stage in a longer unravelling narrative or memory that may be associated with a particular food (such as sweets from childhood). At the moment of eating the sweets move from an idea that connected to the memory to a multisensory experience (such as super sour taste) that relates to the memory. This changes the way the memory is felt moving from a cognitively associated connection to one that is more embodied as well.

And finally for the digestion phase, findings also indicate the aftereffects of common bitter or sweet foods. The aftereffects, or the digestion phase describe the experience of food, once it is inside the body. Unlike the anticipation phase where users may be highly conscious of the experience, the bodily experience of metabolizing sugars, caffeine or simply large amounts of food is less consciously observed but can become noticeable under the right conditions. For instance, P8 described the wariness they felt prior to consuming large amounts of sugar directly derived from the experience of nausea when previously consuming too much. Implicit in this, is a desire for the taste in the eating phase, conflicting with the unpleasant aftereffect of previous indulgences. Mapping out this experience, starts with a negative perception of the sugar/sweet food in anticipation, a momentary overwhelming of this by the pleasure of the eating phase and finishing with the realization of the negative experience in the digestion phase. These findings can open up interesting design opportunities for supporting healthier food choices by providing brief powerful reminders of previous indulgence experiences.

5.5 Implications for HCI Design of Edible Interfaces

Now discussed are the implications of the findings for designing user experience in HCI and in particular edible interfaces. They suggest how greater awareness of taste-emotion mappings in naturalistic can be applied to designing experience in HCI. It also discusses how intensity and temporality can be considered and how to design for anticipation and digestion with food.

5.5.1 Awareness of Taste-Emotion Mappings

Findings aimed to sensitize designers of edible interfaces to the importance of the taste-emotion mappings in naturalistic settings, both across the valence-arousal and discrete model of emotions. The agreement of findings here with prior mappings in both abstract and naturalistic settings indicate these to be the best starting point for designing edible interfaces through taste. Designers should also be aware of the nonlinear relationship between taste intensity and arousal of positive emotions. This opens up the possibility of intensity as a variable of the taste experience, manipulated to change the perception of a singular taste from pleasant to nausea (in the case of sweet) or refined maturity to disgust (in the case of bitter).

5.5.2 Design for Temporality of Edible Interfaces

As outlined with intensity, taste affords the opportunity for experiences that transform over a period of time. It has been shown how narrative and memory can influence this at one level, whilst lingering tastes and digestion can have an impact on another. These compound timelines offer the tools for designers to create complex experiences that last beyond the tasting, connecting back to the users' memory but also creating an on-going experience into the future. This could be achieved through the manipulation of the functional properties of compounds that afford taste. Caffeine is a bitter tastant but also a stimulant, sucrose similarly for sweet. At this point taste extends into physical response and embodiment plays a role. A unique quality of edible interfaces is that computing is extending into the users' body in an ephemeral way, offering designers a bodily space for interaction that doesn't involve permanent or intrusive application of technology.

5.5.3 Exploiting the Limitations of Taste-Emotion Mappings

Findings also indicate that specific emotions such as sadness are difficult to be mapped to taste. This opens up the design space of co-creating tastes that people can identify with sadness, possibly leveraging the power of narrative. In an interactive system this could be constructed at a personal or interpersonal level. The development of culturally specific meanings for emojis (Lu et al., 2016) could provide some interesting insight into such a development. Anger also didn't map to taste, but findings support the possibility of building on knowledge of multisensory integration (Spence, 2003), using touch or temperature to augment the taste sensation and design for a specific experience.

5.5.4 Design for Anticipation

Anticipation around food is shaped through non-contact senses such as vision and smell that work over distance. It allows the food experience to occur at different spatial scales (smells can travel round corners and along streets). Priming towards a particular expected flavour outcome is an important aspect of this phase of experience and can inform the experience when it comes to actually eating (Velasco, Michel, et al., 2016) as it creates a space in which the eating happens, whether that is a space of eager expectation or curious exploration. Experiences can involve a progressive build-up of information for the user, or they can misdirect, i.e., something can look beautiful but smell foul. Interviewees reported the use of such tension in a theatrical sense with potential for storytelling applications.

5.5.5 Design for Digestion

Food experience does not finish with the swallowing of the last mouthful. Digestion is perhaps the least considered aspect of food experience for interaction design. It covers taste sensation that lingered, such as spicy foods or over longer periods of time, the effects of sugar or caffeine that change the internal sensations of the body. This is turn can influence the next interaction with food, such as fullness impacting the desire to eat. Digestion can influence at a cognitive level too, with practitioners designing for reminiscence. Sour sweets and memory were frequently reported and here there are opportunities to connect to previous experiences across time. For instance, the dominance of childhood in shaping our taste experiences suggest the value of playful interactions as previously reflected in LOLLio (Murer et al., 2013).

This study outlined the design space for working with taste and emotion mappings, one quality of food material that could support experiential uses in HCI, building on the direction from Study 1. Taken together they have explored technology, food and experience relevant to this thesis. The next study moves from exploration towards design knowledge for HCI by directly applying insights to human-computer interactions. It proposes the use of 3D printed food to deliver specific taste and emotion experiences as part of interactions with both digital and physical scenarios.

6 Study 3 Taste Your Emotions: An Exploration of the Relationship between Taste and Emotional Experience for HCI

6.1 Aim and Rationale

Awareness is brought to taste-emotion mappings to this study which explores the potential for novel HCI experiences building on this relationship between food qualities and emotional experience. A version of this chapter has been published as (Gayler et al., 2019). This study is the first design and co-design study and studies the relationship between taste and emotion mappings that tend to be consistent between individual in lab settings.

6.2 Method

Having gained an appreciation of potential users, use contexts and insights into the practise of designing experiences with food, the next step was to design interactions that leveraged the potential of 3D printed food to create repeatable edible stimuli as part of emotional interactions with computers.

This exploratory study followed a methodology similar to the one employed in an exploration of novel thermal interfaces in a range of real-life inspired scenarios (Wilson et al., 2015). After careful consideration, 4 real-life inspired scenarios were created for this study which aimed to explore the understanding and expression of emotion in connection with the taste experience of 3D printed food.

6.2.1 Experimental Procedure

This section offers an overview of the entire study, before outlining more details in the subsequent subsections. The four experimental scenarios in the study were split into two blocks, A and B (Figure 14). Block A consisted of the “product ratings” and “sports match results” scenarios, whilst block B consisted of the “experiential vignettes” and “website usability” scenarios. These scenarios were carefully selected to explore the *understanding of emotions through sweet-bitter taste continuum of 5 intensities* (block A), and the *expression of emotional response through sweet-bitter taste continuum of 5 intensities* (block B). In addition, two scenarios capture digitally mediated experiences, i.e., “product ratings” and “website usability”, while the other two capture nondigital (or analogue) experiences, i.e., “sports match results” and “experiential vignettes”. Each scenario included ten stimuli with the exception of “website usability” which only has two stimuli. This was designed differently as the task of booking a trip on the website takes longer than listening to a vignette, or tasting a stimulus of 3D printed food, making it impractical to include 10 websites.

Block A scenarios were undertaken first and involved the consumption of 3D printed tastants (Figure 13). Participants responded to each given tastant, by matching it to the outcome of that scenario, reflecting their understanding of the tastes as emotional information. As they made each decision, participants thought aloud, and answered several questions at the end of both scenarios to reflect on the difficulty of articulating the mappings, their confidence in the mappings, general reflections on scenarios and which tastes they would use to represent scenarios. Participants were introduced to the entire range of tastants only after the completion of block A scenarios as part of the *sweet-bitter taste stimuli calibration*. For this, they consumed each of the tastants so that they could understand the association of each tastant with its unique taste label. The calibration was performed after, rather than before block A, to avoid biasing responses that the awareness of the full range of available tastes could have led to.

Figure 13 The set-up for block A scenarios

For block B scenarios, the calibration served the role of making the full range of 5 intensity levels alongside the sweet-bitter continuum available to participants, so that they could use all those levels to express the emotions elicited in block B. Here they were introduced one by one to emotion elicitation stimuli to which they responded by selecting a taste label from the provided range, that they considered most appropriate

(Figure 14). Similar to block A, tasks in block B also involved think aloud and involved follow-up questions. Within each block and within each scenario the order of stimuli was randomized to limit the order effects. In addition, to limit contamination between taste stimuli, participants rinsed their mouths with water before each taste stimuli. The study concluded with a final interview (Figure 14), this interview helped add a narrative detail to the experience of interacting with computers via taste-emotion mappings,

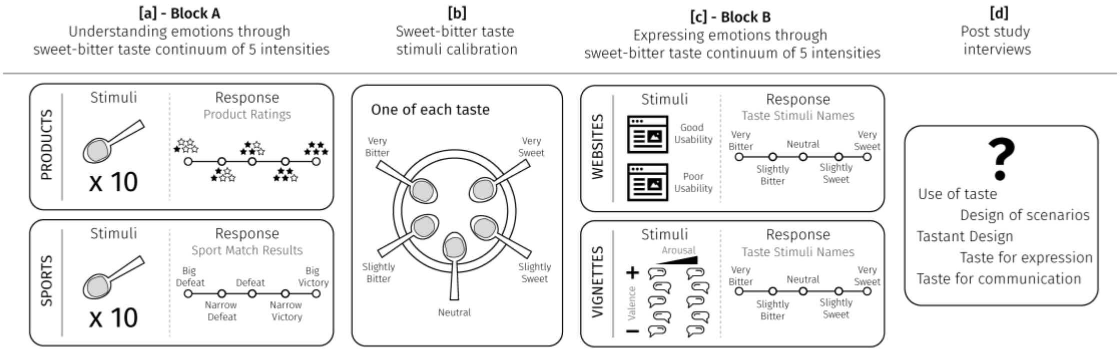


Figure 14 The study design showing block A scenarios, taste stimuli calibration, block B scenarios and interviews

adding depth and richness to the findings.

6.2.2 Design of Scenarios

This section offers a brief overview of the process of selecting scenarios, while each scenario is later described alongside the findings to support increased readability by presenting the hypotheses and results side by side. The four selected scenarios were chosen from a list of 8 generated scenarios, to ensure a balance between scenarios relating to digital, and physical experiences, as well as for exploring both the expression, and comprehension of emotions. The diversity of scenarios was intended to help explore differences in how taste-emotions worked or were perceived as suitable by participants. Creating scenarios covering website usability, product rating, results of sports matches and vignettes of everyday experiences allowed users to consider taste-emotion mappings in a range of contexts. Where possible scenarios were informed by applied taste-emotion mapping as was the case with the sports scenario as suggested in previous work (Noel & Dando., 2015). The intention was to create scenarios that represent a range of emotional experiences, both of positive and negative valence, to match their counterpart taste based on taste-emotion mappings with sweet and bitter as suggested by the literature (Greimel et al., 2006; Kashima & Hayashi, 2011; Robin et al., 2003; Q. J. Wang et al., 2016; Yamaguchi & Takahashi, 1984).

6.2.3 Taste Stimuli Design

Stimuli	Additive	Concentration of mixture prior to printing	Concentration when printed
Very Bitter	Caffeine	1g/L	0.5g/L
Slightly Bitter	Caffeine	0.25g/L	0.125g/L
Neutral	--	--	--
Slightly Sweet	Sucrose	12g/L	6g/L
Very Sweet	Sucrose	48g/L	24g/L

Table 9 Concentrations of tastants in the 5 stimuli used, based on those used by (Bredie et al., 2014)

The selected taste stimuli consisted of: “very bitter”, “slightly bitter”, “neutral”, “slightly sweet” and “very sweet” laying along the bitter-sweet continuum (Table 9), exploring thus the tastes most commonly associated with emotional valence (sweet with positive emotions, bitter with negative emotions), as well as emotional arousal (high and low taste intensity with high and low emotional intensity) (Bredie et al., 2014; Kashima & Hayashi, 2011). This scale was initially derived from Bredie and colleagues’ study on affective response to taste stimulus (Bredie et al., 2014), who used ‘high’, ‘med’ and ‘low’ concentrations of the 5 basic tastes. In the study, the intention was to have perceivable differences between each taste stimuli. Therefore, low and high conditions were used from Bredie et al. (Bredie et al., 2014) to create the 5-point scale. The evaluation of basic tastes in terms of intensity (Very, Slightly etc.) is a feature of validated scales for assessing taste experience (Bartoshuk et al., 2004) and these intensities have been connected to emotional response, both reported by participants and assessed by facial response (Bredie et al., 2014).

6.2.4 Pilot study of taste stimuli

To evaluate users’ ability to discriminate between taste samples and whether the printed bitter-sweet tastes were associated with the emotional responses shown in prior work (Kashima & Hayashi, 2011; Robin et al., 2003; Q. J. Wang et al., 2016; Yamaguchi & Takahashi, 1984) a small pilot study was run. Rather than assessing the exact concentration by instrumental measurement it was considered more appropriate that these concentrations when printed resulted in stimuli that participants were able to identify, discriminate and order the intensities, which was sufficient for this study. For the pilot, 5 participants (4 Female, 1 Male, mean age 28.7 SD=4.0) to tried taste samples and were asked to identify each taste given in randomized order. These participants did not take part in the main study that followed. Participants took a sip of water between each taste to clean the palate. Pilot study findings show that all 5 participants could correctly identify the very sweet taste, and that 4/5 identified the very bitter taste in a free selection. Mean confidence (scored 1-5 with 5 most confident) in these responses was 3.68 (SD=.1.25). There was a positive correlation ($r_s(23) = 0.74$, $p<0.01$) between the stimuli given and the reported taste on a bitter-sweet scale, mean confidence in these scale ratings was 3.8 (SD=1.0). Such consistent ratings suggest confidence that the choice for each taste sample was appropriate both in terms of the two basic tastes and the chosen intensities.

6.2.5 Experimental Apparatus

All scenarios involved entering answers on a laptop provided during the study. Participants sat at a table with the laptop in front and the plate of tastes for that scenario to the side of the laptop. A glass of water was provided for each participant (Figure 13) and topped up as necessary through-out the study. For both the pilot and the main study, the taste samples were 3D printed as small 10ml cubes and presented on identical white plastic teaspoons arranged in their randomized order on identical white china plates (Figure 13) with new plates being used for each presentation of taste samples in block A scenarios, and during the calibration session.

3D Printed Tastant Preparation was undertaken by use of the nūfood printer. The food produced for this study had consistent shape and mass and was colourless and odourless. Due to the current speed of printing and the need for repeated stimuli to be prepared, all printing was done prior to the study session with the prepared samples kept refrigerated until needed for the study appointment.

6.2.6 Participants

16 participants were recruited via social media and mailing lists associated with Dovetailed Ltd. Each took part in a session lasting between 45 minutes to 1 hour and were rewarded £5. Participants were recruited with no food allergies or sensitivities, between 18 and 65 years old, with the upper age limit to avoid the impact of aging upon taste (J. A. Williams et al., 2016). Only non-smoking participants were recruited; non-

smokers were defined according to (Chéruel et al., 2017). The sample was gender-balanced (9 Female, 7 Male), as research suggests no influence of gender on taste-emotion mappings (Robin et al., 2003). Half of participants (8) hold postgraduate qualifications, 7 bachelor's degrees, and 1 high school educated. The mean age was 36.88 (SD=10.68). With respect to ethnicity, 11 participants were White-British, 4 White-European and 1 Mixed Background.

6.3 Findings

Now described are the design and hypothesis of each scenario, followed by the quantitative data analysis – descriptive and inferential statistics – for hypotheses testing, and an overall qualitative analysis of the study interviews.

6.3.1 Understanding Emotions (block A) - Product Ratings

This scenario aimed to see how participants understood customer ratings through taste. They were given 10 samples (2 x 5 different tastes) and asked to select a matching star rating on a 5-point Likert scale. They were told a 5-star rating was "a very good product" and a 1-star rating was "a very poor product". The star rating of the product was chosen to align with affective response, positive affect with a high product rating and negative affect with a low product rating.

Hypothesis H1 - Sweet tastes map to positive ratings, bitter tastes to negative ones. The intensity of the taste relates to the level of the rating (very bitter would be rated lower than slightly bitter).

6.3.2 Understanding Emotions (block A) - Sports Match Results

This scenario required participants to use provided taste samples to select the appropriate outcomes of a sports match matching that respective taste. Again, 10 samples were given (2 x 5 tastes); for each, participants chose whether they felt it represented a "big defeat", "narrow defeat", "draw", "narrow victory" or "big victory". They sampled each taste and made their selection of the most appropriate match result for that taste. Following Noel and Dando (Noel & Dando, 2015) results of sports matches were used to explore affective experience; positive affect aligned with victory and negative affect aligned with defeat.

Hypothesis H2 – Sweet tastes map to victory and bitter tastes map to defeat. The intensity of the taste maps to the level of outcomes of the sports match (e.g., more bitter = bigger defeat).

6.3.3 Quantitative Findings

For block A scenarios the frequency counts are presented (Table 12 and Table 11) and then H1 and H2 are tested with Spearman's correlation and Friedman tests (as the ordinal data was not randomly distributed). Table 12 shows that participants' agreement on the relationship between taste and product rating, and that this agreement was the strongest for "very bitter" and "slightly bitter" mapped to "1 star", and "2 star" rating, respectively. Table 11 reflects a similar agreement on the relationship between tastes and sports match results, but in this scenario, the agreement is the strongest for "neutral taste" and "draw". Both Table 12 and Table 11 show that on the first diagonal, the

	Big Defeat	Narrow Defeat	Draw	Narrow Victory	Big Victory	**Totals**
Very Bitter	13	6	7	6	0	32
Slightly Bitter	5	7	12	7	1	32
Neutral	3	8	17	4	0	32
Slightly Sweet	2	5	8	12	5	32
Very Sweet	5	2	1	10	14	32
Totals	28	28	45	39	20	160

Table 10 Frequency counts for each taste sample to each sports match result in sports match scenario. Shading shows most common (red) to least common (white).

weakest agreements occur at intermediary points: "slightly bitter" and "slightly sweet", suggesting that greater differentiation in taste needed to identify these points. To further explore the relationship between tastes and the rating/results stimuli, correlation tests were run, with findings showing significant correlations between tastes and product ratings ($r_s(23) = 0.50$, $p<0.01$), and tastes and sports match results ($r_s(23) = 0.43$, $p<0.01$). This is an important outcome indicating that the sweeter the taste, the more positive the experience, and the more bitter the taste, the more negative experience, in both of these two real-life inspired scenarios. This confirms H1 and H2 with respect to

	1 star	2 star	3 Star	4 Star	5 star	**Totals**
Very Bitter	17	8	4	3	0	32
Slightly Bitter	16	7	8	0	1	32
Neutral	11	7	12	1	1	32
Slightly Sweet	4	13	7	8	0	32
Very Sweet	3	4	2	13	10	32
Totals	51	39	33	25	12	160

Table 11 Frequency counts for each taste sample to each product rating in product rating scenario. Shading shows most common (red) to least common (white).

the mapping of positive experiences (as positive product ratings or wins for one's team) to sweet tastes, and of negative experiences (negative product ratings or defeats for one's team) to bitter tastes.

Friedman Tests with *post hoc* Bonferroni adjusted pairwise comparisons were run on the tastes matched with each response for both the product rating and sports match result scenarios. These indicate that 1-star ($\chi^2(4) = 22.90$, $p<0.05$) was best represented by very bitter, 4-star ($\chi^2(4) = 17.11$, $p<0.05$) by very or slightly sweet, and 5-star ($\chi^2(4) = 23.20$, $p<0.05$) by very sweet. For the sports match scenario "big victory" ($\chi^2(4) = 27.70$, $p<0.05$) was best represented by very sweet, "draw" ($\chi^2(4) = 22.35$, $p<0.05$) by neutral tastes, and "big defeat" ($\chi^2(4) = 16.76$, $p<0.05$) by very bitter. These findings indicate that mappings are more consistent at the end points, partially supporting H1 and H2 with respect to the relationship between taste and emotional valence, but less so the relationship between taste intensity and emotional intensity (or arousal). The latter would require consistent mapping across all five levels of responses, but found mappings were mostly at the end rather than at the middle points of the response scales. "2 star", "narrow victory" and "narrow defeat" in particular were not mapped reliably to middle intensity tastes ("slightly sweet", "slightly bitter").

6.3.4 Expressing Emotions (block B) - Experience Vignettes

The vignette task asked participants to respond to 10 vignettes taken from the Affective Norms for English Text library (Bradley & Lang, n.d.). Each vignette was read to each participant, who then selected a taste label, i.e., "very bitter", "slightly bitter", "neutral", "slightly sweet" and "very sweet", to best express the emotional experience triggered by the vignette. Vignettes were chosen to cover a range of emotional valence and arousal. Scenarios in block B did not involve the consumption of any taste samples.

Hypothesis (H3) The more positive valence vignettes map to sweeter tastes, and more negative valence vignettes map to more bitter tastes. The intensity of the taste will map the emotional intensity (arousal) triggered by the vignette.

6.3.5 Expressing Emotions (block B) - Website Usability

The final scenario involved the direct experience of using a website. Participants were asked to use two travel websites to book a flight and accommodation for Rome. The websites were selected as landmark illustrations of 'good' and 'bad' usability, according to a recent comparison of travel booking websites (Sigma, 2016). The websites chosen were Skyscanner (*Skyscanner | Find the Cheapest Flights Fast*, n.d.) (best performer in the report) and Co-operative Travel (*Co-Operative Travel® : Cheap Holidays & Last Minute Package Deals*, n.d.) (worst performer). The websites were accessed through a chrome browser on a MacBook Pro laptop. After completing the booking, participants selected one of the five taste labels, i.e., "very bitter", "slightly bitter", "neutral", "slightly sweet" and "very sweet", which best expressed their experience of using the site. Participants also assessed both websites' usability in terms of effectiveness, efficiency and satisfaction on a 5-point Likert scale (*ISO 9241-210:2010 - Ergonomics of Human-System Interaction -- Part 210: Human-Centred Design for Interactive Systems*, n.d.). Usability scores were computed as the average of participant's effectiveness, efficiency and satisfaction ratings for the two sites and ran paired t-tests. Findings indicate that Co-op website had a significantly lower usability score (M=5.56, SD=1.82) compared to Skyscanner website (M=9.13, SD=3.65) ($t(15) = 3.23$, $p<0.05$). This confirms that participants' perception of websites' usability is as predicted.

Hypothesis (H4) more positive experience of using the website (evaluated by a higher usability score) maps to more intense sweet taste, and inversely, a more negative experience maps to more intense bitter taste.

6.3.6 Quantitative Findings

For block B scenarios the frequency counts are presented in Table 14 and Table 14, and Spearman correlation and Friedman tests were run to test H3 and H4. In order to test H3, the vignettes were grouped into 5 classes according to the rating of emotional valence defined for each in the ANET database. Thus, 2 vignettes were in each of the 5 levels: “strongly negative”, “negative”, “neutral”, “positive” and “strongly positive” (Table 14). Table 14 shows participants’ agreement on the mapping between tastes and the emotional responses elicited by the vignettes, with the most frequent matches occurring at the extremes. Thus, strongly positive emotional responses were most often associated with very sweet taste, and strongly negative emotional responses were most often associated with very bitter taste. Similar to findings on block A, the agreement at intermediary points was lower: “negative” and “neutral” emotional response received the least number of matches with “slightly bitter”, and “neutral” tastes on the first diagonal. Table 14 reflects a similar agreement on the relationship between tastes and website usability results, but in this scenario, the agreement is the strongest for “very bitter” and “slightly bitter” taste (over 80% of participants) and Co-op travel website’s poor usability. Interestingly, the mapping of tastes to the Skyscanner website’s strong usability has been less consistent, with the highest frequency of counts (4) mapping its usability equally to “very sweet”, “sweet”, and surprisingly, also to “slightly bitter” tastes. Indeed, only 50% of participants associated Skyscanner website’s usability with “very sweet” or “sweet” tastes. To further explore the relationship of the elicited emotional responses via vignettes correlation tests were run. Findings show a significant positive correlation between taste and valence of the emotional experience elicited by vignettes ($r_s(23) = 0.61$, $p<0.01$), supporting H3, but no significant correlation between arousal and taste.

These findings suggest the increased importance of valence in the relationship between tastes and emotions. The outcomes of “website usability” scenario also show a significant positive correlation ($r_s(8) = 0.62$ $p<0.01$) between the usability scores and tastes, supporting the hypothesis that sweet tastes are associated with positive usability experiences. and bitter tastes to negative ones (H4). Friedman Tests with *post hoc* Bonferroni adjusted pairwise comparisons were run on the number of tastes assigned to each vignette. These findings indicate that: “very bitter” ($\chi^2(4) = 9.30$, $p<0.05$) was best represented by strongly negative or negative vignettes, “slightly sweet” ($\chi^2(4) = 16.32$, $p< 0.05$) positive vignettes, and “very sweet” ($\chi^2(4) = 26.22$, $p<0.05$) strongly positive vignettes.

	Very Bitter	Slightly Bitter	Neutral	Slightly Sweet	Very Sweet	**Totals**
Strongly Negative	18	10	1	1	2	32
Negative	15	7	4	3	3	32
Neutral	4	10	10	7	1	32
Positive	2	4	5	15	6	32
Strongly Positive	1	2	2	9	18	32
Totals	40	33	22	35	30	

Table 13 Frequency counts for each taste sample to vignettes grouped by valence in experience vignette scenario. Shading shows most common (red) to least common (white).

	UX Score	Very Bitter	Slightly Bitter	Neutral	Slightly Sweet	Very Sweet
Co-op	M=5.56, s.d. 1.82	7	6	2	0	1
Skyscanner	M=9.13, s.d. 3.65	1	4	3	4	4
	Totals	8	10	5	4	5

Table 13 Frequency counts for each taste sample to websites in website usability scenario. Shading shows most common (red) to least common (white).

These findings also suggest that mappings are more consistent at the end points as in block A. This partially supports H3 regarding the relationship between taste and emotional valence, but less so the relationship between taste intensity and emotional intensity, due to the absence of significant difference in the mappings of bitter and neutral.

In order to test H4, Friedman tests were conducted for this scenario but did not find significant differences between the tastes selected for each website. Due to the small sample size for this scenario (only two stimuli given compared to 10 in others) it is not possible to draw robust conclusions. Together with the correlation results, study findings partially support hypothesis H4 that poor usability is more often associated with bitter taste. They also only partially confirmed the mapping between strong usability and sweet taste. Indeed, findings indicate a less clear picture, as strong usability has been most often associated not with one but three tastes: “very sweet”, “sweet”, and “slightly bitter”. This suggests that taste has potential to communicate both high and negative emotional responses, albeit it more consistently communicates emotional responses of intense positive valence.

6.3.7 Qualitative Analysis

Now reported if the thematic analysis (Braun & Clarke, 2006) of the interviews and the key findings regarding participants’ perception of tastes, perceived difficulty of each scenario, and the specific tastes, flavours, or foods that each scenario suggested to them. All responses during exposure and after each scenario were audio recorded and fully transcribed. I conducted an initial deductive coding from the collected material. Themes were identified and iteratively refined through discussions between myself and my supervisor.

The taste stimuli were commonly described as ‘watery’ (n=37) or ‘fruity’ (n=18), or in terms of texture (n=14) reflecting the material qualities of the 3D printed food. This makes sense since the 3D printed stimuli consisted of liquid-filled gel balls, giving the appearance of fruit and the sensation of liquid when bitten into. Participants also reported how their taste experience was highly embodied, focusing on the mouth (n=9) : “*[it] does fill your mouth”* (P13); *it's not like too much in your mouth. It's quite a pleasant flavour when it is first on your tongue*” (P8). These findings suggest that taste-based interfaces have the potential to further advance the growing HCI interest in embodiment. Through the think-aloud process during the scenarios, participant’s made comparisons from sample to sample based on taste (n=15) *“it has definitely got a sweetness to it which I prefer to the others’* (P9), arousal (n=13) *“maybe not as much as the one before because on the first taste it was stronger”* (P8) and valence (n=9), *“it wasn’t as unpleasant as* [previous] *ones”* (P4).

In the post-study interview, participants were also invited to rate each scenario for difficulty. The scenario perceived as the easiest was the website scenario (n=9), and the one perceived as the most difficult was product ratings (n=7). P3 described the difficulty of the product scenario arising “*because I was reviewing an undescribed product*”. This imagined product review contrasted to the direct experience of using the booking websites where "*the functionality didn't seem to work, so because it was quite frustrating, it instantly became very bitter*" (P3). The sports and vignettes scenario were rated as easy by 7, and 8 participants respectively. When asked to propose their own tastes, flavours, or foods to understand or communicate the experiences involved in each scenario, a theme of favourite and least favourite foods was observed, suggested to map to the either end of the scale. Example foods being "*hot, buttery toast*" [favourite food suggested for a 5-star product rating, P16] or "*carrots because I hate carrots*" [least favourite for a big defeat, P10]. In addition, participants identified foods relevant for that specific scenario, or what were called *context-related flavours:* "*I am always relating post game beers [to] watching football*" [sports match results, P11]. Interestingly, "sweet" and "bitter" (both n=5) remained popular choices for the sports match scenario but not for the product scenario. P8 acknowledged the role that taste metaphor plays in such choices by referring to the common metaphor of "*sweet taste of victory*" as highly appropriate for the sports match scenario. Findings also indicate that flavours tended to trigger remembering of specific past experiences: "*wallpaper paste […] when I was a kid, I remember tasting it when my parents were papering the wall*" (P7). This kind of artificial, wet-like taste resembles qualities of the 3D printed food. What is interesting here is the ability to connect the taste sample (very bitter in the case of P7) to a childhood memory. This is an important outcome suggesting that unlike taste which maps mostly to emotional valence (but not arousal), flavour may better map to specific episodic memories (Le et al., 2016; Sas et al., 2013).

6.4 Discussion

Findings and their novelty are now discussed by reflecting on the research questions. With respect to the first research question on the relationships between taste and emotions in real-life inspired scenarios, findings indicate taste-emotion mappings as hypothesized in each of the four scenarios presented. Study outcomes confirm that "sweet" tastes are understood by users as a "positive product rating", "one's team winning a sports match", and conversely, "bitter" tastes were understood as a "negative product rating" and "defeat of one's team". In addition, participants were also able to use tastes to express their own emotional experiences in the vignettes and travel websites scenarios. Thus, "sweet" tastes were used to express positive emotions elicited by the vignettes and positive experiences of engaging with a website with strong usability.

The findings make two contributions to the state-of-the-art. First, evidence is provided that the taste-emotional valence mapping (sweet-positive, bitter-negative) extends beyond lab-based studies (Greimel et al., 2006; Kashima & Hayashi, 2011; Robin et al., 2003; Q. J. Wang et al., 2016; Yamaguchi & Takahashi, 1984) into real-life inspired scenarios, although such extension has been previously questioned (Desmet & Schifferstein, 2008) . This also applies to the less explored mapping of taste to emotional arousal (intense taste-intense emotions) (Q. J. Wang et al., 2016; Yamaguchi & Takahashi, 1984). In particular, the findings indicate that the latter mapping is more challenging in real-life inspired scenarios and that while the highest arousal emotions are consistently mapped to the strongest tastes, intermediate levels of arousal in emotional responses are not. In addition, when both emotional valence and arousal are considered, tastes can be used to communicate both high arousal and negative valence emotional responses. These findings suggest interesting potential for HCI research, where the exploration of taste as resource for design has focused mostly on taste types (Moser & Tscheligi, 2013; Vi, Ablart, et al., 2017; Wei et al., 2012, 2014b) and less on taste intensity, nor on the relation between taste type and intensity with user experience (Gayler & Sas, 2017; Obrist, Comber, et al., 2014a). Future work should further explore the relationship between taste intensity and user experience, possibly by leveraging flavour experience and other multisensory stimuli (Ranasinghe, Nguyen, et al., 2017).

The second research question is on the feasibility of 3D printing food technologies for exploring the taste-emotion mappings in HCI. This study's exploration with taste was enabled by the novel technology for the 3D printing of food. This allowed the non-taste aspects of food experience to be kept constant (e.g., texture, colour or smell), which in turn, enabled a more controlled exploration of taste. Previous work on 3D printing of food technology suggested that its acceptance will be driven by its experiential rather than gastronomic value (Gayler et al., 2018). Such an opportunity is offered by using such technology to support affective interactive experiences. The *nūfood* printer used in this study has two tanks allowing the varied tastes to be delivered on demand. In this way it offers an advantage over the single-tank extrusion printers used in *EdiPulse* (Khot, Pennings, et al., 2015b) and co-dining experiences (Wei et al., 2012). In particular, the findings suggest that 3D liquid food printing is a suitable technique for stimulating taste sensation in HCI contexts. As explored in the study, the printer is able to produce taste output, but it is also capable of producing more complex flavour experiences. This is an important functionality to be leveraged in future work.

Indeed, participants suggested the value of flavours which could be more personal and scenario-specific, as alternatives to the limited range of sweet and bitter tastes used in the study. Also for future consideration is the combination of taste-stimuli with other multisensory aspects of experience, including colour and shape (Spence, 2010) manipulated through 3D printing of food technologies. Findings provided evidence for the embodied quality of user experience mediated by 3D printed tastants. Such outcomes extend the current HCI approach to embodiment which emphasizes the human body, emotions, and the challenge of mind-body dualism (Obrist, Comber, et al., 2014). The key new insight in this direction is the value of mouth as a novel space for bodily interactions. the findings highlighted movement within the mouth as well as ideas of filling and coating as qualities of bodily experience. For designers interested in taste-based interfaces, the mouth should not be seen simply as part of the body, but as a gateway, unique as a space for entry into the body, extending the traditional approach to the body as a resource for design (F. 'Floyd' Mueller, Andres, et al., 2018). Compared to haptic experiences *on* the body, taste experiences are taking place *within* the body. This internal-ness is unique to the way we experience food, and opens up a space for more intimate interactions, more related to users' physical selves.

With respect to the third research question on the relevant HCI scenarios for taste-based interactions, four scenarios are now reflected upon: "product ratings", "sports match results", "experiential vignettes", and "website usability". Their choice was grounded in their connection to tastes, and ability to capture both analogue- and digital-related contexts. Regarding the potential for different scenarios of use, validation of each hypothesis indicates that taste-emotion mappings are likely to work well across a range of scenarios where there is a clear emotional aspect to the information being communicated. However, qualitative findings indicate that although all scenarios allowed the exploration of taste-emotion mappings, they differed in participants' perception of their difficulty level.

At a closer look, this suggests the importance of user's direct engagement in the experience outlined by the scenario. For instance, the "website usability" scenario allowed for the highest level of engagement as participants actually performed the booking tasks themselves. Thus, their ratings were grounded in their personal, almost visceral experience, given the high negative arousal experienced with the poor usability website. In contrast, the "product ratings" scenario facilitated the least engagement, as participants neither chose the product themselves, nor had had prior experience with the rated products. This made it challenging to deliver a rating, as this was not grounded on any personal experience. The "sports match results" and "experiential vignettes" scenarios can be placed somewhere in between, as although they did no enable direct experiences, they provided common contexts or *cultural scenarios* (Rosenberg, 1990) that people could easily connect to and imagine the associated emotional experience. Some participants could even remember sport matches they attended, and hence could bring a valuable experiential quality to their rating. Hence on the continuum of engagement, the scenarios varied from involving direct experience (i.e., "website usability"), remembered or easily imagined (i.e., "sports match results" and "experiential vignettes") to difficult to imagine (i.e., "product ratings"). The best scenarios for taste-based interfaces are those engendering directly mediated emotional experiences that leverage cultural scenarios that people can easily make sense of. One way to strengthen these scenarios is by leveraging taste metaphors. For instance, in the "sports match" scenario the taste-based metaphors of winning and losing were easily drawn upon by participants.

6.5 Design Implications

Three design implications are offered for novel taste-based interfaces drawing on the identified mappings, the design of flavour-based interfaces, and the use of taste for evaluating user experience.

6.5.1 Novel Taste-based Interfaces with 3D Printed Food

Findings indicate that 3D printed food with "sweet" and "bitter" tastes map to, or connect best with, the emotional valence of the associated experiences. Different levels of intensity of "sweet" and "bitter" tastes were used to support both the understanding and expression of emotional experiences with different levels of intensity in four scenarios. the findings open up new opportunities for taste-based interaction design. One could imagine *emotastes*: droplets of sweet or bitter taste 3D printed in real time to augment mediated communication. This could support remote connectedness, adding a layer of embodied affective response to the expression of emotions between two people, extending thus previous explorations with visual, thermal, and haptic information (Kowalski et al., 2013).

Findings also suggest the importance of choosing application scenarios which can benefit most from taste-based interactions. It has been seen how those leveraging taste-related metaphors and the personalization of tastes, possibly through 3D printed foods or flavours, are better positioned to reflect intuitive and easy to understand mappings between tastes and emotions. Such scenarios could offer the best starting points in the exploration of taste-based interfaces in HCI. For instance, one can think of scenarios where taste-based interfaces can be used to support reminiscing of "bittersweet memories", a metaphor capturing ambivalent feelings of happiness and sadness.

6.5.2 Designing Novel Flavour-based Interfaces

Findings also indicate that flavours best map or connect with specific, personal, emotional narratives. This suggests the value of augmenting 3D printed tastants such as the ones used in the study, with smell, texture or temperature qualities to support a more embodied experience of food and its flavour. Flavours will not be as universally perceived as tastes but do offer opportunities for strong personal narratives to be built that better position the user in relation to the interaction scenario. In turn, this could allow for stronger recall of personal past experiences. One can think of new flavour-based interfaces that can reconstrue and deliver droplets of flavour to support reminiscing in old age (Sas, 2018; Sas, Ren, et al., 2016) or for sufferers of dementia, or connect with aspects of identity curation and expression, particularly amongst migrant communities.

6.5.3 Novel Taste-based Methods for Evaluating User Experience

Findings indicate that 3D printed tastants worked best in the "website usability" scenario as tools for expressing the user experience prompted by the website's usability, such as frustration with poor usability. This is a significant finding given the limited

HCI tools for measuring user experience. Findings suggest that through its powerful emotional and temporal qualities, taste offers an exciting avenue for accessing user experience in less verbal and more embodied ways. HCI work exploring such nonverbal means to assess user experience has been limited. A notable exception is the *sensual evaluation instrument* (Isbister et al., 2006) that leverages affective dimensions through sculptural shapes. Taste provides a similar embodied experience, whilst adding an additional layer of meaning making through reliable emotion mappings. For instance, one can think of using tastes during website evaluation which may allow real-time experience capture, as tastes are adjusted and printed on-demand until the best taste expressing one's emotions is found. User experiences could leverage metaphors such as "sour note", "bitter end" for expressing negative experiences, or "sugar" and "honey" for positive ones. This is consistent with neuroscience findings indicating that both taste sensation and taste-related words used in sentences activate emotional processing areas of the brain (Citron & Goldberg, 2014).

6.6 Limitations and future work

This work aimed to explore the application of taste-emotion mappings for use in HCI contexts. Most of the findings related to the appropriateness of the 3D printed tastants as stimuli in such interactions. Of future interest would be further refinement of both the design, production, and consumption of 3D printed tastants for user interaction design in HCI. The design of the 3D printed stimuli in this study used concentrations from in prior work in the format of water-based mixtures, while future work could be more creatively explored and experimental validation of the appropriate format for 3D printed tastants, including previously suggested multisensory design involving colour, odour, and form. It is also possible to consider the scenario design in a more open ended and exploratory way, either through explaining the choice of scenarios to participants to support some co-design of further applications or through a pre-experimental collaborative design phase to consider a diversity of perspectives on the appropriate contexts.

The taste scale used in this study had five points, in comparison to the original work which had 3 intensities for each taste (Bredie et al., 2014). Due to the move from evaluation of tastes towards operationalisation of tastes in applied contexts, fewer points on the scale were chosen to aid discriminability (the intermediate intensity was dropped). There are alternative scales which may have been employed for evaluation of taste experience such as the generalised Line Magnitude Scale (Bartoshuk et al., 2004). However, such an approach would not allow for a matching between the taste stimuli used and the scale for reporting as the scales are unipolar and labels set relate to reported experience (i.e., none or threshold) which are known to vary person to person and thus require a calibration of taste materials to each individual. If such personalised approaches are used, then it leaves open the opportunity to design with further multisensory aspects of food experience which could enhance the overall experience.

This study has identified the potential for taste-based interactions, but also indicated a potential for more complex flavour-based interactions. In Study 4 this potential is explored through the context of intimate relationships. Whilst both Study 3 and 4 explore the potential of food for experiential uses as suggested by Study 1. Study 4 marks an evolution of approach. Taste-emotion mappings are shared experiences across participants, whilst experiences with flavour are much more idiosyncratic, as can be seen by the variety in favourite foods suggested by participants in the above study. The nature of flavour perception means a change in the way the participants need to be involved in the research through design. Universal phenomenological experiences are more appropriately assessed through lab-based studies (Koskinen et al., 2011), as one set-up can be repeated used by many people. However the more personalised nature of flavour requires an approach more aligned with field-based methods (Koskinen et al., 2011) which can engage with the individual and their contexts in the creation of design and design knowledge. Therefore Study 4's methods differ significantly from Study 3 as they move from taste to flavour, continuing an exploration of novel experiential uses of food within HCI. Study 4 also focusses more closely on a specific group of users, those of couples in romantic relationships.

7 Study 4 Material Food Probe: Personalized 3D Printed Flavours for Emotional Communication in Intimate Relationships

7.1 Aim and Rationale

This study (Gayler et al., 2020) extends work on taste towards multisensory conceptions of flavour and explores further emotional experience for couples through personalised flavours of 3D printed food. It considers flavour – emotion mappings as more personal and idiosyncratic related that the more universal taste-emotion mappings in Study 3. To better support exploring relationships of this nature this study is conducted in field settings rather than in lab settings. Whereas the lab supports the exploration of psychological phenomena, working in the field and in particular in a collaborative way allows the exploration of more powerful personal experiences based on flavour. Flavour-emotion mappings have been identified by participants in Study 3 but appear to be more idiosyncratic contrasting with the more shared taste-emotion mappings.

Boxes of chocolates, oysters and, for the ancient Greeks, prunes, there is a long and storied relationship between food and romance, from foods seen as aphrodisiacs to the 'dinner date' as a courtship archetype. Previous work has shown the value of food for enhancing communication in romantic relationships by ensuring both increased awareness of one's own and partner's emotions (Croyle & Waltz, 2002), as well as impacting upon emotional responses (Evers et al., 2010). Evidence for connection between food and emotions have been provided by research on the meaning of food in religious celebrations (Feeley-Harnik, 1995), fasting and feasts (Insoll, 2011). The limited HCI work on technologies engaging directly with the making or eating of food has explored mostly universal basic taste experiences such as sweet, bitter and sour (Gayler et al., 2019a; Gayler & Sas, 2017; Murer et al., 2013; Vi, Ablart, et al., 2017) rather than flavour-based experiences which are complex and idiosyncratic (Spence, 2013). Moreover, making, sharing, and eating food, particularly with the ones we love, offers a sensory and experiential richness often less available in interactions with digital technologies, even with those purposefully designed to foster intimacy (Hertlein & Stevenson, 2010). This study argues that the advancement of 3D printing of food technologies is an opportunity to further explore food as material resource for communicating and regulating emotions. However, little is known in terms of how to work with food within the design process, and in particular in the context of intimacy.

This work sets out to answer the following research questions:

- What personalized flavours do people co-design for emotional communication in intimate relationships?
- How do people engage in 3D printing of such flavours in everyday lives?
- How does the 3D printed food support intimacy?

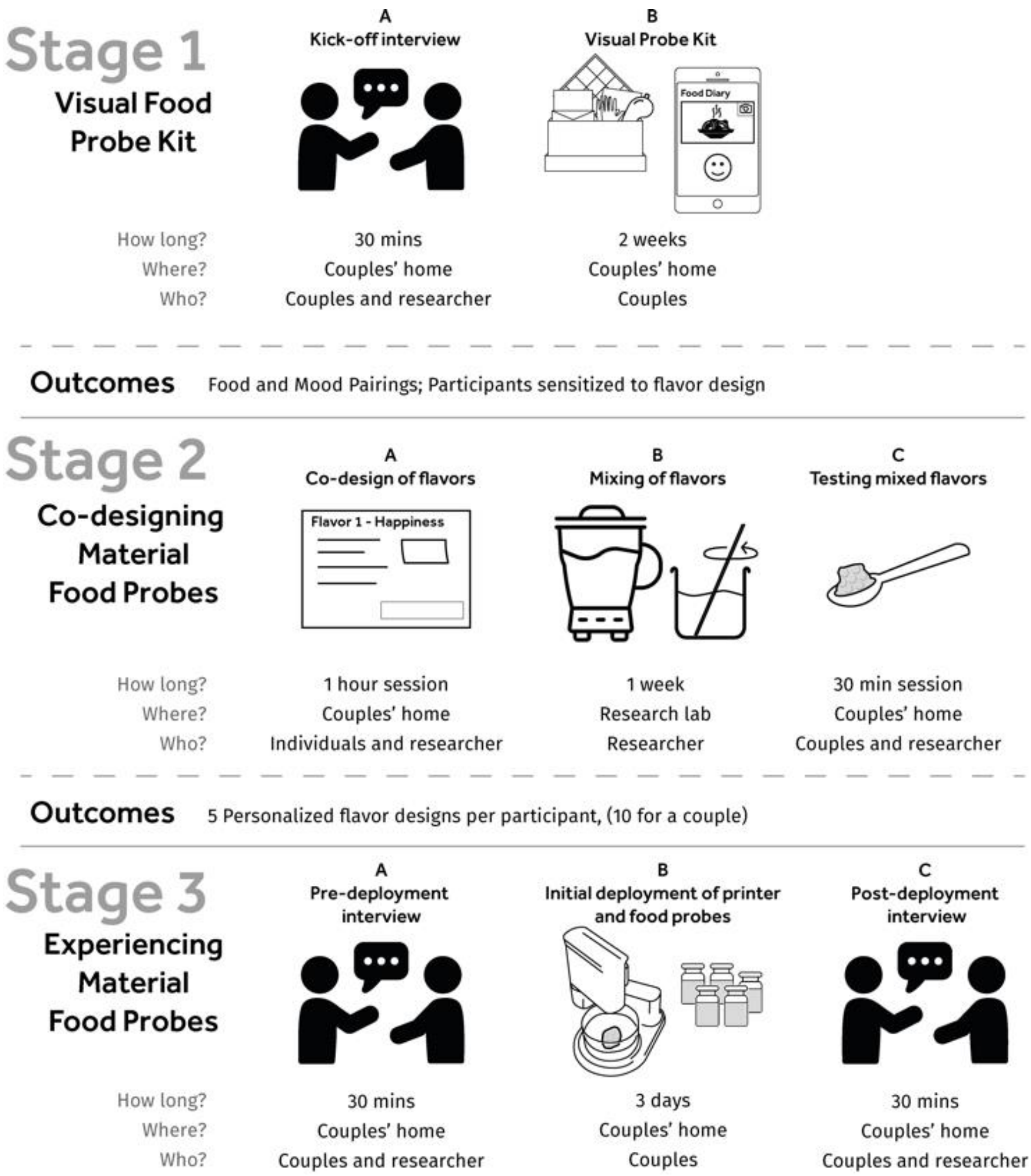


Figure 15 Overview of the three research stages, (Icons: ©Graphic Tigers and ©Adrien Coquet)

7.2 Method

For this study 5 couples took part in a food-based probe methodology which consisted of three stages as part of a full design cycle: (i) a *multisensory visual food probe* kit for sensitizing participants towards food-emotion practices and self-documenting them, in preparation to collaborate on (ii) the co-design of personalized flavours with each participant to be used with a 3D printer for food as part of a *material food probe* kit, in (iii) an explorative study over three days in couples' homes which examined how the probe was used, within everyday contexts (Figure 15). There is a distinction between the visual food probe as cultural probe (B. Gaver et al., 1999), and the *material food probe* as food printer with a set of personalized flavours as a hybrid of material probes (Jung & Stolterman, 2011) and technology probes (Jung & Stolterman, 2011). While the exploration of flavour personalization can be explored in many domains, intimate relationships were particularly suitable due to a threefold rationale. First, a wealth of findings have shown the value of food for expressing and communicating about love (Miller et al., 1998; Namie, 2011). Second, practices around food and love (Bardzell & Bardzell, 2011) are highly embodied (Chan et al., 2013; Maurer, 1996), and third, emotional support is provided within trusted loving relationships thus enabling exploration of food practices for emotion co-regulation (Hamburg et al., 2014).

7.2.1 Multisensory Visual Food Probe Kit - Stage 1B

As described in Study 6, Chapter 9 a Multisensory visual probe kit was used. It was completed over two weeks, a duration chosen to allow the capture of a breadth of food consumption activities, while allowing time for use of, and reflection on each of the kit's component. Part of the probe kit was an online individual food diary to further sensitize participants towards their food eating practices and their emotional aspects (Desmet & Schifferstein, 2008a; Evers et al., 2010), individually and as a couple. The dairy asked participants to photograph and briefly describe each snack or meal they ate, its source (cooked or bought, by oneself or others), social context (eating alone or with others) and associated feelings. All materials were collected at the end of the three days (1B, Figure 15) and analysed to provide input into the co-design phase.

7.2.2 Flavour Co-design of the Material Food Probe – Stage 2

This stage involved an individual session with each participant to co-design 5 flavours to be used as part of the *material food probe kit*: three flavours to communicate emotions of happiness, sadness, and a neutral one such as saying "hi" to one's partner; and two flavours designed to regulate partners' emotions when sad or angry by cheering them up or calming them down (Table 14). These purposes were chosen for the flavours based on findings showing that flavour and taste support the expression and understanding of emotional content in HCI contexts (Gayler et al., 2019a), that phatic communication (general purpose social communication without specific content) is important for supporting intimacy (Gibbs et al., 2005), and that food has been successfully used for emotional co-regulation in couples (Pradana & Buchanan, 2017).

	Purpose	Co-designed Flavours
Expression	To express happiness to your partner	Raspberry and blueberry; Broccoli and seasoning; Maltesers; Meat; Blueberry, strawberry and chocolate (2); Cheddar cheese (2); Nutella; Spinach, potato and garam masala; Egg and cheese; Orange and cranberry
	To express sadness to your partner	Mushroom; Watery tomato; Burnt (2); Pastry; Burnt pasta; Plain pasta; Bland chili sauce; Soggy bread; Chocolate; Sugar
Regulation	To cheer-up your partner	Dark chocolate and salt; Strawberry and banana; Salted caramel chocolate; Oreo; Middle Eastern spice (2); Chocolate; Tiramisu; Chocolate and chai; Chocolate and cream; Lime Curd
	To calm down your partner	Redbush tea; Water; Chocolate; Tomato, anchovy and olive; Banana smoothie; Orange; Chamomile tea; Breakfast tea with milk; Cream; Chamomile tea
Phatic	To say 'hi' to your partner	Spicy chili sauce; Potato; Tomato, anchovy and olive; Salt and vinegar; Zucchini and olive oil; Pasta and tomato; Orange; Smoked cheese; Rice and dahl; Banana

Table 14 Co-designed flavours by purpose, flavours used during the preliminary study (stage 3) are underlined, those used twice are marked with '(2)'

The flavour co-design sessions (stage 2A, Figure 15) started with a discussion of diary and visual probe data using visual summaries. Each flavour purpose was discussed to decide suitable flavours for each of the five purposes, and how the flavours could be re-created in the lab. To do this participants were asked to reflect on probe data, encouraged to creatively consider other flavours (Gayler et al., 2019a), as well as the texture of the printed food and temperature constraints. After being mixed in the lab, the designed flavours were piloted in stage 2C (Figure 15) through partners tasting each other's flavours to identify their intended purpose. Forty percent of the designed flavours were blindly identified (20/50). After disclosing the purpose of each flavour, participants ranked them on a 5-point Likert scale on their match to the intended flavour (1 – not matched at all, 5 – matched perfectly) leading to above average matching score of 3.5 (S.D. = 1.5). Then participants tried their own flavours and provided similar match rankings showing a high matching score of 3.8 (S.D. = 1.2). Feedback was provided on how each flavour match could be improved, by altering the recipe *"more coffee and less sugar would be good"* (P3, cheer-up), and its intensity: "*that is too intense, make it more dilute"* (P2, say hi). As a result, 18 out of 50

flavours were iterated in the lab before being used in participants' homes.

7.2.3 Material Food Probe Preliminary Study – Stage 3

This stage involved the use of the *material food probe kit namely* the 3D printer for food with the 10 co-designed flavours, 5 by each couple's partner, for three days for their initial exploration in real-life settings (Figure 17). At the start and end of the preliminary study, semi-structured interviews were conducted with each couple which were audio recorded. Early interviews (Stage 3A, Figure 15), covered participant's expectations of the 3D printer regarding frequency, location and context of use. Then, each couple was introduced to the printer, shown how to use it, and given a smart phone with an app for controlling the printer and designing the shape of the printed food by drawing each droplet (Figure 16). This meant users could vary the volume of 3D printed food between 5ml and 15ml and select the type of flavour to be loaded into the printer to fit the couple's emotional or communication needs. The app was used alongside an online diary for documenting; each printed flavour, who printed it and time of printing. Participants were asked to use the material food probe kit during their daily intimate conversations or any other contexts they liked. A week later, participants took part in a final interview (3C, Figure 15) to reflect on the experience of using the material food probe kit. The study lasted three days, limited by the shelf-life of the food materials, which participants kept refrigerated when not in use, ensuring food was safe to eat. Caution was taken not to encourage false use of the printer, asking participants to engage with the printer as desired rather than on a predetermined schedule of use.

7.2.4 Participants

5 couples were recruited (4 males and 6 females), (average age 32.5, S.D. = 4.2, range: 26-45), (6 white British, 2 non-British white and 2 of mixed ethnic background) from local communities in the UK. The couples had been in relationships for an average of 65 months (S.D. = 44.8, range 6-120) and spend an average of 47 minutes cooking and preparing food each day (S.D. = 17.7, range 15-120). All but one couple (P1, P2) lived together.

7.2.5 Apparatus

The nūfood 3D printer for food (Figure 16) was used to produce the food used this study as it supported the creation of personalised flavour experiences. It also could be used in participants homes to evaluate how flavours could be integrated into daily lives.

Figure 16 Photo of nūfood printer (left) and app showing design interface (right)

7.3 Findings

Now reported are insights from the food diary, visual probe kit, participants' co-designing and experiencing of the 3D printed food probes, and their impact on couples' emotional communication. The study involved over 10 hours of interviews with the couples, of which 4 hours 35 mins were focused on the co-design of the flavours. All discussions were audio recorded and transcribed. Thematic analysis was undertaken using a mix of inductive and deductive coding, initially by myself and then iteratively with my supervisor until stability was achieved. Participants are identified by number with each pair of consecutive numbers being used for a couple, P1 and P2 for the first couple to P9 with P10 for the last couple. Total number of mentions for that reported finding were reported with "n=".

Figure 17 Designed flavour part of Material Food Probes

7.3.1 Sensitizing Couples to their Emotional World of Food

In the stage 1 food diary, 314 food experiences were collected (Mean=31.4, S.D. = 12, Range 17-56) with most foods being cooked and eaten with others (65.9%). Findings show that feelings associated with food experiences were predominantly positive (55%), with fewer negative (28%), and neutral (17%) ones. The rich insights gained from the probes include individual's and partners' favourite foods, newly crafted recipes with personally meaningful ingredients and foods associated with negative memories from past relationships.

7.3.2 Co-designing the Flavours for Emotional Communication

Findings indicate two broad approaches to the co-design of flavours for the purposes of expressing and regulating emotions in intimate relationships: recreating past flavours or creating new flavours. The broad exploration of these flavours has led to the identification of the 50 flavours to be 3D printed. The first approach of recreating past flavours involves identifying a foodstuff that they or their partner have eaten, and which served one of the five target purposes to communicate or coregulate emotions. Unsurprisingly, flavours associated with happiness and cheering-up are foodstuffs that people enjoy, be they ready-made sweet snacks such as "*Oreo*" (P2, cheer-up) or *"hazelnut chocolate [is a] happy flavour for me"* (P4, happiness), or homemade food: *"a nice Indian meal [...] quite hearty and filling, carbs, a warmth to it, not too spicy"* (P3, happiness) or "*he loves vegetarian meatballs [...] I would make that to cheer him up"* (P5, cheer up). The value of known recipes (n=39) and of their ingredients (n=84) was much acknowledged for inspiring and refining the design of flavours.

An interesting outcome is that rather than being uniquely associated with memorable events (Baker et al., 2005) such as the first kiss, most of the explored flavours relate to frequently consumed everyday foods (7 flavours): *"I always have the same thing at lunch for some reason, I always have granola for breakfast*" (P2). These reflect participants' habits of eating their preferred foods - both personal (n=14) and partner's preferences (n=22) were used to support positive emotions happiness (n=9); or cheer-up (n=8). However, while the association of sweet taste to positive emotions is less surprising (Gayler et al., 2019a), its higher use in coregulation compared to expression of emotions is interesting, particularly in snack form. Indeed, participants selected snacks with a sweet taste (n=8) and chocolate flavour (n=6) for cheering their partner up, while the expression of one's happiness was made not only through sweet taste (n=5) and chocolate (n=3) but also through fruits and vegetables (n=3): *"Yeah, I do love tomatoes, [they] are very important to me"* (P5, happiness). These findings confirm previous ones on the value of such flavours for creating meaningful interactions (Gayler et al., 2019a), and extend them to lightweight interactions such as snacks.

Another important outcome is the limited use of carbohydrate-based food for coregulation, despite their acknowledged value as comfort food (Hendy, 2012). Even more interesting is the association of such food with sadness, albeit due to inadequate preparation: *"tomato juice seeps into the bread and becomes very soggy over time […] mouldy pitta bread"* (P5, sadness) or "*white bread, soggy, without even the sides of the bread, super bland, nothing, like chewing on air"* (P3, sadness). Other ways to communicate sadness were through a diluted version of preferred flavours: *"I remember when I had a flight recently [a] really watery tomato soup, that was low in flavour and a really feint taste [...] it was really bad, that made me sad"* (P5, sadness). In regard to the coregulation of negative intense feelings a significant outcome is the predominant use of drinks (n=7) for helping partners to calm down; be those hot, such as tea (n=4): *"not that much milk [in the tea] just a hint of milk and no sugar"* (P3, calm-down); or cold, such as fruit smoothies or even water (n=2). Even when meals are suggested for this purpose, their less solid quality is emphasized: *"curry, like a creamy coriander masala type thing"* (P6, calm-down).

These outcomes suggest the specific value of *comfort beverages* for co-regulating high arousal negative emotions , in the context of their broader role in emotion regulation (M Umair et al., 2020; Muhammad Umair et al., 2019; van Zyl, 2016). Findings indicate that the phatic communication has been associated with more diverse flavours, including favourite mundane ones, which are highly likely to elicit positive emotions. This suggests that in intimate relationships, even phatic communication is likely to be loaded with emotional undertones.
If the flavours described before reflect individual preferences and partners' intimate knowledge of each other's favourite foods, and even consideration of their misalignment: *"tomato is more something that I like, not that he doesn't like it but seems a bit selfish to put tomato"* (P5), other flavours are those that both partners enjoy together or couple's preferred flavours: *"anchovy, that is something that we both love"* (P2) also supported by his partner: *"he would definitely be like 'yeah, that is a positive thing', it is something we share together"* (P1). Couple's favourite foods are also shared in everyday contexts, often in the form of rituals, either to support calming down: "*I think it would be something familiar [anchovy] for both of us, would calm us down a bit"* (P2), or for communicating happiness: *definitely I can put pancake; it is a ritual"* (P8).

If the above findings present the approach to the co-design by recreating specific flavours experienced in the past, now discussed is the second approach of creating new flavours for the purposes of expressing and regulating emotions. Findings show that almost one third of flavours (17 out of 50) consisted of such *newly created flavours*, most of them to communicate sadness (n=6) and for phatic communication (n=4), and fewer to calm down (n=3), communicate happiness (n=3) or cheer up (n=2). In order to express sadness, participants engaged with the generic taste of burnt food: "*so what can I put here? burning? Sadness. Maybe some burnt thing? […] let's put burnt if I didn't like, that is okay. […] Burnt plus plain"* (P8). This outcome extends the link between negative emotions and bitter taste (Eskine et al., 2012); rather than raw bitter tastes, participants used burnt food to create a bitterness and elicit the emotion of sadness.

Another way to express sadness is through lack of flavour which has not been experienced but imagined: "*lack of flavour [means sadness] […] I think of sadness as a lack of arousal rather than high chili [which] would be a very strong emotion [so] watered down anything is a great idea*" (P4, sadness). This creative search for the best flavour is the hallmark of this approach, which often involves combining flavours in new ways: "*happiness for [my partner] is having something really sweet […] I think very sweet chocolate as well as […] nice chai taste, a sense of home and comfort […] the treat chocolate is a pick me up […] sweet chocolate and chai, quite hot with different spices*" (P3, cheer-up). They can also combine specific texture and odour in original flavours: "*something really quite moist, almost like if it was a bit lavender-y like edible water pods* (Harveston, 2018) *you bite into it [and it] exploded in your mouth like cooling"* (P1, calm-down). Importantly, these outcomes indicate that beyond recreating existing flavours, almost one in three flavours were openly and creatively explored by combining flavours characteristics in unexpected ways. This approach was not only useful to creatively generate difficult flavours like the ones communicating sadness which conflict with the sensorial pleasure elicited by food, but also to materialize imagined positive experiences of food leveraging preferred qualities beyond taste. This opens up an interesting design space of the 3D printing of food for such novel experiences difficult to otherwise access.

7.3.3 Interacting with the Material Food Probe Kit

7.3.3.1 Overall Experience

The overall experience of the material food probe kit during the three-day preliminary study in participants' homes was perceived as highly creative, playful and enjoyable. An important quality of this experience was the creative experimentation mentioned by 5 participants as shown in this illustrative quote: *"It just seemed to be a really simple and easy tool to use, and fun to play with to create what we wanted*" (P7). Findings also indicate that although all couples engaged in experimentation, this was particularly enjoyed by three participants with an interest in tinkering (P1, P5, P8): *"I just like the process of making stuff that was what I really enjoyed [because] I am a making type person"* (P1). This finding indicates surprising making qualities of the 3D printer use, which appears to integrate hedonic qualities of DIY such as watching the 3D printer and trying to understand its workings (Shove, 2007), with cooking practices (Longhurst et al., 2009) such as "preparing" ingredients. P8 describes how this differed within the couple: "*I stayed around because I wanted to see if it was still working, and which shape I would have out of it. [My partner] was more like launch it and just come back when it is done."* A key part of this experimental engagement with the material food probe kit was the creativity enabled by opportunity to mix different flavours, *"[It was] enjoyable to create a unique taste, because we [could] actually mix taste with it. The creation, the creativity [were] enjoyable for me"* (P8). One participant highlighted how open exploration could be generative: "*we can easily picture that we can try to make more fancy things […] mixing the [flavours from the two tanks in the printer to make] different tastes"* (P8). Although a future possibility, the printer's functionality during the study did not allow the mixing of flavours.

7.3.3.1 Patterns of Use

During the three-day preliminary study, 37 separate uses were recorded with 7.4 average uses per couple (S.D. = 2.9, range 5-11). Logged data indicates the probes were printed mostly in the evenings from 7 pm to 11pm (49%), and also in the afternoons from 3pm to 7 pm (35%, all during weekends) with fewer uses on weekday mornings (13.5%) including no printing before 7am (Figure 18). Interviews also indicate participants' attempts to integrate the 3D printer in their daily routines, with the most frequent use around the evening meal as part of, or following, the couples' end of day ritual: "*we were mainly using it at the end of the day, as a reflection. I think in the weekends we did in the afternoon [3pm], sometimes the morning [11am] and we will chat"* (P3, P4). While attempts have been made to use the printer at breakfast time *"I could do that lime curd on toast in the morning. Yeah, that might be quite nice."* (P9) few such uses occurred as *"breakfast was a rushed time of day, trying to get everyone out the house, [using] it was definitely an evening thing."* (P10).

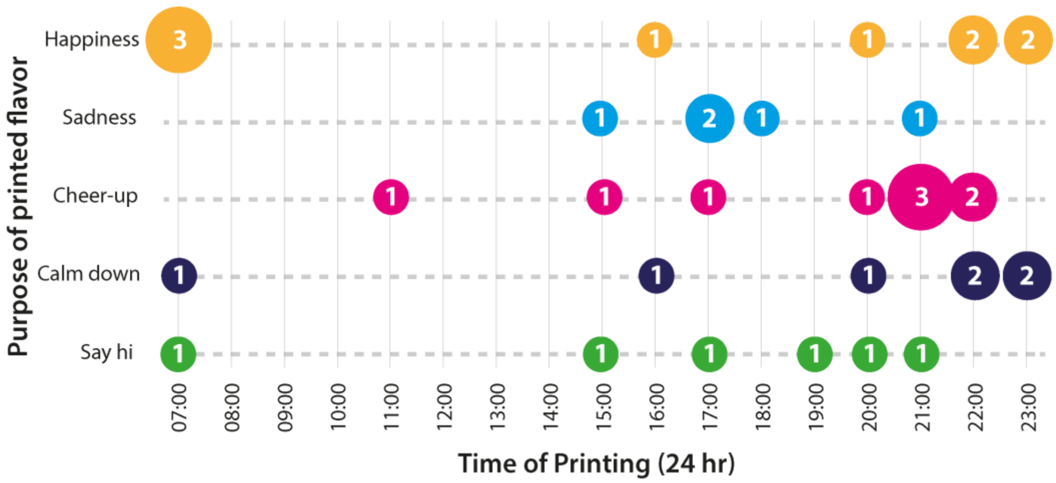


Figure 18 Frequencies of 3D printed food probes by time of day

The printer logs indicate an interesting distinction between isolated (10 times) and sequential use (27 times) of the printer, where participants took turns in printing. Although sequential use may be due to participants' desire to sample as many probes during the three-day study, it still offers an interesting view into how such exchanges become orchestrated. One such orchestration is for emotional expression and coregulation as shown in the following sequence between P1 and P2: P2 expressed sadness (pastry), followed by calm down (tomato, anchovy and olive) to which P1 replied by printing cheer up flavour (Salted caramel chocolate), and concluded with the greeting flavour (tomato, anchovy and olive). The repeated flavour of tomato, anchovy and olive was previously highlighted as a mutually enjoyed recipe. The other orchestration is participants' taking turns to print different probes to express happiness, upregulate (cheer up), or both. This is an important finding suggesting a flavour-based dialogue which may lead or be led by people's emotional responses in the moment, and the possible cumulative effect that a diverse succession of flavours may have for increasing the expressiveness of partners' nonverbal communication.

7.3.4 3D Printed Flavours: Broader Support for Intimacy

The 3D printed food probes appear to broadly support intimacy through expressivity, physicality, joint action and gift giving, four of the six strategies identified as key in supporting technology mediated connectedness between loved ones (Hassenzahl et al., 2012). Less supported were *memories* related to 3D food probes and *awareness* since for all interactions with the printer participants were collocated; however envisaged scenarios of remote use were mentioned, which future work could further explore. *Expressivity* consisting of mediated opportunities for diverse expression of emotions (Hassenzahl et al., 2012) and was the most emphasized strategy in the findings. This is reflected in the diversity of personalized flavours as part of the material food probe kit and their ability to enable non-verbal, flavour-based emotional communication: *"I think it was nice to have a flavour [during our conversations] to try and express a feeling. And I think [the flavours] fit [with the emotions] as well […] it was useful to have a flavour to try and communicate an emotion"* (P3). As this quote indicates, expressivity of 3D printed food probes contributes to verbal communication through novel and intuitive ways to express the richness of, and as shown below, the tacit aspect of emotional experiences: *"I was like 'How are you feeling right now?' and we were like we should probably go [use the printer] to print off how we are feeling as opposed to actually talking to each other about it […] like non-verbal communication [to] portray an emotion that we weren't actually saying out loud. [It was] very good in terms of being more open*" (P2). This non-verbal usage offers a lightweight and indirect method to express the negative experience of the day, echoing qualities previously identified as supporting intimate interactions (Pradana & Buchanan, 2017). The personalized quality of the probes also offer potential for an exclusive flavour-based language between the couple. Participants also suggested how shapes or texture could further support expressivity: "I think if you were able to print shapes that were more evocative of different emotions as well [that would be good]" (P6); "like a heart shape" (P7).

Findings indicate support for *physicality* which consists of mediated physical intimacy (Hassenzahl et al., 2012). This was supported through the embodied quality of the food probes as they got shared and eaten, however not for nourishment purposes: "*not to make stuff when I am hungry"* (P6) but experiential ones through delightful bite-sized treats or a relaxing mouthful of drink: "*maybe the way to use it will be to create something different but in small quantities, like an amuse-bouche more than a big meal"* (P8). There were also indications of *joint action* (Hassenzahl et al., 2012) through participants' engagement in collaborative use of the printer and sharing of food probes: *"we use it together most of the time, we took turns with choosing a flavour that the other person had designed"* (P3), often as part of dining experiences: *"after dinner we sit down and use it together"* (P5). Not least, personalized flavours can be *gifted* (Hassenzahl et al., 2012) as acts of labour and care via their preparation to help one's partner cheer up or calm down: *"It is a nice way of doing something for [my partner] because it is set-up for you. It has told you what that connection is"* (P6).

7.3.5 Specific Support for Emotional Communication

Findings show that half of printed probes were to either cheer one's partner up (n=9), or to express happiness (n=9), followed by calming one's partner down (n=7), saying "hi" (n=7) and expressing sadness (n=5). This outcome suggests a strong preference for emotionally positive flavours (50%) with limited use of negative or neutral ones (both 19%).

7.3.6 Coregulating Emotions

Cheering up was the most common reason for using the printer, with 8 of 10 such printed flavours being chocolate-based. It is unsurprising to find a strong preference for chocolate, a typical comfort food known to induce pleasure was effective in enhancing participants' mood: *"I would say it did connect [with how I was feeling], one time I was feeling down, and we were like let's print the chocolate one [dark chocolate and salt]"* (P5, cheer-up). Opportunities to print cheer-up flavours were often provided as part of dining experiences, with 6 out of 9 flavours being printed between 8pm and 11pm: *"we want to be full first, and then we use the printer [for] a dessert [chocolate]"* (P7, cheer up), to which the partner added: "*maybe we can have a taste of chocolate or we just talked about our days [and] I think we did [print more] sweeter than savoury, because we used it as a dessert related to the emotion"* (P8). This quote is particularly interesting as it illustrates an additional value of cheer-up flavours, to be used *instead of dessert*, which given their bite-size form, may regulate sweet food intake.

In contrast to the printed cheer up flavours, calming down ones were diverse, and predominantly drinks such as juices (2) and tea (3). While cheer up flavours are used mostly during the dinner, calming ones tend to be used after as part of the end of day ritual, most likely before going to sleep, with 4 of 7 such flavours printed after 10pm: "*we were mainly using it [chamomile tea] at the end of the day for a reflection on the day"*(P4, calm down), a flavour which in the design stage was anticipated as helping distress: "*it will be good to have opportunities to use them when you are […] getting frustrated"*. An interesting quote illustrating the actual tasting of tea flavours designed for calming down indicates embodied experience: *"quite bitter, like sour, my mouth is watering but not very strong flavour"* (P5 tasting P6's Redbush tea flavour). An important outcome is the use of herbs such as chamomile known for their beneficial impact on mild or moderate anxiety (Abascal & Yarnell, 2004). The following quote illustrates how calming down and cheering up flavours can be printed in sequence: *"he was going through a lot at work, so I was printing him the nice ones [tomato, anchovy and olive to help] calm down, and [then to] cheer him up [salted caramel]"* (P1). P2's experience of pastry is particularly evocative of the embodied qualities of the material food probes: "*that just tastes like flour, so dry as well, it has really dried my mouth out as well, sadness, that is horrific"* (P2).

7.3.7 Expressing Emotions

Now described are the use of material food probes intended to express emotions. The printed flavours communicating happiness were the most diverse, from sweet, fruit-based ones to dairy flavours, umami flavours and vegetable flavours. Unlike other probe flavours, happiness ones were printed throughout the day, (7am to 11pm). Arguably some of the specific textures of foodstuff inspiring flavours designed for the happiness probes made it challenging to "translate" them into gel-like bites while preserving their experiential qualities. Findings indicate the 3D printer's texture limitation, and how a happiness flavour became less appealing: *"[making Nutella] with the printer into this gelatinous thing […] made it less appealing"* (P3).

The printed flavours for expressing sadness were more homogenous including burnt or bland foods (3) and were mostly printed between 5pm and 7pm (3 out of 5), as participants got home and discussed their days. Indeed, participants' challenge to design flavours for negative emotions: "*that stuff will taste really bad*" (P5), was mirrored by their reduced desire to consume them: "*the ones used least were the burnt and pastry [expressing sadness], [we] printed with it but neither of us tried it because we knew it was disgusting"* (P1), or "*pasta burnt, burnt bread. I think we didn't use it at all"* (P8). There was also scepticism about the intention to create food for negative emotions compared to positive ones, *"[the thought that] if he cooks something I hate, he must hate me. I don't think I've ever thought that there's negative connotations to what you cook. I think just spot the positive connotations and that's really sweet"* (P9). Flavours for *phatic communication* were printed throughout the day, similar to happiness ones, albeit within a reduced window from 7am to 9pm. These probes were again diverse including both preferred flavours (3) as well as mundane ones (6). This means that the former could have been used for other purposes such as calming down, like in the case of tomato, anchovy and olive (P1), or were rather mundane, and less exciting to use: "*I don't know if the middle ground ones [neutral: saying hello] would be used as much"* (P1).

7.4 Discussion

7.4.1 Designing Emotionally Positive Flavours

The first question focuses on what specific personalized flavours people co-design for the purpose of emotional communication. While previous work has explored food as a visual medium on which informal messages can be printed (Khot et al., 2017; Patekar & Dudeja, 2018; Wei et al., 2014, 2011), the findings contribute to the less explored research space (Gayler et al., 2019a) where food itself can be 3D printed. Key insights from the study emphasize the recreation of flavours related to positive emotions informed by individual and couple preferences as well as everyday food sharing practices, with a strong preference for sweet treats for cheering up, and drink flavours for calming down. Previous work has looked into comfort food and sweets as a medium of communication (Khot et al., 2017; Patekar & Dudeja, 2018; Wei et al., 2014),(Wei et al., 2014b) albeit not for supporting intimacy in terms of the type of 3D printed foods that could regulate emotions. The participants also created new flavours for the more challenging to express, negative or neutral emotions; in part explored through burning or diluting preferred flavours. However, given participants' limited appetite for less appealing flavours, it can be argued that there is more value in exploring positive flavours, both those that are familiar and those that are creatively imagined to surprise, delight, and improve both one's own and partner's mood (Evers et al., 2010) by cheering up or calming down. Thus, the identified creative approach to designing flavours from scratch, can open up design opportunities for emotionally positive flavours. Here one can think of flavours for coregulation such as "*chocolate and chai"* for cheering up, or "*lavender-y like edible water pod"* for calming down. For the former, one can imagine innovative caffeine-based flavours leveraging preferred tea, chocolate or even spice flavours as *pick me up* stimulating bite-sized treats. For the second, one can think of nervine herb-infused flavours (Abascal & Yarnell, 2004) such as lavender, chamomile or lemon balm as a *calm me down* relaxing mouthful. Both nervine herbs (Abascal & Yarnell, 2004) and comfort beverages (van Zyl, 2016) have been shown to be beneficial for down regulating arousal in mild or moderate anxiety.

The outcomes also advance the edible interface research (Maynes-Aminzade, 2005; Vi, Ablart, et al., 2017) by highlighting the distinction between idiosyncratic and more generic types of flavours. Indeed, while those for cheering up and expressing sadness tend to be consistent among participants, i.e., sweet or burnt and plain, those communicating happiness, saying hi, and calming down are more idiosyncratic. This in turn suggests stronger benefits from personalizing flavours which can take two forms. First, research on HCI design around food should be responsive and considerate to the range of food being eaten whilst the 'around food' interaction takes place, considering how favourite foods could align with the content being delivering through the digital experience. Second, HCI research with food could benefit from personalization and combination of flavours, moving away from single flavours predominantly used in previous work (Khot et al., 2017; Patekar et al., 2018). Moreover, flavours can be designed both to recreate previous experiences, and also crafted from scratch for novel experiences beyond emotional communication, for instance for creating food-based memory cues for older adults.

7.4.2 Integration of 3D Printed Flavours in Focal Intimacy Practices

Now the discussion turns to the question regarding how people engage with and use in-situ, the flavour-based probes, while being mindful of the reduced duration of the preliminary study, and therefore on the claims that the findings support. Although much

HCI research has explored connectedness in intimate relationships (Hassenzahl et al., 2012) the emphasis has been mostly on remote awareness and presence, mostly through visual or multimedia interfaces (Thieme et al., 2011). Thus, the focus on flavour as an interface for supporting collocated intimacy is particularly novel, allowing us to understand the value that material food probes or printed flavour may take in two important intimacy rituals where they have been mostly used: the end of day, and the evening meal. To further reflect on the findings, these two rituals are framed as *focal intimacy practices*, building on Borgmann's (Borgmann, 1987) conceptualization of *focal practices:* essential for connecting people to what matters most or their "significant realities". Focal practices such as hands-on ones of cooking, gardening, or exercising, or those of connecting, such as family meals, require attention, commitment and skills; they are also at risk of becoming increasingly unfocused or fragmented (Heikkerö, 2005) through the distraction of technology (Bunnell, 2004).

The findings however indicate a more nuanced view, as the 3D printed flavours used by participants in their homes, not only did not disrupt couples' patterns of interaction but augmented them in subtle new ways. For the end of day rituals taking place after people arrive home in order to share and reflect on their daily experiences, findings suggest a strong emphasis on the need for calming down, often after expressing negative feelings such as sadness or stress. Here drinks were mostly related with flavours based on herbs or fruits. While some resembled the traditional cup of tea, others were creatively designed with great care and skill such as the *lavender-y water pod* offering only a mouthful of precious drink to be mindfully enjoyed. Although embodied experiences in the context of intimacy have been previously described, supporting for instance remotely drinking together (Chung et al., 2006), the drink itself has not been technologically mediated. This study argues that technologically mediated food experiences such as those enabled by the co-designed 3D printed flavours can open up novel design opportunities. The evening meal ritual usually starts after the end of day ritual with people preparing and sharing the meal. The 3D printed flavours most often used in this context were those for cheering up, which contributed to the meal in an interesting way: not by adding to, but by replacing the dessert course, through chocolate-based flavours, which may offer the additional benefit of regulating sweet intake through their limited size. This ritual can also continue later in the evening when people printed more idiosyncratic flavours expressing happiness.

7.4.3 Experiencing and Crafting Emotionally Positive Flavours for Coregulation

The third research question focused on how the 3D printed food probes can support intimacy. Findings indicate that through their qualities, the 3D printed flavours support intimacy in two important ways. The first is more broad through expressivity, physicality, joint action and intentions of gift giving (Hassenzahl et al., 2012), while the second one is more specific through the probes' direct support for emotional coregulation. The preference for positive flavours from the co-design became even stronger while experiencing the printed flavours in situ. Initial findings also suggest higher use of probes for emotional regulation compared to emotional expression, as arguably the former not only builds on the latter but supports increased connectedness. Moreover, the pleasure of exploring the flavours and their right combination, as well as the anticipated delight of their partner experiencing them, not only strengthens the craft quality of the practice around the 3D printed flavours, but also contributes to couple's emotional communication. Although couples often engage in affectionate exchanges mediated by food such as cooking a dinner or making a cup of tea, these tend to be either laborious like the former or immediate like the latter. 3D material food probes allow both, 3D printed food as *immediate* tokens of affection through lovingly and *laboriously* crafted flavours. The approach of decoupling the design and the delivery of the flavours is key for enabling such meaningfully rich, personalized exchanges responding to partners' emotional needs at the present moment. There is potential for novel intimate experiences mediated by material food probes to be not only lovingly crafted for personal meaning but also lightweight communications tools (Pradana & Buchanan, 2017) through their quick and easy delivery as needed in the moment. More can be understood around how the use of the 3D printer remakes such meaning, and about the values expressed via food. By crafting the flavours, themselves users reframe the interaction into one which better represents the value a loved one's effort.

7.4.4 Material Food Probes

Now discussed is the approach to the exploration of food mediated intimacy through *material food probes,* defined here as consisting of 3D printer for food and co-designed flavours, allowing the exploration of food's material properties for the specific purpose of inspiring novel design. This concept bears similarities with both material probes

(Jung & Stolterman, 2011) and technological probes (Hutchinson et al., 2003) much used in HCI. Technology probes (Hutchinson et al., 2003) are open ended digital artifacts with a single, simple functionality, deployed in situ, early in the design cycle, not to be evaluated but to inspire the design of future technologies. Material probes (Jung & Stolterman, 2011) on the other hand, enable the exploration of the physical artifacts' material properties such colour, shape or texture and how these may support specific functions that could then inspire design of digital artifacts. The co-designed flavours within material food probes are excellent illustrations of less explored material probes, namely those focusing on flavour-based material properties such as taste, texture or colour, which in the study were explored for the specific purpose of supporting emotional communication. This extends previous findings on food experiences in HCI relying on just one modality (Khot et al., 2017; Obrist, Comber, et al., 2014a; Patekar & Dudeja, 2018; Vi et al., 2018) towards multisensory experiences that material food probes can inspire. Material food probes also resemble qualities of technology probes as they are materialized through participants' in-situ interaction with the 3D printer, its app, and the personalized co-designed flavours, mixed and ready to print. Thus, the functionality of the 3D printer is simple, yet the 3D printed flavours carry strong personal meaning and are open for users' interpretation.

Preliminary outcomes also indicate important qualities of the material food probes shared with both the craft and DIY practices, facilitated by the decoupling of the flavours' earlier co-design in the lab, from their printing in situ. While, the co-design of flavours - through the creative, enjoyable and playful exploration of personally meaningful flavours (Baker et al., 2005) - resembles many qualities of crafts practice (Bunnell, 2004; Rosner, 2009), it also echoes design *around* food through the crafting of new social experiences (Barden et al., 2012; Comber et al., 2014; Ferdous et al., 2016). Independently, the printing of flavours resembles qualities of DIY practice (Shove, 2007; Tanenbaum et al., 2013), through the "assembling" the flavour probes and the 3D printer "components", getting them to work together through the printer app, which carried forward the enjoyable and playful exploration (Bunnell, 2004) from the co-design stage. However, it is now enriched with the experiential qualities enabled by the shared consumption of 3D printed food probes. The printing of flavours is similar to design *with* food research (Gayler et al., 2019a; Murer et al., 2013; Vi, Ablart, et al., 2017) albeit extended towards richer multisensory experiences that integrate the benefits of design-*around*, with the personalized flavours for emotional communication. Also related to DIY practice, the value of personal labour invested in the making of complex electronics has been shown to shift their status from unremarkable objects to things of significance ensuring attachment and long term adoption (Sas & Neustaedter, 2017). Through creative appropriation (Salovaara et al., 2011), the craft quality of the designed flavours may offer similar benefits that future work could unpack. As 3D printed flavours become integrated in couples' focal intimacy practices (Borgmann, 1987) they may also gain the status of *focal things*, authentically contributing to these focal practices which in turn may foster strong long term engagement.

7.4.5 Bodily-actuated Emotional Regulation through Food

Given the potential of material food probes for emotional regulation, which emerging affective interfaces also support (Wilson & Brewster, 2017), one could also explore integrating together such technologies. For instance, one can think of novel interfaces for remotely actuating the 3D printer based on tracked changes in user's emotional arousal. This would allow one's bodily emotional responses to directly drive the 3D printing of flavours. By complementing the current intentive interaction (Simm et al., 2016) described in the work, the affective interface would ensure a hybrid interaction with the printer that integrates both automatic and active printing of emotionally adaptive flavours. Future work should consider how to balance immediate responsive contexts, tailored towards sweet treats, with the long-term maintenance of physical and emotional wellbeing, if food is to further support the emerging interest in emotional regulation in HCI (Lyngs et al., 2019).

This work extends the universal taste-emotion mappings of study 3 and adds the potential for personalised flavour design to create 3D printed food that can be used for expression and emotional co-regulation. The next study repurposes the approach to personalised flavour design to consider a further experiential use which goes beyond emotional experience. Study 5 again turns to the connection between sensory and cognitive experience, however this time drawing on the olfactory aspect of food experience and exploring the connection with memory. Again, personalised design methods are key to researching and design a novel form of flavour-based memory cue.

Study 5 aims to expand the research of the design methods in Study 4, aiming to uncover a further potential of food material, that of supporting memory-based interactions in HCI.

8 Study 5 "It took me back 25 years in one bound": Self-Generated Flavour-based Cues for Self-defining Memories in Later Life

8.1 Aim and Rationale

This study adds further breadth to the experiential purposes for which 3D printed food can be considered, connecting to emotional experience, it draws on the connection between memory and flavour sensation to build 3D printed food as memory cues. As with Study 4, it considers flavour as an idiosyncratic, personal experience studied in field settings.

There is a great deal of research into the odour cues for autobiographical memory (Chu & Downes, 2002; Herz, 1998, 2004). However, Given some of the challenges in providing odour stimuli within computing systems (Brewster et al., 2006; Obrist et al., 2016b) there is potential for 3D printed food to support the delivering of odour based memory cues. This study aims to understand the design and use of personalised food-based memory cues for self-defining memories. It extends the understanding of the design space for flavour, by highlighting the potential for designing flavour experiences with 3D printed food to support memory recall. The study aims to understand how food-based memory cues can be designed by individuals through a co-design process. It attempts this for memories based around food experience as well as memories that are not related to food to understand whether cues can be effective in both relational and abstract applications.

8.2 Method

The aim of the study is to explore the feasibility and value of co-designing self-generated flavour-based cues for self-defining memories. 12 participants were recruited through adverts on social media (Mean age 65.83, range 62-78, all aged 60+, 8 females, 3 males) with no taste or memory impairments. This group was selected for three reasons. The cognitive decline due to normal aging negatively impacts episodic memories and sense of self (Singer et al., 2007), chemosensory cues such as tastes or odours are particularly beneficial in supporting self-defining memories in old age (Zucco et al., 2012), and older people's benefit from rich multisensory stimulation and interest in crafts (Sas, 2018). Although methods are shared between this study and the previous one, adjustments were made to the language and approach to better suit the older adults who took part. As well as extending the co-design approach and flavour cues to memory-based applications this study also explores the potential for involving a different population in the design of flavour-based interactions. The study involved three stages shown in Figure 19, detailed process is described in Figure 20.

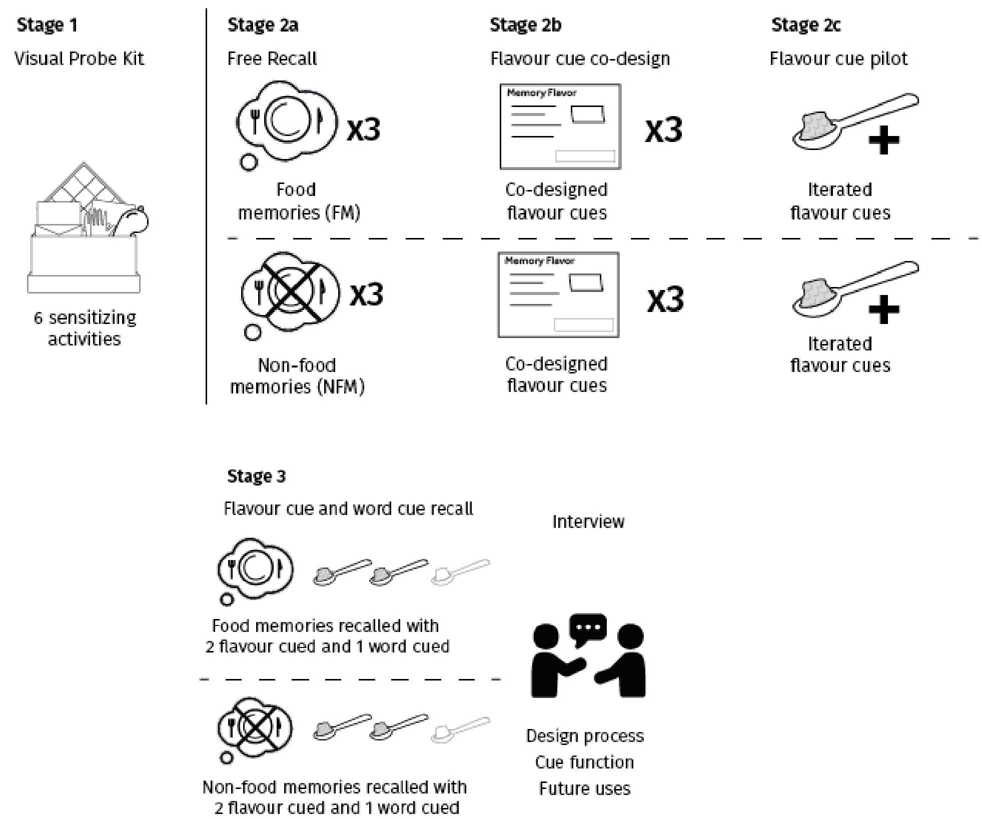


Figure 19 Method diagram showing; stage 1 visual probe kit, stage 2a free recall, stage 2b flavour cue design, stage 2c flavour cue pilot, stage 3 flavour cue and word cue recall and interview.

8.2.1 Stage 1: Sensitizing towards Food Experiences and Memories

Stage 1 consisted of a two-week diary study during which participants used a cultural probe kit in their homes to sensitize them towards food experience and self-defining memories. Inspired by previous cultural probes from HFI work (Gayler et al., 2020), the bespoke kit described in Study 6, Chapter 9.

8.2.2 Stage 2: Co-designing Multimodal Flavour-based Cues

The co-design of flavour-based cues for self-defining memories is likely to depend on how food features in these memories, so the distinction between self-defining memories including food which this study calls food memories (FM) and those without, called non-food memories (NFM) is important. Hence, Stage 2 started with individual interviews focusing on the free recall of 6 self-defining memories: 3 FMs such as a wedding breakfast, and 3 NFMs such as starting at university (Stage 2a, Figure 19). A common method was employed for free elicitation of self-defining memories developed by Piolino et al. (2006). After the memory was freely recalled, 3 prompts for details were given such associated feelings, people, place and time, and asked participants to name each memory. Participants were given 3 days to prepare memories before the interviews which lasted around 45 minutes.

Following the memory recall, participants were given samples of 3D printed food of the five basic tastes (sweet, bitter, salty, sour and umami) to calibrate participant's perception, similar to prior HFI research (Gayler et al., 2019). Then, given the absence of food in the identified non-food self-defining memories, participants were supported to think about the best foodstuff that may cue each NFM, via associations between foodstuffs and key aspects of episodic memories such as people, feelings, places and events. Once a suitable foodstuff was identified, participants went through a flavour design process for all 6 FM and NFM cues. Here, participants were provided with a cue design sheet, asking them to rate on 6-point Likert scales the intensity of each of the five tastes characterizing the foodstuff central to that memory, and two semantic differential 6-point scales for texture (from liquid to solid), and for flavour duration (from momentary to lingering), based on sensory profiling techniques from sensory science (Ozcelik & Karaali, 2002). Participants were also asked to freely profile (A. A. Williams & Arnold, 1985) the foodstuff in terms of ingredients, flavours, and cooking processes. The aim of this activity was to bring the sensory food experience associated with the FM or NFM into focus, to better inform the design of the flavour-based cues. This stage concluded with individual semi-structured interviews to explore participants' perception of their co-designed flavour-based memory cues. The co-design workshops lasted around 75 minutes, with 15 minutes for the interviews.

8.2.1 Stage 3: Evaluating the Impact of Flavour-based Cues on Recall

Between Stage 2 and Stage 3, I used the insights from Stage 2 to create in the lab, the flavour-based cues for each self-defining memory. Once sourced and mixed, the flavours were produced using the 3D printing of food in 10ml samples in line with prior work (Gayler et al., 2019, 2020). The flavour-based cues were piloted with 6 participants (P1-6), who ate each sample, and commented on the match between the flavour cue and its related foodstuff. Of the 12 participants, 10 took part in stage 3 (P1-4, P7-12). Stage 3 consisted of an experimental study to explore the impact of flavour-based cues on the recall of self-defining memories. A within-subject design was used where each participant was given 4 of their co-designed, bespoke flavour-based cues, alongside the name of the memory for 4 of their self-defining memories, 2 FM and 2 NFM (each randomly selected and for clarity described hereafter as *flavour cued*), while the recall of the remaining 2 self-defining memories, 1 FM and 1 NFM, were cued only with the name of the memory. The recall procedure for the recall of all memories followed that used in Stage 1. This approach meant that flavour-based cues for the latter 2 memories were unused, but co-designing them was important, in order to account for the impact of the design process on memory recall. To account for the order effect, the order of memory recall was randomized. The study involved two independent variables namely the type of self-defining memory: FM and NFM, and the cue type: free recall, flavour cued (cued with flavour and memory name) and word cued (cued only with memory name), and four dependent variables: emotional content and sensory details in the recall (both across free recall, word and flavour cued), participants' ratings of the experience of time travel, and of emotional intensity (across the word and flavour cued conditions). To assess the emotional content, Linguistic Inquiry and Word Count (LIWC) was run, a linguistic analysis calculating the frequency of words for positive and negative emotions (Pennebaker et al., n.d.) on each memory recall. Sensory details were derived from a linguistic analysis informed by the Lancaster Sensorimotor Norms (Lynott et al., 2020) derived from over 39K English words (Lynott et al., 2020) computing the dominance of six perceptual modalities (touch, hearing, smell, taste, vision, and interoception) for each word. This recently developed tool was selected because of its potential to explore sensory details present in the memory recall. This meant that some indication of the sensory aspects of the memory could be derived without requiring users to further report their feelings or perspectives.

Stage 1 Sensitizing towards Food Experiences and Memories → **Stage 2** Co-designing Multimodal Flavour-based Cues → **Stage 3** Evaluating the Impact of Flavour-based Cues on Recall

Stage 1 - Sensitizing towards Food Experiences and Memories

1. Each participant used the probe kit (Study 6, Chapter 9)
2. Outcomes were collected by researchers and informed the next stage
3. 3 days before Stage 2, probes were collected and participants were briefed to identify 6 self-defining memories.

Stage 2 - Co-designing Multimodal Flavour-based Cues

1. Participants attended a meeting with researcher.
2. Recall of self-defining memories, each memory is prompted for further details 3 times following Piolino et al. (2006) process consisting of prompts for location, time, people, feelings, and sensory experiences.
3. Participants taste each of the calibrating taste materials to support understanding of basic tastes and familiarity with 3D printed food.
4. Association between memories and foods and flavours for NFM. Participants identified places, events, objects, people and feelings. For each, they were asked if any food or flavours could cue them, e.g. food eaten in specific places or at specific events, food preferred by people associated with that memory, food matching the feeling of the memory, or food they can creatively associate.
5. Cue selection where participants reviewed and chose one, or a combination of foods/flavours.
6. Description of flavour for both NFM and FM including ingredients, cooking process, preparation, and ratings of flavour using the scales for taste, texture and duration. Example facilitative questions include those about recipes ("was lemon added?") and cooking ("cooked with skin on?") which were asked until participants were unable to provide further detail. This was followed by the sensory description of the selected food such as key flavours, smells and colours.
7. Description of environmental details from the memory; sounds, smells, sights or haptic experiences.
8. Selection of the most salient details to support cue making.

Preparation of Flavour cues

1. Sourcing and preparing the key ingredients focusing on what participants considered important based on preference, saliency and memorability.
2. Mixing and cooking the ingredients as per recipe.
3. If solid, blitzing the ingredients in a food processor with water as needed to create a soup-like mixture; then filtering through a cheesecloth.
4. Adding gelling agents to ensure a batter-like consistency and the printing.

Stage 3 - Evaluating the Impact of Flavour-based Cues on Recall

1. Participants are presented with a plate with 4 of the 6 prepared cues presented on spoons.
2. Participant is asked to recall each of the 6 memories in turn by being given the name of the memory. For the 4 memories with flavour cues these are eaten just before the memory recall. For each memory 3 prompts are given as before.
3. Once all memories are recalled participants were interviewed about the experience.

Figure 20 Step-by-step method for the capture of memories and preparation of flavour-based memory cues

After recall, participants immediately rated the travel in time on a 5-point Likert scale (0=not at all, 4=extremely) for the statement, "*I feel that I have travelled back to the time it happened*". They also rated the emotional experience on a 5-point Likert scale from -2, very negative to +2, very positive, both scales based on work on multimodal autobiographical memory (Herz, 2004; Willander et al., 2015). The study concluded with individual semi-structured interviews where participants were asked to reflect on the experience of co-designing the flavour-based cues, the perceived impact of flavour-based cues on their self-defining memories, and potential future uses of such cues. The experimental study lasted around 75 minutes, with about 30 minutes being used for the interviews.

The interviews including memory recall from both Stage 2 and 3, and the co-design workshops were also audio recorded and fully transcribed. For qualitative data analysis, hybrid coding was employed (Fereday & Muir-Cochrane, 2006) integrating theoretically-informed deductive codes such as themes of self-defining memories (Blagov & Singer, 2004), life periods (Crete-Nishihata et al., 2012), emotional and sensory content (Blagov & Singer, 2004) and self-identity levels (Sas, 2018). The inductive codes from empirical data included the role of food in self-defining memories, components of flavour-based cues, and qualities of flavour experience with the code list being iteratively refined through discussions between the myself and my supervisor over several months.

8.3 Findings

Now reported are the findings; starting with the role of food in self-defining memories, flavour-based cues and their design process, followed by analysis of the value of flavour-based cues for the retrieval of self-defining memories, and more broadly for memory technologies in old age.

8.3.1 The Role of Food in Self-defining Memories

In this section, the role of food is explored for self-defining memories contrasting FM to NFM on how they relate to the sense of self, emotions, sensory perception, and lifetime periods when the memories were generated.

8.3.1.1 Food-based Self-Defining Memories More Strongly Reflect Relational Self

An important outcome is the large presence of relationships themes among the 72 self-defining memories, both overall (60%), and particularly for FM (75%) compared to NFM (40%). These themes were identified using Singer’s taxonomy (Singer et al., 2007) differentiating achievement, relational, and negative themes (Table 15) with 8 memories belonging to more than one group. Singer’s findings show that achievement memories were most prevalent in old age, which is reflected also in the NFM. The FM, however, emphasize relationship memories including group celebrations such as anniversaries (P2), weddings (P2, P3, P6, P12), and small group or dyad experiences such as honeymoon meals (P1, P12), overseas trips with loved ones (P1, P4, P5, P9, P11, P12), or the birth of a child (P1, P3, P5, P7, P9). These outcomes are important since self-defining memories with achievement theme are key for the personal self (Table 15), while those with relationship theme support the relational self (Sas, 2018), shown as the most important aspect of self in old age and particularly in dementia (Addis & Tippett, 2004). To illustrate the findings, brief descriptions are provided of 5 self-defining memories from the prevalent relational theme, 2 for FM and 3 for NFM (Figure 21).

Self-defining memories themes	**Self-identity levels**	**Life period (Singer et al., 2007)**								**Emotion (LIWC** (Pennebaker et al., n.d.)**)**			
		Childhood		**Youth**		**Adulthood**		**Old Age**		**Positive**		**Positive**	
		FM	NFM	FM	NFM	FM	NFM	FM	NFM	FM	NFM	FM	NFM
Relationship (48) FM (31) NFM (17)	Relational	22	16	15	5	49	57	14	22	2.77	2.34	0.4	0.76
Achievement (20) FM (7) NFM (13)	Personal	14	0	14	8	57	62	14	31	2.84	2.68	0.22	0.95
Negative (11) FM (3) NFM (8)	Mix	67	63	33	0	0	25	0	13	1.80	2.20	0.14	0.45

Table 15 Self-defining memories grouped according to relationship, achievement and negative themes; and the relational, personal or mixed levels of self-identity, showing percentages for both FM and NFM from childhood, youth, adulthood, or old age as life periods, and percentages of emotional terms for both FM and NFM when freely recalled.

8.3.1.1 Food-based Self-Defining Memories are Mostly from Adulthood and Early Life

Findings indicate that participants’ self-defining memories come from across the life span (Table 15, col 3), predominantly adulthood, rather that early life as shown in previous work (Sas, 2018; Singer et al., 2007), although early life provided almost two time more FM reflecting a relationships theme (37%) than NFM (21%) (Table 15, col 3). This emphasis on adulthood may reflect the increased agency of adults to eat novel foods and foods they like. the findings partly confirm the reminiscence bump theory (Rathbone et al., 2008) according to which formative years lead to many first time experiences which are more memorable, especially with respect to FM, whose additional value is indicated by more adulthood memories that can strengthen the relational self in older life. Related to life periods, previous work has classified self-defining memories as generic (repeated general events over a life period), episodic (general events of lengthy duration), or specific (unique events, less than a day) which tend to occur with the frequency of 4%, 24%, and 72%, respectively (Blagov & Singer, 2004).

The Best Strawberries Ever
Food Memory - Adulthood
"being given strawberries and fromage frais after I had my second daughter in hospital, and my partner came to see me the next morning and he brought me strawberries sliced out into a pot of fromage frais… it was a great sensation. I felt, I've never tasted strawberries before that moment, they were so delicious and I can remember sitting on the hospital bed, just not wanting to talk to anybody, not being engaged in any conversations […] I just wanted to eat the strawberries. So, it was a very strong and sensation of deliciousness. I was exhausted but happy […] it was a strong memory. It is connected with to my baby, to my partner […] I've a memory of early sunlit day […] The hospital room is at the 14th floor of the Hospital. So, it's looking out over the sea and you get some kind of a reflected light from the sea, you know, very clear sort of white, shining light which seems to be a reflection of the sea in the sun." **(P9)**

Golden Wedding BBQ mackerel
Food Memory – Old Age
"My sister and brother in law's golden wedding celebration [on] Tresco, quite a small island […] We had a couple of barbecues […] in the morning, we went down To the quay and bought fresh fish … from the small local fishing boat so we had mackerel […] it was a super evening and it got chilly […] so people have got sort of coats and blankets and things to wrap up with them[…]. also I remember, a dead dolphin on the beach, which the children were very excited to tell us about in absolute horror and disgust. And […] poking the dead dolphin. Like children do […] the smells from the fish cooking on the barbecue and […] those kind of meaty smells, and the sounds of the singing." **(P2)**

A Beautiful Wedding
Non-Food Memory – Adulthood
"I remembered the getting married. So […] the vicar […] got me to stand in the vestry, which is like a big cupboard basically, where they change their clothes. He said you wait there. Until the bride gets here, then you go up and then she come up and I can remember my wife […] it is still quite visceral as you can see… She bought a hat she hardly ever wore a hat. Infact she hardly ever dressed up.[…] but in the end she found this lovely hat really, really suited her. And I remember walking her walking in the door. I remember my heart sort of went ker-donk. So it was you know, it's just a lovely feeling. I mean, I remember that bit, you know, viscerally." **(P3)**

Saying Goodbye to Mum
Non-Food Memory - Adulthood
"The death of my mother, where I went home to visit my father and I went to visit the chapel of rest, [and] stayed with her. And that's the only time I've ever been in that situation to collect the body. I was not feeling really… I can recall that [room]. The colours of the curtains and the layout of the room and things. I [felt] confused because I'm thinking, how would one normally, what should one normally feel at this moment […] not upset because my mother had been very ill for a long time and we'd known she was going shortly." **(P7)**

An Exhilarating Dip in the Sea
Non-Food Memory – Old Age
"swimming in the sea in North Norfolk […] a wonderful sort of exhilarating feeling because it was actually freezing cold, rainy, stormy as anything that was really rough and me and my daughter and my granddaughter, my grandson all said right we don't care and just went in the waves and got absolutely freezing cold and had a great time [I remember] crashing waves and my grandaughter's shrieking and screaming with fun and fear together." **(P12)**

Figure 21 Five self-defining memories; The best strawberries ever, a food memory from adulthood (P9); Golden wedding BBQ mackerel, a food memory from old age (P2); A beautiful wedding, a non-food memory from adulthood (P3); Saying goodbye to Mum, a non-food memory from adulthood (P7) and An exhilarating dip in the sea, a non-food memory from old age (P12)

Findings confirm the prevalence of specific self-defining memories, albeit more so for NFM (36/36) compared to FM (28/36). Interestingly, the remaining 8 FM were generic, often from childhood such as “*Grandma’s Yorkshire puddings for Sunday lunch”* (P6), or from holiday locations where a particular food was repeatedly eaten “*moussaka at Dimitris’ restaurant*” (P10). Such prevalence of over 22% of generic FM is important as unlike specific ones, they contain more abstract, less specific sensorial content (Meléndez et al., 2018), and are more prevalent in old age (Levine et al., 2002).

8.3.1.2 Food-based Self-Defining Memories Relate to More Positive Emotions

Findings indicate a high prevalence of positive emotions in participants’ descriptions of self-defining memories, most commonly *happy* and *delight*, while negative ones were often *disappointment* or *poignant.* Based on LIWC analysis (Pennebaker et al., n.d.), findings indicate that FM were described by 2.77% positive emotions and 0.4% negative emotions, while NFM by 2.65% positive emotions and 0.96% negative emotions (Table 15). Compared to 2.7% for positive, and 2.6% for negative affect from Pennebaker’s personal writing corpus (Pennebaker & Chung, 2011), findings show similar frequencies for positive emotions, albeit higher for FM, and lower frequency of negative emotions, particularly for FM (over 6 times fewer).

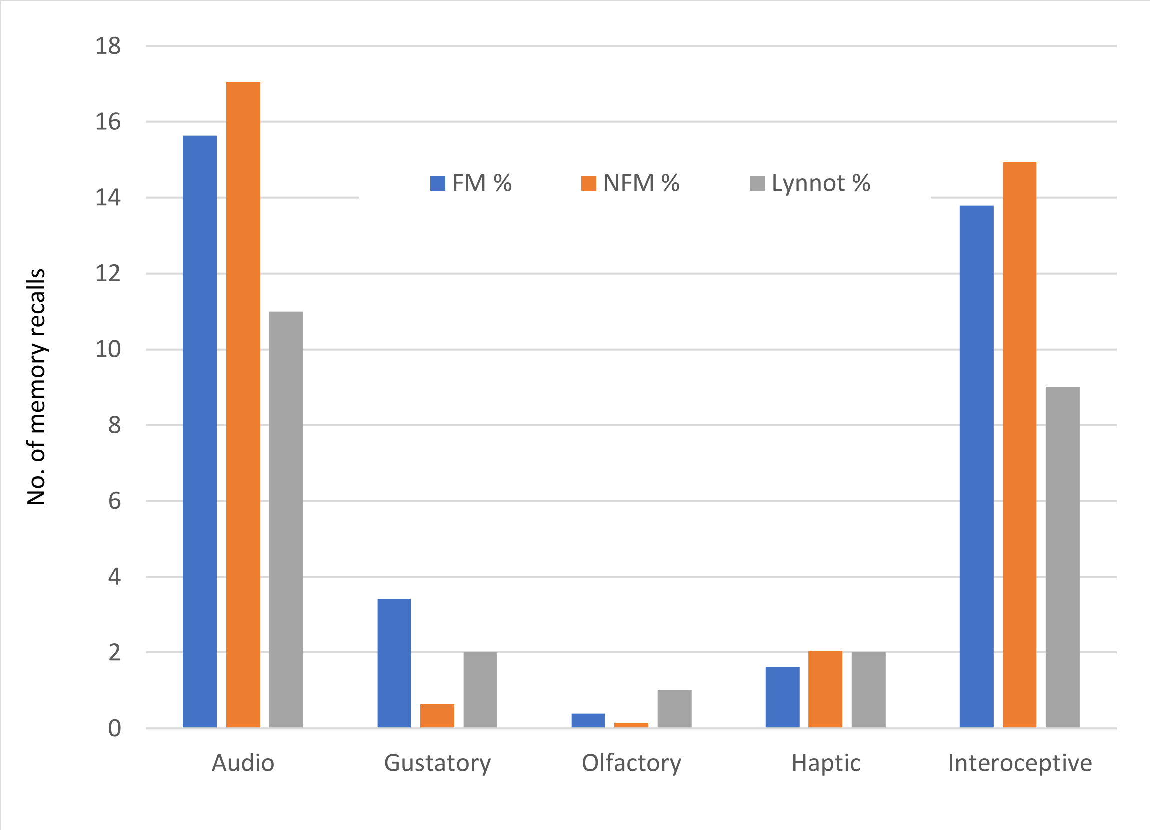


Figure 22 Percentages for Food Memories and Non Food memories and corpus scores (Lynott) for dominant perceptual evaluation of terms according to Lancaster Sensorimotor Norms (Lynott et al., 2020)

8.3.1.3 Food-based Self-Defining Memories are Sensorially Richer

Participants' free recalls of their self-defining memories were rich in sensory details, which has been suggested in previous work (Martin A. Conway et al., 2004), albeit limited empirical exploration supported it. To address this, a linguistic analysis was performed informed by the Lancaster Sensorimotor Norms (Lynott et al., 2020) which indicates that vision is the most common dominant modality in English language (74%), followed by auditory (11%), interoceptive (9%), haptic (2%), gustatory (2%), and olfactory (1%) (Figure 22). By comparing the percentages present in the memories recalled by participants it was possible to assess changes following cueing as well as to understand the sensory richness of FM and NFM. Assessing all memories it can be seen that the percentages for each dominant modality from participants' recall of their self-defining memories (Table 16) indicate fewer visual details than the Lancaster Sensory Norms corpus, but for both FM and NFM about 1.5x greater numbers of interoceptive terms (describing emotion such as *excited*, *remember*, feeling *full*), gustatory terms (describing eating and food terms such as *eating, lunch, meat*), and auditory terms (Table 16). A MANOVA test of the impact of FM or NFM on these modalities also shows significant main effect for gustatory modality ($F(1,9) = 168.75$, $p < 0.05$, $\eta p^2 = 0.949$) with more gustatory terms in FM (Mean=4.6, SD = 0.95) than NFM (Mean=0.83, SD = 0.63), and a similar effect approaching significance for olfactory modality showing more olfactory terms in FM than NFM.

Self-defining memories themes	Self-identity levels	Visual		Interoceptive		Auditory		Gustatory		Haptic		Olfactory	
		FM	NFM	FM	NFM	FM	NFM	FM	NFM	FM	NFM	FM	NFM
Relationship (48) FM (31) NFM (17)	Relational	66.5	65.2	13.4	14.5	15.2	17.4	4.1	0.8	1.3	1.9	0.5	0.3
Achievement (20) FM (7) NFM (13)	Personal	65.4	65.8	13.8.	15.1	15.8	16.9	2.7	0.4	2.1	1.6	0.2	0.1
Negative (11) FM (3) NFM (8)	Mix	59.4	65.8	16.8	13.8	16.6	17.8	4.3	0.8	2.4	1.8	0.5	0

Table 16 Self-defining memories grouped according to relationship, achievement and negative themes; and the relational, personal or mixed levels of self-identity, showing percentages for both FM and NFM of the dominant perceptual classifications of terms by Lancaster Sensorimotor Norms (Lynott et al., 2020) used in food and non-food related self-defining memories when freely recalled

8.3.2 Design Process Engaged the Senses: Before, During & After

This research and design approach emphasized senses, both participants' and researchers', before, during, and after the co-design of cues. *Prior to design* participants engaged in a two-week cultural probes study intended to provoke exploration of food through sensory deprivation and augmentation. Key insights from this were participants increased familiarization with descriptive flavour terms, sensitivity towards their body experiences and insights into their food cultures. Also prior to the design stage, participants were given 3D printed food sample of the five basic tastes which raised sensitivity to flavours, or as mentioned were: *"a good way of getting it straight in your head"* (P12).

During the co-design workshop the conversations were tailored to support participants' identification of the foodstuff associated with their self-defining memories, and to engage them in the remembered multisensory experience of that foodstuff. This allowed for rich descriptions of flavours and tastes, cooking processes, and assessment of texture and flavour duration, with the aim to create a flavour-based cue that would reproduce this flavour experience. This worked well, with all participants enjoying it, and some even suggested the use of a spiciness scale to better describe the flavours. In contrast to FM*,* for NFM, most participants (6) mentioned the additional work needed to identify such foodstuff: "*it is easy when food is at the centre of it [but] it's harder when it's a tangential [and] not a direct experience"* (P1), which "*perhaps didn't have that sort of realism [while for FM it] reinforces the memory […] made it richer […] triggered some more details"* (P2). For NFM, they searched for other associated episodic memories featuring food, albeit not self-defining ones.

Findings show that most associated memories are temporally proximal, such as meals occurring closely before, during, or after the original event (11/36), while other associations (25/36) were made with other, more temporally distant episodic memories featuring food, selected because of some shared content with the original event such as places (8), people (7), contexts (5), or feelings (5).

Each identified foodstuff was intended to be reproduced as a flavour cue, with one exception, where it was creatively made from scratch to capture the feeling of the original *An exhilarating dip in the sea* memory (Figure 21): *"[To match the feeling] I would say something lemon-y because it was so vivid and then also like sugary. Something very lemony and sugary […] because the other two [choices for cues] are quite comforting. And it was lemon or sugary because it was quite daunting […] I want it to be crunchy but not too chewy [and the colour should be] acid yellow"* (P12). This is a key finding, indicating that a memory experience and its emotional and sensorial, yet not gustatory, details can be explored to identify emotionally evocative ways of associating them with flavours, such as the association of vividness to lemon flavour.

Once the foodstuff was identified, participants rated the intensity of each of the basic tastes present in that foodstuff, with findings indicating the prevalence of umami (33/72) for both FM and NFM, often co-present alongside salty or sweet taste (Figure 25), followed by salty (27/72) mostly co-present with umami, and sweet (25/72) often co-present with umami and sour. Sour (5/72) and bitter (5/72) were less frequent. Participants also rated foodstuff's texture with an average score of 3.17 out of 5, and the lingering quality with average score 3.71 out of 5. This suggests that longer lasting taste experiences may be needed to ensure flavour experiences are intense enough for memory recall.

Apart from tastes, participants also identified additional sensory details, most of them not present when the self-defining memories were initially recalled in Stage 1. Such details included smells (41 identified smells for all the 72 cue designs), both from the foodstuff (22 of 41 identified smells) and the external environment which is classified according to (Almagor, 1990) as related mostly to social and natural processes (30/41): *"sea water drying"* (P9), with fewer culturally specific odours (9/41): "*school dinner smell"* (P8), and even fewer that held individual significance (2/41): "*my dad's car the smell of the leather seat"* (P12). Participants also recalled additional auditory details (17 sounds from 72 cue designs): "*sound [of] the crashing waves and my granddaughter's shrieking*" (P12), or visual (14/72) from both food itself: "*very much a red meal"* (P1, pasta and tomato sauce) or from environment: "*a quality of light that was very clear and bright. And I was wearing a hospital gown"* (P9, *Best strawberries ever memory,* Figure 21). These are important findings, illustrating the value of design activities and the purposeful engagement of senses. Interestingly, such additional sensory details, although elicited, were seldom included in the foodstuff, with the noticeable exception of the creative flavour cue (lemon and sugar) designed for the memory A*n exhilarating dip in the sea* (Figure 21).

After the co-design activity, I crafted the cues, preparing the food material and 3D printing it. Attention was paid to recreate as many specific details of the cues as possible, for example ensuring that the cue for *Golden wedding BBQ mackerel* (Figure 21), was made from charred mackerel to develop a smoky flavour. Oil-based recipes were more challenging to produce with the 3D printing of food, including P12's *truffle butter pasta.* Most easily reproduced were single ingredients cues that were moist or fluid such as marmite (P7*, Saying Goodbye to Mum,* Figure 21). Given the diversity of the identified foodstuff, in both solid and liquid form, and the fact that liquids better support taste sensations, nūfood was chosen to produce the food. When piloted, half of the tested cues (17/36) provided good matching quality as illustrated in this quote: "*mackerel absolutely, wow, that's really good. That's amazing"* (P2). For 19/36 cues participants made suggestions to improve them, most often by increasing the flavour intensity (6 cues), or by adjusting ingredient balance: *"herbs [are] overpowering"* (P4).

8.3.3 The Value of Flavour-based Cues & Food for Self-defining Memories

Now reported is the cued recall, particularly the impact of flavour-based cues on the feeling of being brought back in time, the emotional and sensorial aspects of the recall, the qualities that make the best flavour-based cues, and participants' perception of these cues' value.

8.3.3.1 Flavour-based Cues: High Recollective Retrieval or Feeling of Travelling Back in Time

A striking outcome is that 60% of the 40 self-defining memories that were cued by flavours were recalled with strong feeling of being brought back in time (scores of 3 or 4 out of 4). More specifically, significantly more memories that were recalled with high time travel feeling were cued by participants' bespoke flavour-based cues (78%) rather than word-based ones alone (22%) ($X^2(1,60) = 5$, $p<0.05$) (Figure 23). This is reflected in participants' answers as shown in these illustrative quotes: *"[The roast beef and horseradish cue] took me back 25 years in one bound […] I was bit sceptical until it suddenly happened […] I could place myself [at the table in the room…] I ate that and that actually provoked out of all the memories quite strong reaction actually. Just suddenly I was back*" (P3, *A Beautiful Wedding*, Figure 21). Another similar example: "*[The BBQ] mackerel […] was the most evocative of all of them and was […] a trigger [that] brings you back"* (P2, *Golden wedding BBQ mackerel, Figure 2*).

8.3.3.1 Flavour-based Cues: Intense Positive Recollective Retrieval

As shown in Figure 24, high time travel feeling was associated with intense positive emotions ($X^2(4,40)=12.15$, $p<0.05$), with over 3 times more self-defining memories characterized by "very positive" or "very negative" emotions being recalled with high, rather than low feeling of travel in time: "*it's very real, because it's in your mouth and then that generates other feelings".* This shows how less intense emotional memories are associated with a low feeling of time travel in flavour cued recall. Figure 24 also shows that this pattern does not hold true for the recollective retrieval cued by words, where strong positive emotions supported both high, and low feeling of travel in time.

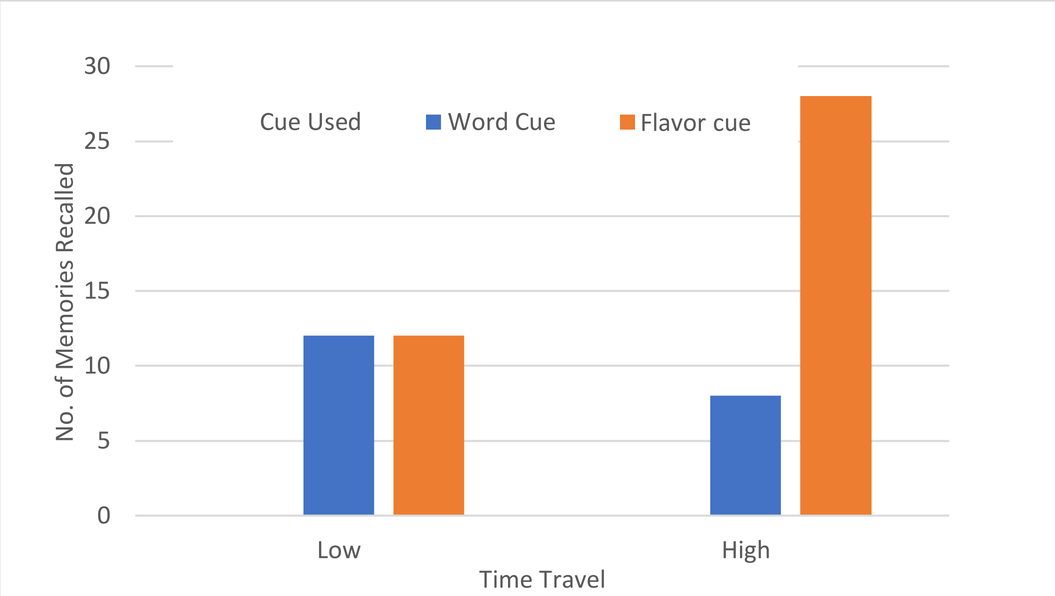


Figure 23 Bar charts showing the number of memories recalled with high and low time travel by cue used (40 total flavour cued recalls, 20 total word cued)

8.3.3.1 Flavour-based Cues: Rich and Visceral - Gustatory and Olfactory Recall

Another key finding is that all participants provided rich sensory accounts when prompted by flavour-based cues, most of them not present in the free recall of Stage 1. Interestingly, the mere act of eating the cue was seen as a bodily re-enactment of the original event: "*[When I had the food] I tended to talk a little bit faster and a little bit louder [like I did in the speech at the Christmas party….] I think memory and physical reactions are quite closely linked […] you're using an extra sense […] because it's very real because it's in your mouth and then that generates other feelings*" (P3). As indicated by most participants, flavour-based cues supported a strong visceral experience: "*the taste encapsulates, in a tiny thing [the memory, it's] visceral; you've got to kind of feel it with your body more*" (P3). "*It just kind of triggers a few more sensations. Perhaps when you're tasting it, you imagine yourself there*" (P2). To explore the impact of cues on sensorial recall, a repeated-measures MANOVA was run with Memory Type and Cue Type as independent variables on the dominant sensory modalities (Lynott et al., 2020), and found a main effect of Cue Type on the number of gustatory terms ($F(1,9) = 3.80$, $p < 0.05$, $\eta p^2 = 0.30$), with more in the flavour cued recall (Mean=4.28, SD = 0.53) compared to free recall (Mean=2.72, SD = 0.21), and a similar main effect approaching significance for olfactory terms ($F(1,9) = 3.04$, p =

0.073, $\eta p^2 = 0.25$) with more such terms in flavour cue recall than free recall, indicating that flavour-based cues support sensorially richer recall, in terms of gustatory and olfactory modalities, for both FM and NFM.

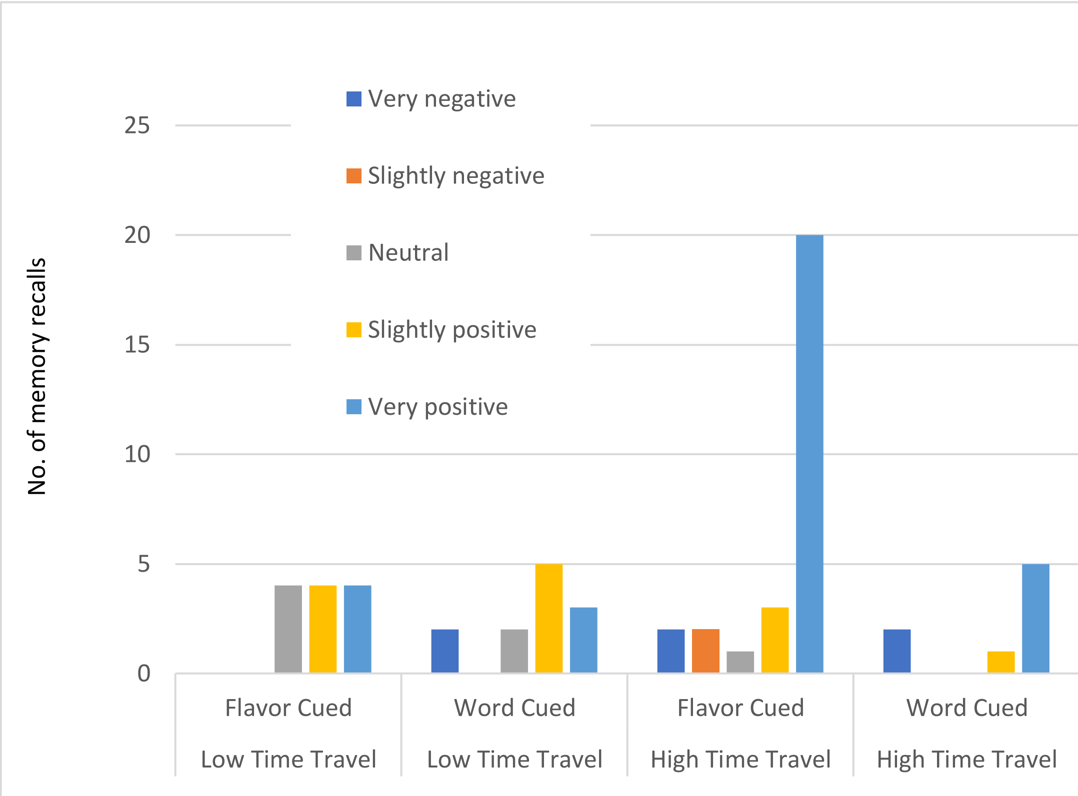


Figure 24 Emotion rating by low time travel for both flavour and word cued memories, and for high time travel for both flavour and word cued memories

8.3.3.2 Flavour-based Cues: Taste Profiles

Findings indicate that most of the flavour-based cues consist of a dominant flavour, most often umami, salty, or sweet, usually combined with others, such as P7's cue for *Saying goodbye to Mum* (Figure 21), "*The flavour with the Marmite was very good […] it's quite a strong umami flavour"*. The charts in Figure 25 depict the taste profiles for each dominant taste, separately for flavour-based cues associated with high vs low recollective retrieval. A visual inspection of these profiles suggests specific patterns with interesting distinctions emerging for each taste. The most noticeable is for umami,

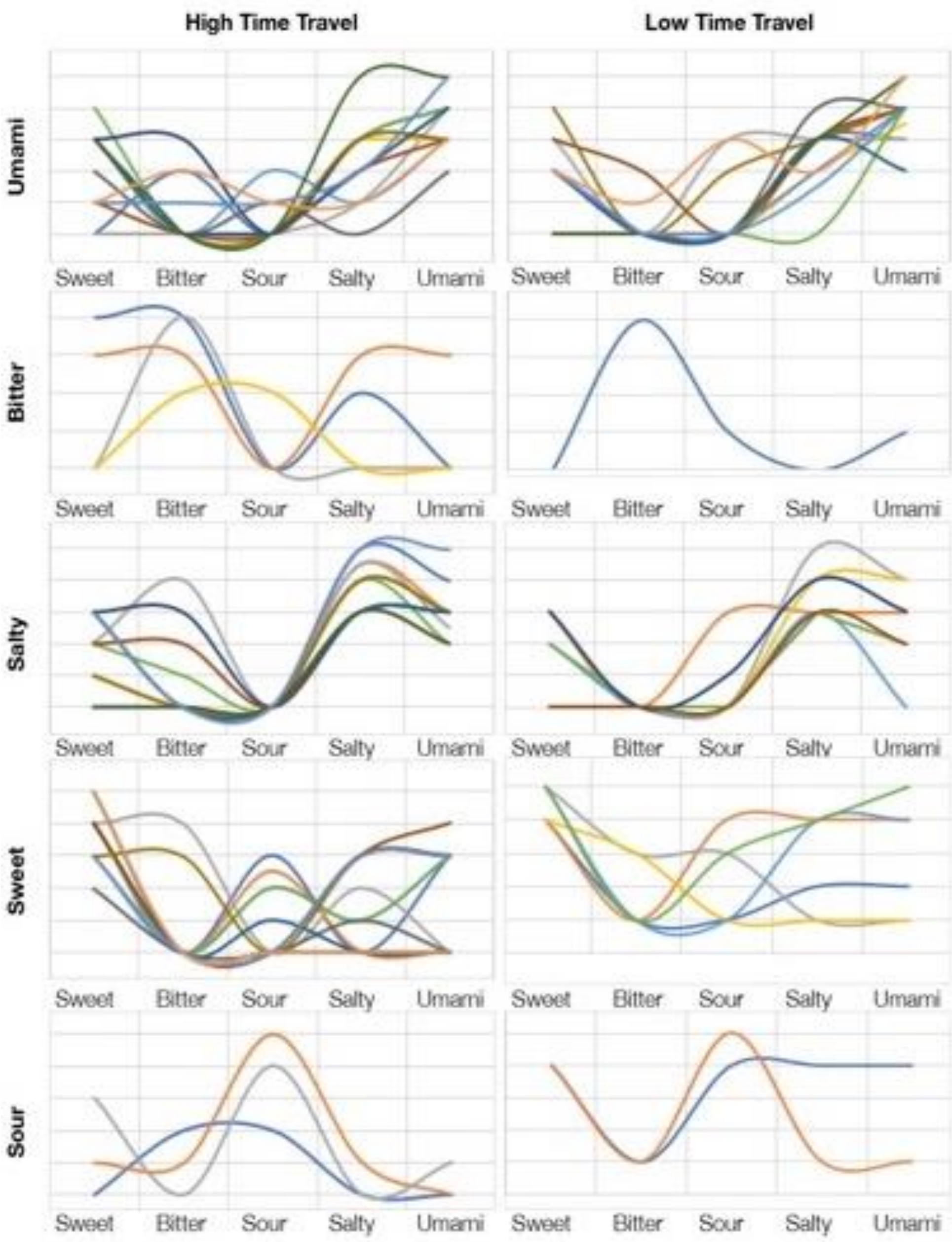


Figure 25 Charts showing the taste profiles for dominant tastes: umami, bitter, salty, sweet and sour by the cued high vs low time travel

where the co-presence of umami-salty-sweet is shared by high and low recollective retrieval patterns, although the latter also consist of taste profiles with

more intense sour taste. Umami is also the only dominant taste showing a finding closely approaching significance ($X^2(1,60) = 3.71$, $p = 0.054$), with 2x greater number of flavour-based cues with low intensity of umami taste being associated with high rather than low time travel. This is an important finding, given that umami was the most common dominant taste for flavour-based cues. Future cue design processes could prompt participants to consider other taste-dominant flavours which maybe more effective. It is not argued that these distinctions in taste profiles are the only ones impacting on flavour-based cues' experiential rating of recollective retrieval, as other emotional qualities are also at play. However, such profiles may sensitize designers interested in gustatory experiences towards configurations of tastes better aligned with the ones supporting high time travel. In relation to taste, the duration of the flavour experience was described by all participants (n=10) as lasting long enough, and most of them (8/10) felt that the quantity of foodstuff in the cues (10ml) was sufficient, while 2/10 would prefer greater quantities (P2, P7). Together, these findings indicate that the sample size and flavour intensity were appropriate to ensure sufficient duration of sensorial experience, albeit for older users with decreased taste sensitivity small adjustments to the foodstuff quantity in the cues may support more intense flavour experiences.

	Food Memories				**Non-Food Memories**			
	Free Recall	**Word**	**Food**	**All**	**Free Recall**	**Word**	**Food**	**All**
LIWC_Pos	2.73 (1.01)	3.83 (2.21)	3.41 (1.32)	3.32 (0.32) *	2.57 (1.13)	2.33 (1.10)	2.67 (1.01)	2.52 (0.17) *
LIWC_Neg	0.40 (0.44)	0.39 (0.35)	0.39 (0.35)	0.39 (0.65) *	0.81 (0.51)	0.60 (0.58)	0.90 (0.65)	0.77 (0.12) *
Visual	87.53 (30.19)	81.7 (27.59)	81.7 (27.59)	85.11 (8.31)	86.3 (35.85)	99.2 (31.40)	83.95 (34.53)	89.82 (9.76)
Audio	21 (6.6)	20.3 (5.42)	20 (6.76)	20.43 (1.71)	22.57 (7)	22.7 (6.77)	22.6 (4.43)	22.62 (1.46)
Gustatory	4.6 (0.95)*	3.6 (2.17)	3.6 (2.17)*	4.48 (0.35)	0.83 (0.63)*	3.6 (3.53)	3.3 (2.96)*	2.58 (0.62)
Olfactory	0.53 (0.61)	0.3 (0.48)	0.3 (0.48)	0.54 (0.13)	0.2 (0.23)	0.1 (0.32)	0.2 (0.26)	0.17 (0.54)
Haptic	2.17 (1.42)	3.1 (2.69)	3.1 (2.69)	2.81 (0.45)	2.7 (1.83)	4.1 (2.88)	2.9 (1.47)	3.23 (0.60)
Interoceptive	18.53 (6.26)	16.5 (6.15)	16.5 (6.15)	17.38 (1.59)	19.77 (6.35)	20.1 (4.79)	17.6 (7.21)	19.16 (1.65)

Table 17 Mean scores (SD in brackets) for LIWC emotional content and Dominant Perceptual terms from Lancaster Sensorimotor Norms (Lynott et al., 2020) between memory type and cue type NB. significant differences are marked with an asterisk

8.3.3.3 Food-based Self-defining Memories: Positive Emotions

Findings indicate that self-defining FM recall is rich in positive emotions as reflected in most participants' answers: *"[emotions] were part of the experience. Like in Greece,* *we anticipate that going to the restaurant […] because it was so nice and I couldn't get it anywhere else […] Mum's roast potatoes […] without the potatoes, it wouldn't have been the same dinner […] Sundays were special dinners"* (P10). The impact of memory type (FM, NFM) and cue type (Free recall, Word cue, Flavour cue) on the emotional content of participants' recall measured was further explored with LIWC scores. Findings of a repeated measures MANOVA (Table 17) show main effect of memory type for both positive emotions ($F(1,9)=8.78$, $p<0.05$, $\eta p^2=0.49$) more present in FM (Mean=3.32) than NFM (Mean=2.52), and negative emotions ($F(1,9)=14.13$, $p<0.05$, $\eta p^2=0.61$) more in NFM (Mean=0.77) than FM (Mean=0.39). This indicates that, irrespectively of how they are cued, self-defining FM are more likely to be recalled with more positive emotions than NFM, highlighting the value of food for imbuing strong positive emotional content in the original event when the memory was encoded. Without reaching significance, findings indicate that this benefit may also extend to flavour-based cues which allow for more positive emotional cued content particularly for FM (Mean=3.41, SD = 1.32) compared to Free Recall (Mean=2.73, SD = 1.01).

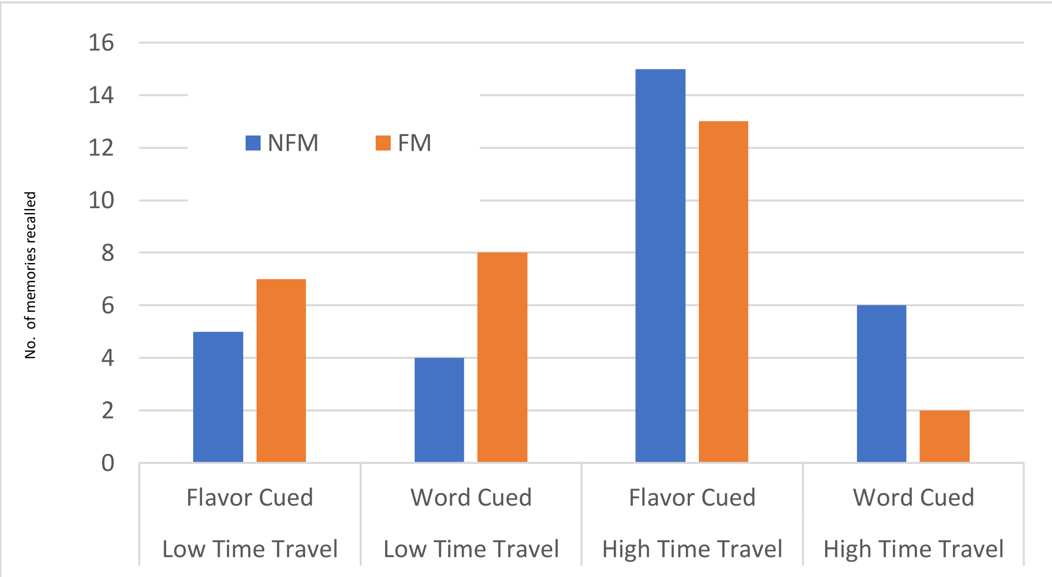


Figure 26 Bar charts showing number of memories recalled by feeling of time travel for of memories cued by flavour and word for both food memories and non-food memories

The type of self-defining memory also impacts on recollective retrieval (Figure 26), with more NFM evoking high rather than low (21 vs 9) time travel feeling, compared to FM which evoked equally high and low time travel feeling (15 vs 15). This difference was even larger for flavour cued recall, with over 3x times as many NFM being recalled with high level of time travel (15) rather than low (5). These outcomes are important, as they suggest that NFM can also benefit from strong recollective retrieval, particularly when cued with flavour-based cues. In other words, the intense feeling of being brought back in time when eating a flavour-based cue is not restricted to food memories only, but extended to non-food memories too, massively increasing the potential value of such cues for memories more broadly.

8.3.3.4 Value of Flavour-based Cues beyond Self-Defining Memories

Most participants saw value in the flavour-based cues, beyond the recall of self-defining memories, and particularly for *multisensory reminiscing*. Here, participants draw from their experience of reminiscing with photos, highlighting the value of flavour-based cues to heighten both the emotional quality: "*I think the trouble is some of my memories are quite strong but not as emotional as some; so that [flavour based cue] might actually be more of a sort of trigger if you like to combine food and memory"* (P4), and its sensorial richness: "*if I'm going to look through my holidays in Italy, photographs, then it would be worth perhaps recreating the taste or enjoying the taste while you looked at them"* (P1). Participants made further suggestions of integrating sound cues, as different modalities may provide complementary support for recall: "*photographs would go quite well with [flavour-based cues]. Possibly sound recordings would be good, the sound is always another good trigger*" (P2).

Another important envisaged value of flavour-based cues concerned dementia and was mentioned by 4 participants based on their own experiences of caring for the loved ones. "*My mother has Alzheimer's […] a couple of times we bought her food [she grew up with] in theory, she would reject it because she said she doesn't want to eat very much. As soon as she smelled and tasted the food, she would say something like, "Oh, this is like old fashioned food. This takes me back" [...] the taste definitely triggered [memories] she felt that it was something that she had had a long time ago."* (P4). This quote suggests ways in which food can not only trigger memory recall but supports a shared experience between the adult daughter and her elderly mother. Another participant envisaged multisensory scrapbooks where photos and flavours may be stored together: "*My dad has dementia, [so with flavour cues] I could put ideas in the scrapbook […] and foods connected to [his memories]*"(P10).

8.3.4 Best Flavour-based Cues

As shown above, the flavour cued recollective retrieval involved sensorially rich and strong positive emotional experiences that participants deeply enjoyed. Among the many flavour cues that facilitated such strong feelings of time travel, 14 cues stood out in participants' spontaneous accounts, which are now reflected upon and their shared aspects identified.

8.3.4.1 Strong Match: Flavour Cue Experience - Original Food Experience

Matching flavour's details was the most common aspect of best cues, referring to both the presence of relevant flavour details, and absence of less relevant ones. For instance, when such matching occurred, the recognition and time travel was strongly supported: "*the truffle one was exactly like I [remembered] it to be*" (P12). In contrast, 10 of the least successful cues were mentioned as not being well matched or with irrelevant details, confirming their negative impact on recall (Mazzoni et al., 2014): *"[The cue for The best strawberries ever (Figure 21)] doesn't really work […] because the point about that memory of the strawberries is that it was absolutely intense, [the flavour cue] is only very slightly reminiscent of strawberries and fromage frais*" (P9). Interestingly, for the only one flavour-based cue which was made to create the memory experience rather than to reproduce foodstuff flavour, namely *An exhilarating dip in the sea (*Figure 21*)*, the matching was also successful, despite not being mediated by a remembered food experience. P12 illustrates this enjoyment: "*I actually really enjoyed the ones we had to create new foods for the memories […] the lemon and sugar one, I found that was actually really interesting".*

8.3.4.2 Distinctiveness: Intense or New Flavours

Unlike the matching aspect which all cues attempted, distinctiveness was not easy to achieve, and most participants did not explicitly consider it in their design. Whether intentional or not, best cues however appear to ensure distinctives in two ways. First, it is the intense flavours often experienced with heighted delight like in this quote: "*chickens spit roast. I'll think: Oh, that time, it was the best I ever had"* (P1). In contrast, the perceived lack of flavour intensity was a common aspect of less successful cues: *"[They did work] the roast potatoes [as they] just tasted like potatoes, not quite the* *richness of the roast potatoes that my mom did, not that slightly salty, Oxo type taste"* (P10). Similar views of "*watered down*" (P10) flavours were shared by 6 participants: *"[the cues] were disappointing; I don't quite know why, I would expect them to carry the weight of the intensity of the flavours, I wanted them to have"* (P9). This is an important outcome, particularly in the context of aging's impact on taste sensitivity and people's increase need for sensorial stimulation (Suto et al., 2014). Second, distinctive cues also reflect novel flavours: "*when I taste, lobster thermidor, I'm always going to think of lobster thermidor. It's a standalone experience"* (P1). These were usually linked to first time experiences such as "*papaya"* (P9), "*mango cordial"* (P10), or less common combinations such as "*fruitcake and champagne"* (P3).

8.3.4.3 Positive Emotion Congruency: Flavour-based Recall and Original Memory

Best cues illustrate an important property: they ensure strong positive emotional recall, cued by intense flavour-based cues, albeit of self-defining memories that are *exclusively* emotionally positive. In contrast, less effective cues evoked emotional ambivalence, as a result of some of the strong positive self-defining memories being transformed through the passage of time into less positive ones such as a wedding followed by negative events such as divorce (P3), or bereavement (P3). Such memories are likely to lead to mood incongruity, limiting people's engagement with the cue and recollective retrieval. Thus, findings extend mood congruency theory according to which people recall better those memories whose emotional content matches their emotional state at the time of recall (Rusting & DeHart, 2000), to self-defining memories and more importantly, to the value of flavour-based cues for the exclusive recall of positive self-defining memories and not negative or ambivalent ones. These outcomes emphasize the dynamic nature of memories which in later life is particularly important, given people's increased striving for self-coherence (Martin A. Conway et al., 2004). In this respect, flavour-based cues offer an additional surprising benefit compared to photos, as indicated in this quote: "*what you remember [with food] there is no challenge… nice things in your memory tend to happen on sunny days really, if you had a photo to prove actually it wasn't that nice a day. So that wasn't quite how I remember this. So, you could get potentially [get] conflicting signals*" (P3). This outcome is important suggesting that benefit of the non-representational quality of flavour-based cues, which unlike photos (Herz, 1998, 2004), could support the recall of emotional experience albeit *not as it has been originally encoded, but how it is remembered in the present*, after it has been processed and integrated within the self-memory system (Martin A. Conway & Pleydell-Pearce, 2000). Thus, flavour-based cues may be better suited to support experiential recall, i.e., the bodily feeling of the memory, and less so the accuracy of recall in terms of specific visual details.

8.4 Discussion

Now discussed are the theoretical implications of the findings and their value for multisensory food interaction, and particularly memory technologies. Flavour-based memory cues are introduced as a novel type of cues, with specific value for the phenomenal experience of memory recall whose qualities include strong recollective retrieval or feeling of being brought back it time, intense positive affect, and strong sensorial richness. They also allow for the recall of a dynamic past, and for generic self-defining memories to be recalled with episodic richness. Such cues are emotional catalysts to be sensitively designed for. Also advanced is a novel co-design approach that engages the senses in order to support the self-generation of cues and argue for the value of this approach for uniquely crafting *the flavour of memory* rather than merely reproducing existing flavours.

8.4.1 Theoretical Implications

8.4.1.1 The connections between Multisensory Food Experiences and Emotionally Meaningful Food Memories

This study make key contributions to the understanding of chemosensory modalities more broadly, showing that the well documented value of olfactive cues for emotional (Herz, 1998, 2004; Herz & Engen, 1996), vivid recall (Chu & Downes, 2002; de Bruijn & Bender, 2018; Herz, 2004), and strong recollective retrieval (Larsson et al., 2014), also applies to the less explored gustatory cues. Findings also highlight that food is quintessentially social, interlinked with enduring concerns regarding loved ones, within the context of cultural practices of food sharing, where significant events for the relational self tend to take place. This new perspective on food as resource for design has been less explored in multisensory food interaction research (Altarriba Bertran et al., 2018; Choi et al., 2014; Gayler et al., 2021a), suggesting that not just *multisensory food experiences* abstracted down to just their hedonic qualities are worth designing for (Altarriba Bertran et al., 2020; Arza et al., 2018; Yan Wang et al., 2020), but also the connected and resulting *emotionally meaningful food memories* such as self-defining ones, whose recollective retrieval has rich multisensory experiential qualities. Not all multisensory food experiences are related to food memories, but those which are connected are difficult to be decoupled from the food memories (e.g., someone's grandmothers apple pie). To some extent for that individual eating any apple pie it is likely that childhood memories will be elicited. For designers it is important to acknowledge both the opportunity to consciously leverage such connections and the need to account for them where they may interfere with a wider experience.

8.4.1.2 Flavour Cues Support Strong Recollective Retrieval: Intense Positive Emotions & Sensoriality

Food related self-defining memories are sensorially richer in gustatory and olfactory modalities, have higher positive emotional and less negative content than non-food memories. Most importantly however, when cued by bespoke flavour-based cues, the recall of self-defining memories is also viscerally rich in gustatory and olfactory modalities, marked by strong positive emotions and experienced to an impressive degree through an intense feeling of being brought back in time. Also key, is that such qualities of flavour-based cues not only hold true for both food and non-food related self-defining memories, but that the recollective retrieval is even stronger for non-food ones. This is particularly important, extending the value of flavour-based cues beyond the niche space of food related memories.

8.4.1.3 Flavour-based Cues Support Experiential Recall of a Dynamic Past

Study findings further extend HCI work on memory cues, from the emphasis on visual and aural modalities (Dib et al., 2010; Frohlich & Murphy, 2000; Isaacs et al., 2013; Le et al., 2016; Sas, Davies, et al., 2020; Sas et al., 2013; Sas & Coman, 2016), towards the less explored gustatory one. Photos and videos are ideal for capturing episodic content in the *here and now*, supporting thus more accurate recall of the original event (Herz, 1998, 2004). In contrast, the non-representational quality of flavour-based cues, does not necessarily demand verbatim recall. Instead, such cues offer flexibility to recall the experience, *not merely as it was originally encoded, but also how it is presently remembered,* after being processed and integrated within the self-memory system (Martin A. Conway & Pleydell-Pearce, 2000). Participants appreciated flavour-based cues for helping them re-experience the original event, albeit not through the factual details that photos depict. Thus, flavour-based cues may be better suited to support experiential recall, i.e., the bodily feeling of the memory and less the accuracy of recall in terms of specific visual details. In other words, unlike the representation aspect of *photos that freeze the past,* flavour-based cues allow for dynamic nature of memory processes by supporting more integrated emotional recall, more *flavours to feel the past*. This can be particularly valuable in older age as people strive for self-coherence (Martin A. Conway & Pleydell-Pearce, 2000).

8.4.1.4 Flavour Cued Rich Experiential Recall Could Address Older People's Semanticized Memories

Findings indicate that flavour-based cues are particularly strong in supporting experiential recall that is rich in emotional and sensorial aspects. It has been shown how generic self-defining memories were recalled with rich details that characterize episodic retrieval. This is particularly relevant for older people, given the impact of aging on the specificity of episodic memories, namely fewer episodic details, and more generic or semantic memories (Piolino et al., 2006). As further argued by Piolino (Piolino et al., 2006), the development of episodic memory theory has started to emphasize more the phenomenal experience: the emotional, sensorial, and spatiotemporal details of the episodic memory, which in turn facilitates recollective retrieval. In other words, the high occurrence of strong feeling of travelling back in time, that was cued by participants' flavour-based cues, is a reflection of such phenomenal experience, and of cues' potential to both support and guard against the growing number of semanticized memories characterizing old age. This is an important future direction for HCI research on aging and in particular on memory technologies for dementia.

8.4.1.5 Flavour-based Cues are Emotional Catalysts

Findings indicate that while flavour-based cues predominantly prompt intense positive emotional recall, on fewer cases, they can also prompt strong negative affect. This was due either to the negative emotions of the original memory, or to the emotional ambivalence experienced towards a positive emotional memory altered over time through loss. Such outcomes suggest that the rich experiential qualities of the flavour-based cues help them catalyse the emotional content of the recalled memory, irrespectively of its emotional valence, extending findings on the impact of taste on emotions (Gayler et al., 2019, 2020). These outcomes suggest the value of sensitivity when designing flavour-based cues, to ensure their exclusive matching to positive memories. Future work may also explore their value for originally negative memories that people transformed into redemption narratives. In such cases, later positive emotional meaning may be associated with crafted flavour-based cues to further strengthen the experiential quality of positive emotions underpinning this meaning.

8.4.1.6 Novel Co-design Approach Engaging the Senses for Making Self-Generated Cues

Because of their ability to integrate personally relevant salient features, self-generated cues hold strong potential to support recall (Hunt & Smith, 1996). However, most HCI research has focused on automatically or manually captured cues, with a few exceptions which looked at visual cues self-generated by young people (Le et al., 2016; Sas et al., 2015). Successful flavour-based cues indicate the feasibility of the co-design approach for their making. This is an important outcome, as previous work on older people's self-generated memory cues has shown that these are less distinct (Mäntylä & Bäckman, 1990) or contain more generic and semantic details rather than episodic ones, similar to the cues generated by others rather than the self (Wheeler & Gabbert, 2017). Such work however has looked at word-based cues requiring limited engagement. In contrast, the co-design approach and its sensorial and emotional richness was more likely to boost the generation effect (Slamecka & Graf, 1978) and participants' investment in their cues, with the additional benefit of ensuring recall marked by rich phenomenal experience instead of generic recall.

8.4.1.7 Distinctiveness of Flavour-based Cues: Crafting "The Flavour of Memory"

The study shows an approach to cue design that has focused on reproducing the food that either formed part of FM or was associated with NFM. This reflects the encoding-specificity principle (Tulving & Thomson, 1973) according to which retrieval is supported by increased matching of the content in the memory and of its cue, with the outcomes confirming this principle's value for flavour-based cues. However, an additional, cue distinctiveness principle argues that matching is necessary but not sufficient for accurate recall, and that the cue should also be uniquely associated with one memory only (Schmidt, 1991; Wheeler & Gabbert, 2017). Most successful cues ensured distinctiveness through foodstuffs with intense or novel flavours, which were however difficult to identify among the familiar foodstuffs people gravitate towards, due to familiarity or neophobia (Gayler et al., 2018; Pliner & Salvy, 2006). One way to ensure cue distinctiveness (M. L. Lee & Dey, 2007) is through the crafting of new flavours, an approach taken surprisingly by only one participant who explored the emotional and sensorial aspects of her memory experience (which did not involve food) to identify crossmodal associations to flavour domain, such as vividness to lemon flavour. In this way, she created a unique "lemony and sugary" flavour, or in other words, *The flavour of that memory*. These outcomes suggest the value of integrating new sensory design methods within crafts approaches that older adults particularly enjoy (Lazar et al., 2017b, 2017a; Sas et al., 2015, 2017; Wallace et al., 2012).

8.4.2 Implications for Design

Now discussed are findings' implications for design, highlighting the value of novel multisensory design methods, and of recreational, as well as therapeutic multisensory reminiscing through gustatory stimulation in dementia.

8.4.2.1 Towards Novel Multisensory Design Methods

Now reflected upon is an overall design approach which purposefully engaged both participants' and researchers' senses through the sensory deprivation and augmentation probes in the sensitizing stage, to the co-design, making, piloting, and consuming the flavour-based cues in order to viscerally experience their impact. Three key things were learned. First, the challenge of participants' accessing the felt-life quality (McCarthy &

Wright, 2005) of their rich multisensory experiences. Here, the range of objects in the cultural probe kit was found to have worked well to evoke distinct sensory experiences by turning off some senses. So did the process of sensory deconstruction in the memory elicitation stage, where focus was on each modality separately, or in the co-design stage, where there was an even stronger focus on flavour experience. Nevertheless, this challenge required an introspective, bodily and inwards looking stance, less familiar to the participants, who could benefit from a more structured facilitation inspired for instance by the emerging micro-phenomenology approach in HCI (Prpa et al., 2020). Second, the challenge of communicating about rich and nuanced experiences with the participants. While all participants shared them, the depth of their verbal descriptions varied largely, and could benefit from sensory vocabularies to better support sharing of expressive multimodal experiences leveraging soma design (Hook, 2018) and somatic approaches (Schiphorst et al., 2020). Third, the challenge of writing about this work. It was felt there was a need to be more creative in the writing of this study, as traditional descriptive accounts would have left out much of the richness of the data. Hence, it was necessary to reach deep into the data to craft concise descriptions of 5 self-defining memories (Figure 21). These experiential vignettes were used to better illustrate key findings, alongside evocative quotes and visualizations such as the extended taste profiles (Figure 25) but could benefit from even more tailored approach inspired for instance by sensory ethnography (Pink et al., 2013). To conclude, there is a strong emerging foundational HCI research for how designers can better work with the body, both their own (Alfaras et al., 2020) and participants' (Daudén Roquet & Sas, 2020), but more research is needed to inject an explicit multisensory lens into such approaches and to better inform new sensory research and design methods. These would firmly support the *sensory turn* in HCI (Brulé & Bailly, 2018), started two decades ago in social sciences (A. Harris & Guillemin, 2012) and humanities (Lauwrens, 2012).

8.4.2.2 Recreational Multisensory Reminiscing

Findings suggest the value of flavour-based cues for multisensory reminiscing. This is a new space for interaction design, from augmenting the capture of memory content with additional flavour qualities, to consuming flavour-based cues for multisensory reminiscing in familial settings. For the former one can imagine rich vocabularies and icon libraries that can be used to capture episodic content of flavour experiences for instance on smartphones. The vocabularies would include expressive terms for tastes, smells, and flavours, while libraries would consist of expressive icons for tastes, aromas, textures, or lingering feelings visualized with affective qualities. For multisensory reminiscing, one can think of novel interactions where captured flavour experiences can be browsed by emotional, perceptual or spatio-temporal metadata, and selected for 3D printing, either at home with small printer like nūfood (*Nufood*, n.d.), or by new 3D printing services providing on demand personalized flavours in the form of precious pods, or as one of participant referred to as "*a tiny thing"* encapsulating the memory in a taste. For instance, for an evening in, a family decides to reminisce over the photo album of their last holiday in Morocco. They had some delightful experiences from a small restaurant with open fire which they would love to relieve. The flavour printed pods are small, so they need to be slowly savoured for extending the delicious flavour sensation, and one by one, family members share their feelings of being brought back in time.

8.4.2.3 Therapeutic Multisensory Reminiscing and Emotionally Meaningful Gustatory Stimulation in Dementia

Participants also saw value of flavour-based cues for their loved ones living with dementia. This is an interesting design opportunity, given older adults' need for increased sensorial stimulation (Sas, Davies, et al., 2020), including gustatory (Møller et al., 2007) and their increasing eating difficulties (Watson, 2002). In contrast, the small 3D printed flavour encapsulating the memory of their wedding or the birth of their child could support intense feeling of time travel, strong positive emotions, and sensorial richness, much needed in dementia. Flavours will need to be carefully designed, given the reduced taste/flavour recognition and sensitivity (Suto et al., 2014). Future work would explore the feasibility of a sensory co-design approach with people living with dementia and their loved ones, to understand how such cues can be crafted with vulnerable users in sensitive settings and how they can be leveraged as a site for commensal experience shared by those with dementia and their loved ones.

Both Study 4 and 5 use probes for sensitizing participants. These were key in engaging and supporting participants to consider food in new ways and imagine new possibilities for how experiences with food could be. Study 6 further details the development and design of this novel research tool, which draws on previous work to create a bespoke tool designed to meet the specific challenges of working with personalised flavour experiences. The next study is a key part of the co-design method which underpinned the approach in Study 4 and 5 and helped evolved the research from universal taste-emotion mappings towards idiosyncratic and personalised flavour-based interactions.

9 Study 6 The Design of a Sensory Probe Kit to Support Personalised Flavour Design

9.1 Aim and Rationale

Taste experiences are largely universal as reported in Study 3, however in Studies 4 and 5 flavour was found to support experience but only if tailored to each individual through the co-design of personalised flavours. As part of supporting users to participate in the co-design phase it was important to sensitize them to their own flavour experience. This study reports on the design and evaluation of a tool aiming to do just that. This final design and co-design study considers methods for designing with flavour experience as personal experience through field studies.

The tool was developed to engage participants in design studies to understand and appreciate a range of perspectives on their own experience of food. This meant bringing attention to the perspectives themselves (e.g., multisensory integration or mood relationships) as well as detailing the specific, personal discoveries made through each perspective. This generated both knowledge and data which supported a co-design process. These tools are designed to be flexible to adapt to varying contexts (in this case applied in Study 4 on food, emotion and relationships and Study 5 for food and memory) to support their wider use in studies engaging with food and the eating experience. The tools developed follow the rationale of sensory profiling strategies developed for food science purposes (Varela & Ares, 2012) that promote and support untrained, non-experts to fluently understand and express their opinions on personal food experience.

Part of the study took place during the coronavirus pandemic and slight adjustments were made to the probe package to address this, including the change in packaging and the packages being sent by post rather than handed over in person. However due to the nature of probes as a remote research tool the major aspects of the method remained the same.

This study asks two questions:

- How to design a sensory probe kit for understanding food experience?

- What value such a kit would have for work across multisensory experiences in HCI?

To support the novel method developed, further literature is reviewed in relation to reflection-in-action, co-design and design worlds.

9.1.1 Design rationale – Probes that disrupt

The mundanity of food experience can discourage thoughtful reflection. In order to design for an individual's sensory experience, that individual needs to recognize and articulate their mundane experiences themselves. An approach to this issue with wider mundane embodied experiences comes from Wilde et al. (2017), who propose a framework for embodied ideation, based on 'DISRUPT – DESTABILISE – EMERGE – EMBODY'. It aims to create estrangement or unfamiliarity as a tool for expanding the design. It frames design activity around the body to support an, as full as possible, expression of rich bodily experience. This is perhaps most useful when thinking about non-expert designers who can be more easily 'disrupted' and 'destabilized' to approach experiences from new perspectives than trained to analyse the experiences.

Four methods are proposed for disruption;

- Re-contextualization - objects in new contexts to promote new perspectives
- Changing bodily sensations through artefacts - artefacts to manipulate the sensory experience to create new perceptive perspectives
- Enactments - instructed actions that open up new perspectives
- Alterations - changing materials so they are used in different ways

9.1.2 Reflection-in-action, co-design and design worlds- approaches to reimaging how we design

A key action in the above cycle of *disrupt – destabilize – emerge – embody* is the ability to reflect upon experiences. *The reflective practitioner* by Donald Schön (2008), identifies *reflection-in-action* as a key activity for designers, to reframe given problems to creatively consider solutions. This process creates *"a web of moves, discovered consequences, implications, appreciations and further moves"* (Schon, 2008, p. 155). Key to a belief in the value of reflection-in-action is the principle that designers often "*know more than they can say"* (ibid., p. 8). This aligns with how food experience can be overlooked and the complexity of the multisensory experience unappreciated (Spence, 2010). Dewey, key to informing Schön's work, states that personal and subjective experience are critical at the start of an enquiry, titled '*perception'* by Dewey (Hickman, 1998) which is then developed through *conception* - the ability to imagine alternatives. Schön builds on the personal and subjective *perception* (1992) through his description of *Design worlds* (taking from Goodman, 1978) based both on their individual perceptual sensitivities but also their pre-existing values and perspectives. Schön states that the challenge for designers working together is to communicate in a way that helps decode each other's design world.

Food experiences are often mundane, and some estrangement may be beneficial for bringing them into focus. The probes presented here attempt to disrupt the problem as it is, prompting reflection-in-action that helps centre food experience design around *perception*, important in any design process, even more so for a multisensorial material like food. Probes aim to expose participants to food experiences in ways which encourage the *emergence* of design worlds based on food experience, leading to *Flavour Design Worlds*. This is a novel concept that is defined as the *Flavour World* of an individual made available for design through activities such as probes and co-design. Finally design probes aim to support participation in later co-design providing insights that could fuel *joint inquiry and imagination* (Steen, 2013, p. 16).

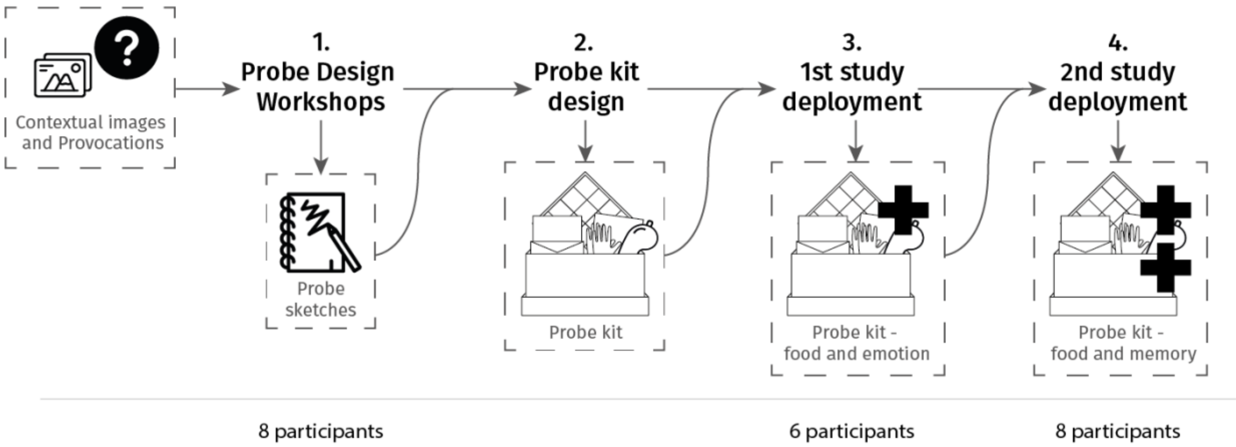


Figure 27 Method diagram for probe development

9.2 Method

The probes were developed through an iterative process starting with probe design workshops with designers and HCI researchers (1, Figure 27 Method diagram for probe development). Following these workshops, a first version of the kit was designed and produced (2, Figure 27 Method diagram for probe development) for use in the food and emotion study (3, Figure 27 Method diagram for probe development) with one probe (TasteWho Gameboard) going through further design and evaluation. 3 couples in the food and emotion study (6 participants, 3 female, 3 male) took part in the evaluation of the probe kit via interviews following collection of the probe kit. Through both designer

Figure 28 Provocation slides used in workshops, slide on the right is a list of provocative questions, slide on the left features images and quotes connected to the theme

and participant evaluation this kit was iterated and updated for the context of the food and memory study (4, Figure 27 Method diagram for probe development). Final evaluation on the design was gathered through interviews with participants and from the research teams' reflections. 8 participants (6 female, 2 male) in the food and memory study took part in an interview to evaluate the probe kit. All interviews were audio recorded and fully transcribed. Thematic analysis was performed via a hybrid approach (Fereday & Muir-Cochrane, 2006) of inductive codes such as identifying disruption, destabilization, emergence and embodiment (Wilde et al., 2017) and deductive codes emerging from the data such as the reported impact of the probe, the experience of undertaking the probe and participants' opinions on the difficulty of the probe.

9.3 Probe design workshops

As the probes were created with the intention of engaging a broad range of participants it was important that their design was conceived through a collective engagement with design and HCI practitioners who each have differing cultural and academic experiences. To achieve this, two workshops were conducted, one with 3 participants (postgraduate researchers in HCI) and one with 5 participants (postgraduate Design students). The workshops lasted 2.5 hours and engaged with 6 sections: Taste and flavour, Embodied, Multisensory, Emotional and cognitive, Material qualities and Practicalities. Each section was briefly explored amongst the group, who then created proposals for probe designs which could help understand each aspect of food experience. The group discussed the proposals, refining and adding to suggestions through exchanging and challenging ideas. To support the participants in approaching each section, contextual images and provocations were offered (Figure 28 Provocation slides used in workshops, slide on the right is a list of provocative questions, slide on the left features images and quotes connected to the theme

). The practicalities section differed from the 5 previous ones as it engaged with the functional aspects of probe design for food engagement. These workshops resulted in hand-drawn and annotated sketches for various probes to be part of a probe kit, these were reviewed and refined into the design of the first kit.

9.4 Sensory probes

Now detailed is the aim, design and application of each probe (Figure 29 Multisensory probe kit) across the two studies. Also reported are findings into the function of each probe drawing on interviews with participants.

9.4.1 Overall format

The probes were conceived to be delivered in person to participants in a box for use in the food and emotion study. The box was a plain white hat box with the couple's name handwritten on top. The intention was to associate the kit with the design aesthetics of personal gifts. Once opened each probe element was layered with instructions between tissue paper (Figure 30 Probe instructions with box

), echoing the unboxing experience of gifts, as well as connecting with chocolate boxes, a common gift between lovers.

Figure 29 Multisensory probe kit

For the food and memory study the format had to be significantly adapted due to the onset of the COVID-19 pandemic, which meant participants were all remote to the research team, therefore kits were sent and received by post. As a result, the probes were more functionally packaged in a padded envelope and the design decisions that aligned with romantic gifting were removed. The intention of this was to move towards a conception of the kit as a toolkit rather than gift, with separately bound instructions, probes and response materials.

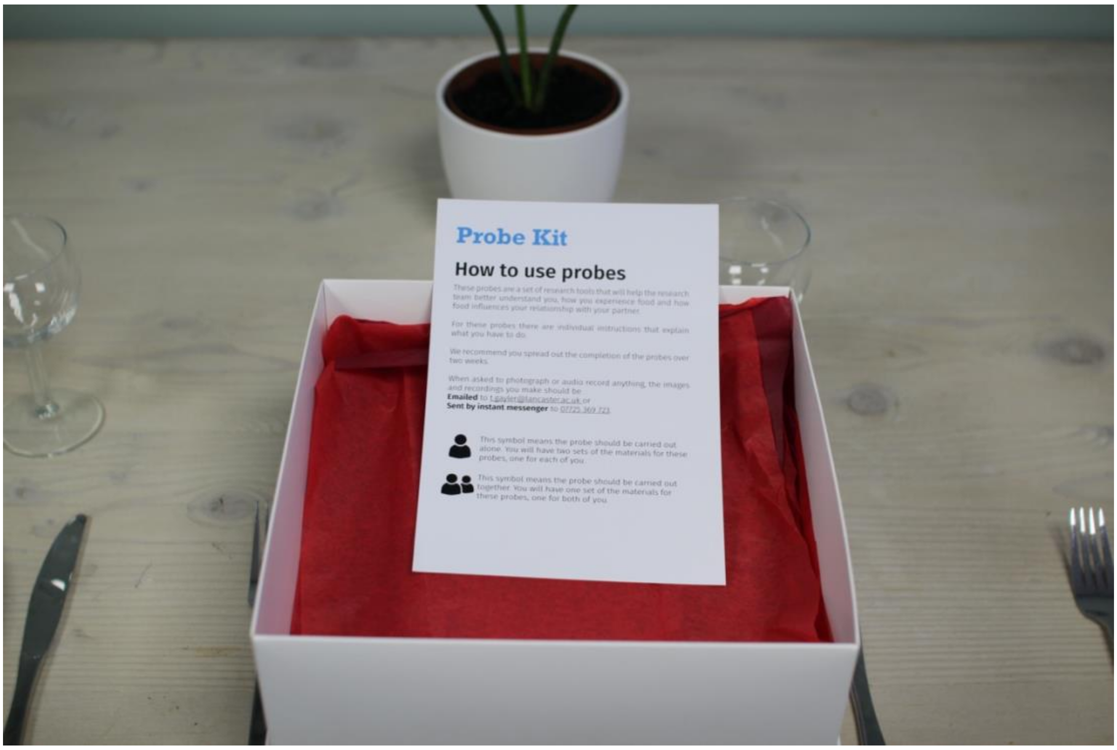


Figure 30 Probe instructions with box

9.4.2 Taste Who Gameboard

Aim – Familiarize participants with descriptive flavour terms and explore pairing foods with feelings and memories. This probe drew on naming and descriptive approaches to flavour experience as well as prompting reflection and attention by participants towards flavour experience within mundane food settings.

How it works – Probe consists of a gameboard with squares each showing an abstract illustration and flavour descriptor. Participants are asked to select several foods from their kitchen cupboards that represent different feelings or memories. They then eat each of these foods in turn, placing counters on the flavour descriptors that match the food they are eating.

Use in Study 4 – This was played as a game between a couple with one participant trying to guess which food the other was eating based upon the flavour descriptors.

Use in Study 5 – Played alone with participant using this as a reflective activity to practice tasting and describing foodstuffs.

9.4.2.1 Board design iterations

For the taste and flavour perspective the intention was to create a playful probe based upon the board game 'Guess Who' (*Hasbro Games*). This approach borrows from a check-all-that-apply technique used in sensory profiling in which various descriptive terms are presented to a participant who indicates if the term applies to the flavour they are experiencing (Varela & Ares, 2012). The advantage to these approaches was that it could introduce participants to the range of terms that could be used for describing flavour, supporting them to make the descriptions of their experiences. The initial design of the board was created using words and abstract illustrations to support the comprehension and allow image-based as well as text-based engagement with the terms.

To evaluate the suitability of each abstract illustration with each descriptive term 25 word-illustration pairs were freely matched by 11 participants (v1, v2, v3, v4 boards can be seen in Figure 31 Taste Who Gameboard iterations V1-4, with annotations describing changes between versions
). The results of these pairings were used in two ways. Firstly, any image-term pairs with over 50% correct match were selected (n=5; spicy, crunchy, sharp, soggy, cool), secondly any terms which had high percentage incorrect matches were repaired based upon this (n=4, 'hot' with tangy image, 'floral' with umami image, 'zesty' with sickly image, 'burnt' with stale). This left a further 16 terms, of these 7 were selected to be redesigned - 'bitter', 'sweet', 'salty' and 'sour' were selected as basic tastes; 'hot' was selected to offer an opposite for 'cool'; 'bland' and 'burnt' were selected to describe absence or corruption of taste and oppose descriptive positive terms. The 2nd version board was evaluated in the same way as the 1st by 5 new participants who hadn't taken part in the initial evaluation. 6/16 were correctly paired most the time (floral, sour, burnt, salty, creamy, sweet).

For some others there were pairs which were confused (for example 'bitter' was mapped to sharp image and 'crunchy' to bitter image and 'spicy' to crunchy image three times each). 'Hot' and 'cold' had two correct pairings each. For the third version, 'Bitter', 'Hot', 'Creamy' and 'Soggy' were given a new illustration to support better mapping. For bitter the change was informed to make it more distinct from sharp and crunchy with which it was confused. Hot was made a more obvious opposite to cold to reinforce the relationships between terms in their formal presentation.

Figure 31 Taste Who Gameboard iterations V1-4, with annotations describing changes between versions

A final qualitative evaluation of the board with 10 older adults (all female) who were part of an arts and crafts was undertaken to support adjustments for use with older adults. This can be seen in v4 board with ‘Warm’ used to oppose ‘Cool’ more directly and ‘Savoury’ replacing ‘Umami’ as a more commonly understood term which largely matches the experience of umami.

9.4.2.2 Experience of use

The user of the probe (Figure 32 The Taste Who Board in use by participants with one participant’s food on a plate and counters on the board to describe the taste) was seen as *easy* to complete (n=4 participants) and *fun* (n=4), *“it felt like it was a game, and it was fun. It was light to do and yeah, it was enjoyable.*” (P9, Study 5). This probe's primary impact was to encourage more thought to be given to experience of eating (n=6), disrupting the act enough that participants could become aware of the experience in more detail, *“everyday taste […] you take it for granted, you are generally just eating without thinking, it makes you think. For an example this chocolate, I can just go and* *buy some chocolate […] I would not even get a thought, is it burnt? is it sweet? is it bitter? Yeah, so I think this exercise is very fruitful."* (P10, Group study).

Figure 32 The Taste Who Board in use by participants with one participant's food on a plate and counters on the board to describe the taste

The *choice of foods* used in this probe were seen as important (n=3) with participants describing sometimes selecting similar descriptors and the experience becoming *repetitive* (n=4). Participants recommended improvements to the board including adding extra terms (n=6) and perhaps a personalization of terms beyond a basic set, *"I did write a list of additional […] adjectives for your game board […] I didn't think it gave me enough choices really."* (P9, Study 5).

9.4.3 Writing recipes as letters

Aim- Participants practice matching and describing foodstuffs in relation to specific memories or as expressions of certain emotions. This probe is rooted in the process of meaning-making that is possible through food, exploring how users label and associate foods with different meanings.

How it works – Participants are given letter paper and asked to write a recipe to represent a feeling or a memory (Figure 33 Writing recipes as letters materials

Figure 33 Writing recipes as letters materials

). This was deployed as two letters that approached opposite but related tasks (one for love, one for heartbreak; one for a memory of food, one for a memory without food). These letters used cues from personal communication to elevate the importance of the recipe writing from a purely intellectual challenge in meaning-making to one that imbued the process with emotional importance.

Use in Study 4 – One probe requested a letter including a recipe written as a love letter to their partner, the other probe requested a recipe that matched an experience of heartbreak. The participants then made both recipes. For the love letter recipe, they made it for their partner, for the heartbreak letter recipe they made it and burnt it, not eating the food afterwards. This process attempted to connect with the physical process of both making food as a gift and act of care in the case of the love letter recipe, but also through burning for the heartbreak letter recipe, creating an act of catharsis that was disconnected from the normal functions of nourishment.

Use in Study 5 – Participants wrote a letter including a recipe representing a memory with food and a memory without food relating to a memory occurring within the last year. This closely matched the task they were to perform in the following co-design part of the study but focused on a less specific type of memory.

9.4.3.1 Experience of use

This probe disrupted the mundanity of creating food by drawing on strong emotional experiences (love and heartbreak), "*it really makes you think about you are eating and because we had to specifically think about certain meals that would be like romantic* *for your partner"*, (P2, Study 4). Leading to a destabilization of the meaning making of food, in particular for the heartbreak letter, *"the heartbreak one I found really disgusting because I left this chicken for like ages and it just, it was probably a bit dangerous being in the fridge and being so over passed, it made me feel really repulsed. Which is maybe how I feel about [the relationship]"* (P2, Study 4). Emerging from the letters were connections between food and memory and perspectives on visceral reactions to food and negative experience (such as the disgust at the chicken). These recipes came to embody these relationships as in Study 4 participants made both recipes. The process of actually producing the food led to enactments that humanized the experience, bringing it out of the abstract, with interesting results, *"[I was making the love letter recipe] and our oven broke! so in the end we had to go to a neighbour and literally never met them before and ended up, being like 'Hey, can we borrow your oven?'"* (P2, Study 4). In the memory study the food was not connected to such emotional memories or actually made by participants which resulted in a lower engagement and the abstraction of the task led to confusion over detail, *"I wasn't sure how detailed a recipe one needed to go into, how much preparation of the food or you know whether if it was a bowl product, where I would have to describe how one would have created the product"* (P7, Study 5).

9.4.4 Sensory Deprivation

Aim - Increase awareness of the role of different sensory systems in the experience of flavour.

How it works – Participants were instructed to eat a normal everyday meal (something that would be familiar with the experience of) but as they ate apply a series of individual sensory deprivations such as blind fold, earplugs, nose clip and gloves. After use they described the impact, each had on a record card (Figure 34 Sensory deprivation probe kit materials).

Used as above in both studies.

9.4.4.1 Experience of use

This probe consisted of a range of artefacts that *changed bodily sensations* (Wilde et al., 2017), *disrupting* the normal experience (n=5) and fragmenting the compound flavour experience, so that individual elements could be appreciated, *"I found that some of the senses […] really help you taste the food and some detract"* (P6, Study 5). From this process there were many reports of *emerging* conceptions of experience (n=7), *"It made me think […] that I'd like to go on a meditation retreat, eating in silence.*

Figure 34 Sensory deprivation probe kit materials, including gloves, eye mask, nose clip and earplugs

The ear-plug one that was the strongest experience, I found the most fascinating […] just focusing on the experience of eating" (P8, Study 5). With 3 participants feeling this activity *embodied* experiences changing the way they ate - the nose clip made it "*difficult to swallow"* (P6, Study 5) and the blindfold resulted in "*difficulty in eating with your eyes"* (P7, Study 5). The overall outcome of this probe was to expose participants to *novel sensations* (n=4),*"It did feel a bit sexy, in a weird way"* (P2, Study 4) as well as providing *novel perspectives* on the multisensory experience (n=4), *"So, eating blind […] felt like more of manual dexterity challenge. 'Where's the fork going?', 'How's the sound of the plate?' even, you know that sort of thing was my overriding sensation"* (P9, Study 5).

9.4.5 Body mapping

Aim - Increase interoceptive perception related to the experience of digestion and metabolization.

How it works – Participants were instructed to eat a normal everyday meal. They were given a booklet and instructions to record feelings immediately after, 30 minutes after and 2 hours after eating. For each time slot 4 body outlines were provided each focusing on a different aspect of the internal experience: mouth and tongue, stomach and gut, brain and nervous system, and heart and circulatory system (Figure 35 Body Mapping probe kit parts showing the tied bundle (left) the timing divider in booklet (centre) and the maps printed on tracing paper (right)

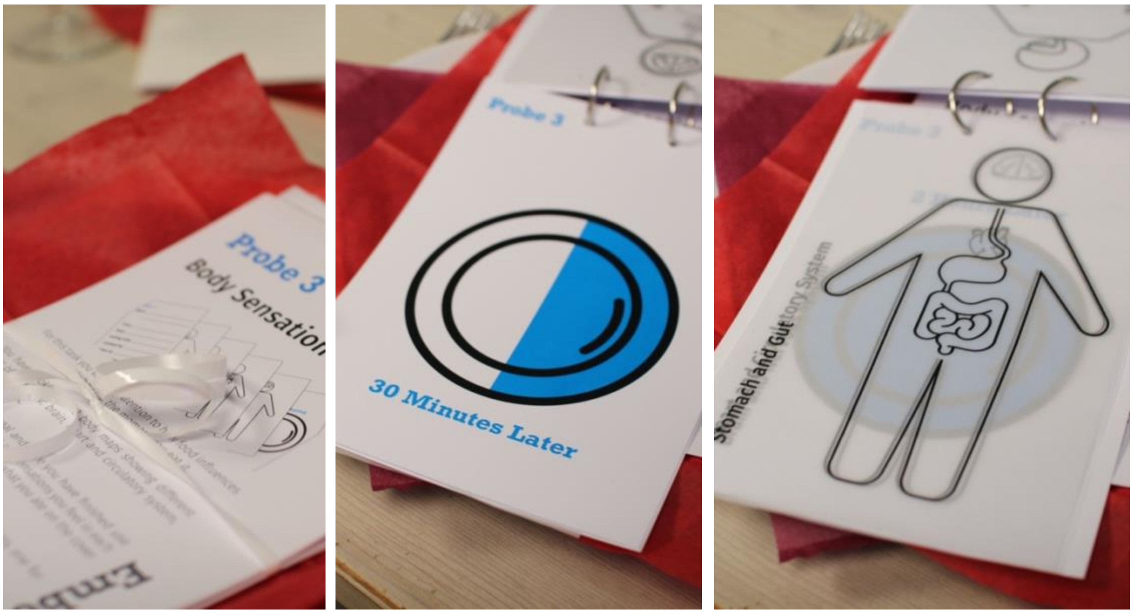


Figure 35 Body Mapping probe kit parts showing the tied bundle (left) the timing divider in booklet (centre) and the maps printed on tracing paper (right)

Onto these participants wrote or drew the experience they were undergoing at that time in relation to each bodily system.

Used as above in both studies.

9.4.5.1 Experience of use

Body-mapping disrupted the familiarity of eating, "*you are being so aware of your […] normally I just eat it and think nothing of it, I think about the taste, but I don't really think about how it is making my body feel later"* (P1, Study 4). In some cases, participants struggled to notice any impact on their body, a key reason for the probe being described as difficult to complete (n=6) and suggestions to choose particular foods that would result in stronger internal responses, *"I should have over-eaten rich foods that have made me feel sick or something"* (P8, Study 5). Despite some challenges this probe was still seen as providing novel perspectives (n=3), *"[It made me] more aware, because you're talking about different parts of your body"(*P2, Study 4).

9.4.6 Environmental mapping

Aim – Gather insights into, and direct attention towards the environments where eating takes place.

How it works – Participants were instructed to collect audio recordings and take photos of the places they made and consumed food.

Use in Study 4 – Participants recorded images and took photos via a smartphone, completed as a collaborative task.

Use in Study 5 – participants were provided short period audio recording devices and disposable cameras or chose to use smartphones.

9.4.6.1 Experience of use

This probe was found to *disrupt* eating experience to a large extent, impacting on the ability to capture details of experience as they would normally be, *"I think knowing that I was being recorded [meant] I wasn't saying anything"* (P9, Study 4). This led to a shorter recording period for the memory study implementation but there were issues with the ability to use bespoke recording devices that required buttons to be pressed, *"It is tricky trying to record what you're eating, or cooking is tricky when you've got to hold it down"* leading to (P2, Study 5) to suggest recording *"on the phone and [then send] the sound clip".*

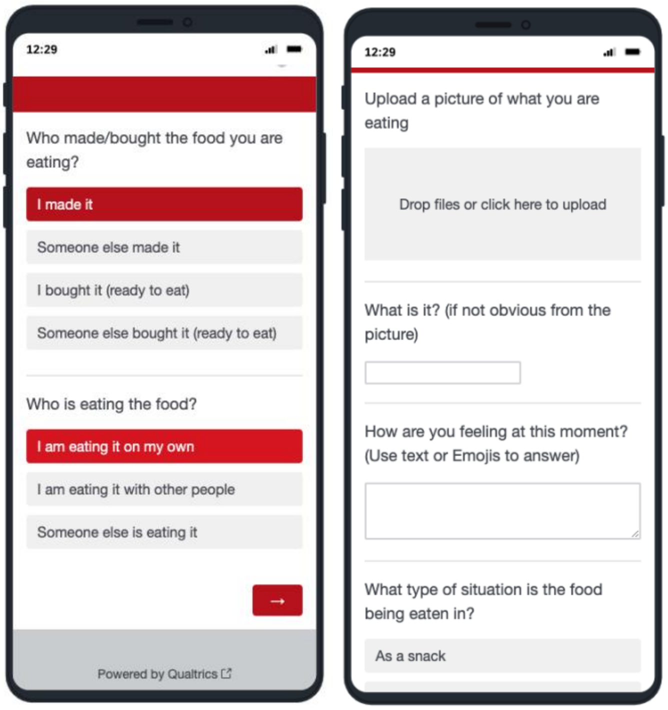


Figure 36 Food diary recording screens showing the multiple-choice questions to define who made the food and who eat the food (left), and right the screen to capture the image, enter details of the meal and how the user was feeling.

9.4.7 Food and Emotion diary

Aim – To collect insights into relationships between foods and moods, as well as prompt reflection through experience.

How it works – For two weeks participants photographed everything they ate and recorded their mood at the time. To support this process a bespoke webform was designed via Qualtrics (Figure 36 Food diary recording screens showing the multiple-choice questions to define who made the food and who eat the food (left), and right the screen to capture the image, enter details of the meal and how the user was feeling.). They also recorded who made the food and who they ate the food with, date and time was automatically recorded. Visualizations of the data were produced to compare foods by mood, the maker of the food and the social context of dining.

Use in study 4 – The visualizations were reviewed between participant and researcher to uncover insights for use in the co-design process.

Use in study 5 – as mood and emotion was not relevant to this study and this probe required a significant time investment, this section was removed from the probe kit for this study.

9.4.7.1 Experience of use

Participants described the act of recording food *disrupting* habits related to food (n=2), as participants considered more deeply their choices, *"[I am not eating it] because I want it. Yes. But just because things are not going very well. And so that made me think well, this is not the answer"* (P3, Study 4). When reflecting on the data collected in the diary, what *emerged* were insights into decision making process, emotional experiences and connections between various social and bodily experiences and food, *"since doing this it has made me realise that my food consumption I was just getting takeaway things just bits and pieces"* (P1, Study 4), *"we had stir fry's and things like that which I would never normally have but it is because whenever we meet up we tend to make different dinners"* (P2, Study 4). Through the process there were many examples of participants *uncovering habits* (n=7) that they were previously oblivious to, which led to them *reflecting upon behaviour and choices* (n=5). Both the *uncovering* and *reflecting* were important actions to be stimulated by the probe kit to support the following design process. A direct contribution to the design process came through an uncovered connection between types of food chosen to eat and emotion felt at that time, *"these two [foods are] really comfort food [...] the slice of cake would be that for example"* (P6, Study 4). As well as contributions to the design process through the practice of reflecting, that led to participants *enacting* a storytelling through food, providing a walkthrough for participants in how food can act as a *memory cue* (n=4), *"[I had] a friend visiting [...] I can see a scone that reminded me of that"* (P5, Study 4) or exposing the social and environmental conditions shaping food experience *"I mainly do the cooking and I think it is really hard because, whenever we are in his house we are in a shared kitchen but when we are at my place, I don't have an oven, so we are so limited in what we cook at my place"* (P1, Study 4). *Uncovering habits* not only surfaced isolated connections between food and experience but exposed more structural influences, the process of *reflecting* then support participants to both appreciate and practice the process of building narratives through food experience, drawing on the immanence of personal experience to support more conceptual connections around how food might be used to create interactions.

9.5 Overall themes from Probe kit

9.5.1 Difficulty and challenge

Of note is the difference between elements of the probe kit described as *difficult* (Letters – 5, Body Mapping – 5) and those described as *easy* (Taste Who – 4): *"[The TasteWho Board is] a game, you're playing […] it's less kind of demanding of your deeper kind of insight. So that was quite fun"* (P9, Study 5). This quote suggests that the gameboard was less cognitively demanding than other probes, one difference between these two groups is that probes described as difficult required participants to freely choose how to describe an experience whereas for the easier probe all the terms were provided, and participants had only to 'check-all-that-apply'. These two approaches are reflected in different methods of sensory evaluation by non-experts, namely free profiling (Jack & Piggott, 1991) and check-all-that-apply (Ares et al., 2010).

9.5.2 New perspectives on food experience

Both the sensory deprivation probe and the body mapping probe aimed to provide new perspectives on multisensory experience. In the sensory deprivation probe this was through *changing bodily sensation through artefacts* (Wilde et al., 2017), whereas the body-mapping probe drew on *re-contextualization* (Wilde et al., 2017), mapping the internal bodily experience through external visualizations over time. The impact of recontextualization to make salient details of their experience that are normally unapparent is described by P1 (Study 4), *"[The body mapping] was almost like mindfulness, because you are being so aware of your body and normally you just eat […] and think nothing of it, I think about the taste, but I don't really think about how it is making my body feel later".* For some participants these new perspectives were unsettling or *"weird. I had not done something like that before [it was] quite interesting [but] difficult"* (P11, Study 5). This weirdness indicates the challenge that the newly apparent experiences offer to food experience, making it more difficult to make sense of as it requires more thought and attention.

9.5.3 Sense-making through reflection and recording

Both the sensory deprivation probe and the food-emotion diary required participants to reflect on their experience, either immediately and self-led (sensory deprivation) or after a period of time and facilitated by a researcher (food-emotion diary). These reflections represent what *emerged* from the interaction with the probe. Sensory deprivations were described by reliance on metaphor connecting the experience with "*having a bad cold"* (P4, Study 5) or *"eating inside a container"* (P5, Study 5). Food-emotion diaries drew more on the context of each experience to help understand why each food had been eaten, *"we had guests this week, so the meals were really big and all of us were cooking at the same time and such big elaborate lunches"* (P6, Study 4). From the diary, habits and personal behaviour *emerge*, whereas sensory deprivation isolated eating as sensory experience and as such supports the emergence of details focused on sensory phenomena. That the diary required a repeated and extended engagement, and the sensory deprivation could be completed in one go reflects the nature of the experiences they tried to capture, respectively, accumulated repeated habits and momentary sensory experience.

9.5.4 Narrative construction

In both the letters probe and the food-emotion diary reflection participants constructed narratives through food. In the letter's participants started with an experience and connected them to a foodstuff. These included some letters requiring imagined narratives and some that requested simple reconstructions of food eaten at the time. In contrast, for the diary reflection participants started with the food and worked to recreate the narrative of the specific experience or to construct a broaden narrative connecting several foodstuffs through a theme as seen in this quote by P7 (Study 4) " *I would put these [foods] in the same camp […]I maybe didn't like them as much, they are a bit stodgy, that is why. [Whereas] you definitely see the positive emotion with the healthy stuff"*. The probes worked to seed the idea of food as a meaning making tool and trial how participants would be asked to use food in the later study, *"the whole thing has been quite an exercise in excavating memories and thinking about them, and also thinking about the part that the food plays in daily life, obviously [and] the link between food and memory"* (P9, Study 5). Or as P11 (Study 5) reported, "*The probe was sort of similar to some of the [co-design. The probes were] a bit like a practice run".*

9.6 Discussion

The findings covered both detail of the design and reflections on use for the probe kit, through assessing individual elements as well as shared themes across the kit. Now returned to are the research questions; *how to design a multisensory probe kit for understanding food experience?* and *what value such a kit would have for work across multisensory experiences in HCI?*

9.6.1 Embodied design approaches for a multisensory probe kit

Disruption has been proposed as the first step of a 4-part design process to support better designing for embodied experience (Wilde et al., 2017), it was applied to the design of the probes to support the intention to better understand food experience from the individual and embodied perspectives of each participant. In particular it answered a need to disrupt food experience so as to elevate it from mundanity. Within the probe kit elements each of the 4 strategies of disruption were applied to food experience as have already been highlighted for changing bodily sensations and re-contextualization (in *New Perspectives)* and also for enactment in the cooking of love letter recipes and alterations through the burning of food material for the heartbreak letter recipe. In the findings were examples of disruption that were beneficial but also others that were restrictive, this aligned with the extent of the destabilization (Wilde et al., 2017). Beneficial disruption maintained the experience of interest but destabilized the familiarity a person had with that experience. The 'Taste Who gameboard' and sensory deprivations were a good example of this. When it was not beneficial disruption extended beyond just removing familiarity but also destabilized the experience of interest, examples of this are the sound recordings of meals which resulted in a self-conscious acting for the probe or sensory deprivations that were uncomfortable to the extent that the experience of interest was impacted. In cases where disruption was too great what emerges from the probe experience embodies more the material structure of the probe rather than the detail of the experience. These unintended consequences of disruption are noted in the proposal for embodied design ideation methods (Wilde et al., 2017) as the method does not prioritize knowledge of the experience above knowledge of the material, instead treating them as one. It is not that disruptions that destabilize the experience of interest are not useful, indeed they do reveal details of the experience through absence. Designers can also learn from what disruption destabilizes and how it differs between participants. However, in these probes there were occasions where the material used to create the disruption becomes more focal than the food experience. Refinements may look to draw on *alterations* to the food material replacing the distraction of *changing bodily sensations through artefacts* (Wilde et al., 2017), moving from object orientated methods to more bodily enactments.

9.6.2 Challenging probe elements

It was seen that the freedom to describe experiences was both more challenging for participants but also that it potentially stimulated deeper engagement with multisensory experience. The difficulty or challenge reported from using a probe reflects the impacts of *disruption* and *destabilization* (Wilde et al., 2017) and the resulting *uncertainty*, *provocations* and engendered *interpretation* (Graham et al., 2007). However these outcomes need to be balanced with the support for *emerging* (Wilde et al., 2017) perspectives and the probes ability to *inspire* (Graham et al., 2007) users. One option is to provide a basic language (whether words, images or other) with which to describe an experience alongside the ability for participants to use their own language as well. Another is to use differing approaches in tandem as was the case in this probe kit, allowing for different modes of engagement across different probes. The choice between approaches may be influenced by available time (combining approaches may be quicker) or the desire to create certain interaction contexts (game play was supported by a predefined and ready-to-go set of terms, letter writing needed to be freely written to not influence the participant through predetermined words).

9.6.3 The value of probes to multisensory HCI

To help understand the value of the probes, it is important to return to the functions of probes as set out in (Graham et al., 2007). The probes presented *humanize* through the elevation of individual experience, a key requirement of improved ways of designing multisensory interactions, particularly including taste and smell (Obrist et al., 2016a). In the probes the use of personal experience and narratives combined with individual sensory perceptions to engage both with the phenomenological as well as cultural and social experiences of each individual. Through probes such as the letters it was possible to *create fragments* that inspired and informed the following co-design, this was particularly important in allowing space for practicing the design activities that would later take place. The way fragments were collected and subsequently applied in co-designs for flavour-based cues (Gayler et al., 2020) extended the deconstruction of multisensory experience (Merter, 2017; Schifferstein, 2011) to cultural and social experiences with multisensory materials (in this case the material was food).

Uncertainty was used through consciously challenging participants to complete difficult tasks that required cognitive effort and challenged assumptions. The probes were *inspirational* through proposing a variety of perspectives through which participants could access ideas across sensory, cultural and social experience, combining both design *with* and design *around* food (Gayler et al., 2021a). *Engendering interpretation* occurred in two ways through the use of the probe kits, firstly the various descriptions which participants had to provide, either through the gameboard as check-all-that-apply or through the letters using participants own vocabulary. The second way was through the sense-making applied in the review of the diary, here participants were placed in the position of considering the motivations and drivers for their own behaviours, reflecting on and connecting together, feelings, foods and environments, offering both individual insights as well as a broader appreciation. Finally the probes *provoked* participants by enforcing certain ways of thinking and consideration of emotionally charged topics such as heartbreak or by physically augmenting their sensory capacities to experience food in a new way, drawing on A-labs (Höök, 2018) and sensory bodystorming (Turmo Vidal et al., 2018).

9.6.4 Constructing flavour design worlds

The term *taste world* was used by Bartoshuk (Bartoshuk, 1978) to define an individual personal perception of taste due to the difference in threshold perception between individuals. The same lemon drink could be too sweet for one person, too sour for another and just right to a third in part due to their sensitivities to sweet and sour tastes. This individual variance underpins the design approach for this probe kit, however with the distinction that taste worlds were extended to flavour worlds (considering the multisensory experience beyond just taste) and it is proposed that it extends further to *flavour design worlds*. This concept connects the proposal for sensitivity to an individual’s perception with the notion of *design worlds* from Schön (Schon, 1992). *Flavour design worlds* are built on a commonality between what Bartoshuk and Schön describe. Both *worlds* evolve as a result of what is perceived by the participant but are also informed by their personal and subjective experience. *Flavour design worlds* are the result of design activities such as the probe kit in this study. They are a collection of fragments (Graham et al., 2007) which describe the sensory, cultural and social perspective of an individual's food experience and makes it available for design. This thesis argues that these are important to support any design for food experience as they shape the context within which any food-based interactions occur. They not only highlight opportunities (e.g., associations between vanilla flavours and memories of grandma) and but also identify where pitfalls lie (vanilla ice-cream results in painful eating experience due to the sensitivity of the participants gums).

These probe tools are an attempt to increase the knowledge of the flavour design world for an individual and to create a way of collaborating with a designer. The flavour design world is not just about *joint inquiry* to discover what it looks like for an individual but also *joint imagination* (Steen, 2013), as it is shared to inform the creation of new experiences with a co-designer. The disruption (Wilde et al., 2017) to the roles of food help open new spaces for design by taking down the predefined nature of food experience and by forcing new connections (such as with emotion (Gayler et al., 2020) or memory (Gayler et al., 2021b)). This probe kit set out to reframe food experience and build a bridge for collaboration with a flavour design world, however they also have had a further role to give permission both through removing barriers and cutting paths to new space. They also support a design orientated standard setting which moves beyond sensory profiling (Varela & Ares, 2012) to not just use scales and defined terms, but to incorporate personal histories, and multimodal responses. In this way the design of flavour experiences can move away from the engineered compromise of mass-produced foods towards personalized and intensely meaningful food experiences.

Flavour design worlds call for an approach to design which recognizes the role of the individual in each sensory experience and moves beyond previous approaches to multisensory design which deconstruction and reassembled sensory experience from a singular perspective (De Giorgi et al., 2011; Merter, 2017; Schifferstein, 2011). They place the multisensory experience within the context of the particular body where they are perceived. To do so they must be constructed from discovery techniques that cover the breadth of external, object-, or material- led investigations such as the Sensual Evaluation Instrument (Isbister et al., 2006) to the bodily enactments such as in *Sensory Bodystorming*. Additionally, flavour design worlds are not only about extraction of data from the person being designed for but about building lasting sensitivity for the individual themselves towards their own experiences. What *emerges* from the *disrupting* and *destabilizing* (Wilde et al., 2017) involved in the construction of these worlds is not singular insights but new perspectives that support participation in the co-design process, that participants now *embody* (Wilde et al., 2017) the knowledge of their flavour design world.

9.6.5 Limitations and challenges

This approach attempts to overcome some of the difficulties of working with novices when designing experiences and interactions with flavour and food. The probes themselves are not only intended to collect data that can be processed and reflected upon by the research team as per Gaver and colleagues (1999), instead the outcomes also included the learning and sensitivity gained by participants. As with the original probes, the completion and collection of all data was not the intention. Although some participants found some of the probes too challenging or time consuming (e.g., the noseclip in the sensory deprivation probes) but these challenges were not consistently experienced by participants and did not prevent participants from completing the other probes. As a level of challenge was felt necessary probes were kept consistent following this feedback. The noseclip was particularly problematic for older adults and demonstrates the need for the probes to be designed to the bodies of the users. Further the language used to introduce those activities should be considered to support as many of the targeted users to engage with as many probes as possible.

The probes here are tool for designing food experiences and in their current incarnation are most suited to use by researchers. The next chapter, Study 7, aims to create a tool that can be adopted beyond research by creating a digital tool that draws on the novel co-design approach in Studies 4 and 5 to create a mobile application in which users can themselves create flavour-based cues without necessarily involving an expert in the form of a researcher or designer. The application moves this research towards further future applications of flavour-based cues, with emotional communication and memory cues being already explored here.

10 Study 7 The Design of a Mobile App for Capturing Multisensory Experience and Designing Personalized Flavour Cues

10.1 Aim and rationale

This study builds on the flavour co-design processes that were detailed in Study 4 and 5. It aims to create a digital tool to support individuals to design personalised flavour cues and takes memory cues as its application. The purpose of the app is to support a scaling up of the existing design strategies so that it could be feasibly disseminated and used across a range of research and design applications. The app replaces the need for a skilled co-design facilitator and should be able to support individuals to design flavour cues on their own. This final chapter is on technology design and evaluation, presenting a study on app as a method for designing personal flavour experiences in field settings.

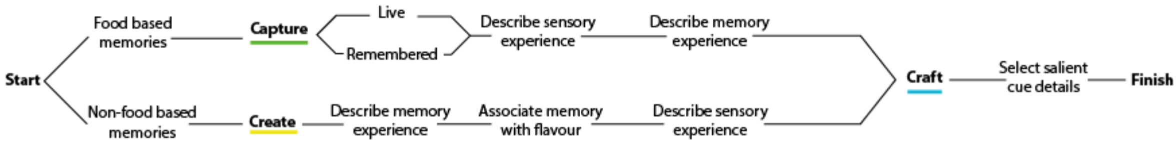


Figure 37 Structure of the app for capturing and designing multisensory flavour cues

10.2 Design of app

This app builds on the design process used in two previous studies in which users co-designed flavour cues for emotional (Gayler et al., 2020) and memory-based experience (Gayler et al., 2021b). The app consisted of three distinct functionalities, *Capture*, *Create* and *Craft* (Figure 37). Each of these sections drew on the co-design process that was facilitated by the designer in Study 4 and 5. In some parts of the Capture functionality, visual data entry features were informed by the flavour design sheets used previously (e.g., capturing taste), however other sections required the design of novel approaches that could support the elicitation of details around the sensory experience (e.g., smell). These were intended to replace the ability of the expert researcher in the co-design studies to explain or probe around details of the experience. For the Create and Craft functionalities, the app was to replace a set of questions which were used in the co-design process. These sections started by capturing details of the memory and then prompting association with sensory experience or food material, closely following the co-design process.

10.2.1 Capture

This app functionality supported the live and remembered description of food experiences. It borrowed the approach of previous models for multisensory experience design by focusing individually on each sensory pathway such as taste, smell, touch and vision (Camere et al., 2015; Schifferstein, 2011).

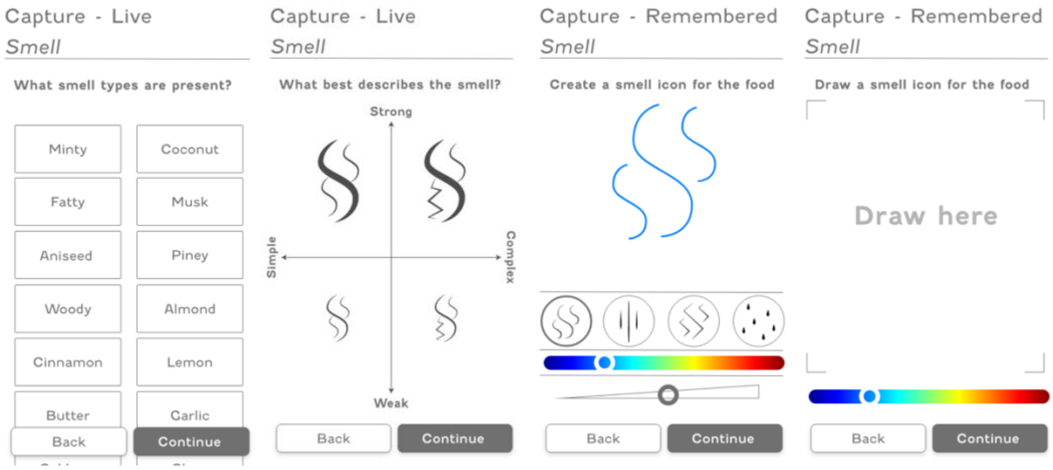


Figure 38 Smell wireframes from Capture functionality; left and centre-left from Live, centre-right and right from Remember. From left showing classifications, smell matrix, supported draw and free draw

For taste scales for bitter, salty, sour, sweet and umami were taken from those used in work with children (Ervina et al., 2020). In addition, example foodstuffs were provided to better support understanding of the provided taste labels : bitter - black coffee (Crisinel & Spence, 2009; Sammons et al., 2016), salty – salt (Ervina et al., 2020), sour – lemon juice (Crisinel & Spence, 2009; Sammons et al., 2016), sweet – sugar (Ervina et al., 2020) and umami – tomato paste (Bellisle, 1999). This was presented both as linear scales and radial scales (Figure 43 Taste experience entry; left showing linear Likert scales and right showing radial scale entry

. Whilst linear scales were used in the validating study, radial scales had been used in the prior co-design processes (Gayler et al., 2021b, 2020) that emphasised the connected nature of taste qualities.

Smell descriptors were taken from a classifications used for food additives (Furia, 1973) which included piney, fatty and minty, these were also accompanied by different visual representations of the smell characteristics. The first representation was a matrix of strong-weak, simple-complex with accompanying illustrations (Figure 38 Smell wireframes from Capture functionality; left and centre-left from Live, centre-right and right from Remember. From left showing classifications, smell matrix, supported draw and free draw

), the second was a free draw option with which participants could draw an image representing the smell by tracing their finger across the screen, changing the colour as they wished. The matrix dimensions were chosen to reflect two aspects of smell experience, strong-weak axis is directly related to the intensity of the smell. Simple-complex axis reflects the character of the smell and the degree of fragrances that are combined together in the smell experience. For the creation of flavours, simple smells reflect raw and easily identifiable smells (e.g., orange, chocolate) whilst complex smells represent those as a result of cooking processes (e.g., roasted, charred) and thus inform the preparation process for each flavour. One of the challenges of working with smell is the lack of taxonomy for all types of smell with classifications often tied to specific domains such as wine-making (Nobel, n.d.) or food additives (Furia, 1973). Finally, a supported drawing option was provided, this used 4 set patterns, colour selection and size selection to support smell icon creation.

Trigeminal experience was rated on a linear scale developed in sensory science (Carden et al., 1999) marked with none, threshold, slight, moderate and strong. Texture descriptors (Meilgaard et al., 2006) (and the definition between semi-solid and solid textures (Szczesniak, 1963)) were also taken from sensory science. Thermal properties of the food were rated used a scale for reporting thermal experience in thermal comfort studies (Fanger, 1970) Participants captured food images (if live) and described colours of the food. In addition, participants also freely described ingredients, flavours, names of dish(es), cooking and preparation style. These were intended to support a holistic approach to describing the multisensory food experience alongside details such as feelings, people involved, location and time of the experience which are typical to episodic memory experiences (Johnson et al., 1988). This reflects the approach used in the co-design part of Study 5 (section 8.2.2). A textual description of each of these elements was preferred rather than scales for reporting emotion valence or arousal. The ability to freely describe these aspects was felt to better match the intention of the app to support individuals to create flavours for each memory.

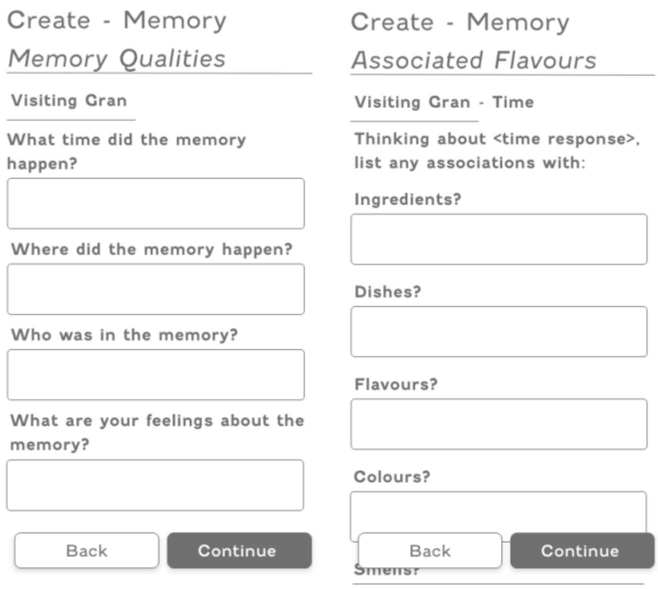


Figure 39 Wireframes for the Create functionality, left screen shows the capture of memory details, right screen shows the associtaed of time with ingredients, dishes, flavours, colours and smells

10.2.2 Create

Another functionality of the app aimed to support creative association of a non-food related memory with a flavour cue. Again, this work drew on the co-design process which had been developed previously (Gayler et al., 2021b). The app first supported participants to identify characteristics of the episodic memory (including location, people present, time (Johnson et al., 1988)). And then supported them to associate each of these aspects with ingredients, flavour's, dishes, colours and smells (Figure 39 Wireframes for the Create functionality, left screen shows the capture of memory details, right screen shows the associtaed of time with ingredients, dishes, flavours, colours and smells

Figure 40 Wireframes for the Craft functionality, showing navigation between flavour qualities (left and centre) and the adding of salient qualities to the flavour cue (left and right)Figure 39). Once complete these details could be curated to create a cue, which was then described using the sensory description process described for *capture*.

10.2.3 Craft

The third functionality of the app relies on the data collected through the *capture* and *create* functionalities. It presented all the details about a flavour cue in a way that

participants could select and combine the most salient aspects of the experience to refine the cue design and support cue distinctiveness (Figure 40 Wireframes for the Craft functionality, showing navigation between flavour qualities (left and centre) and the adding of salient qualities to the flavour cue (left and right)
). The wireframes presented all the details about a cue that had been entered in the lower half of the screen, with selected details in the upper half of the screen.

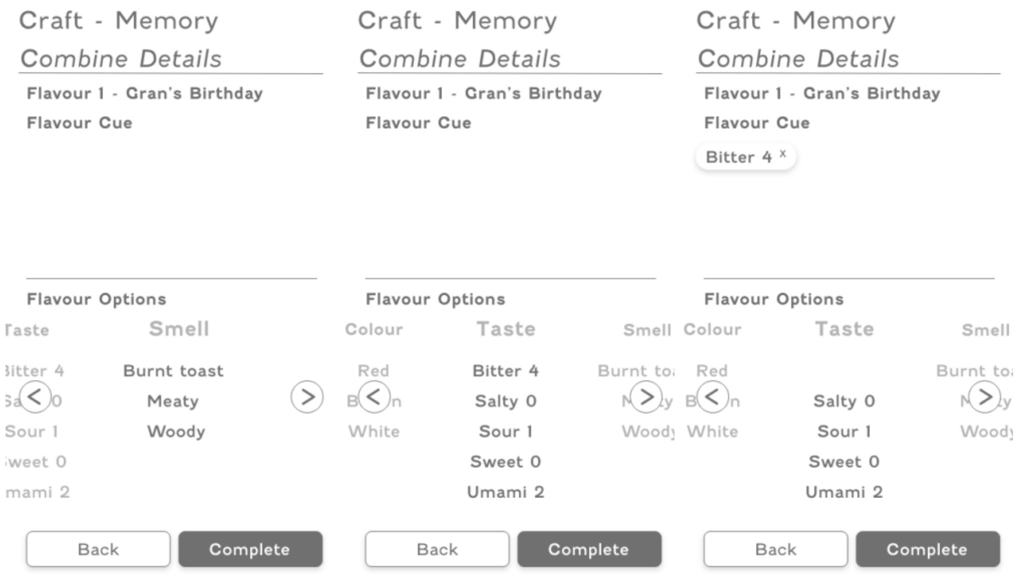


Figure 42 Wireframes for the Craft functionality, showing navigation between flavour qualities (left and centre) and the adding of salient qualities to the flavour cue (left and right)

10.3 Method: Evaluation of App's Wireframes

The evaluation of app wireframes involved Wizard of Oz (WoZ) approach (Dahlbäck et al., 1993) through online focus groups. Study participants were instructed to enter data for both *Capture* and *Create* functionalities and engage in the cue curation supported by the *Craft* functionality as part of the WoZ approach. Following the entry for each section they reviewed and discussed each screen to assess the clarity of what the user was required to do, how effective they felt the input/output functions to be as well as the opportunity for users to suggest alternative solutions. The focus groups were split into sections examining the overall concept, onboarding, capture, create and craft functionalities. The focus groups concluded with semi-structured interviews to gather overall feedback from interacting the app's wireframes. Participants remotely contributed via video conferencing, the researcher shared their screen to allow viewing of a .pdf showing the wireframes and question prompts (Figure 40). The Wizard of Oz app interaction was facilitated through the Qualtrics platform, with each app's wireframe being explored by adapted data entry forms (Figure 41 Wizard of Oz of app screen (left) and data entry (right) for Ingredient's screen of the capture functionality of the app

Figure 42 Online focus group[material, PDF that was navigated through showing links to videos of app function, individual screens annotated with specific questions and general discussion questionsFigure 41).

10.3.1.1 Data collection and analysis

The focus groups were audio recorded and fully transcribed. The transcripts were then coded following a thematic analysis to identify emergent themes including aspects of the design that were successful and why, where the design did not achieve its aims, common themes in an effective design approach across the app and highlighting outstanding challenges for future work for multisensory HCI. Themes were analysed for each of the app's functionalities, in terms of best design elements and potential improvements, and across the whole app, in terms of overall flow across functionalities.

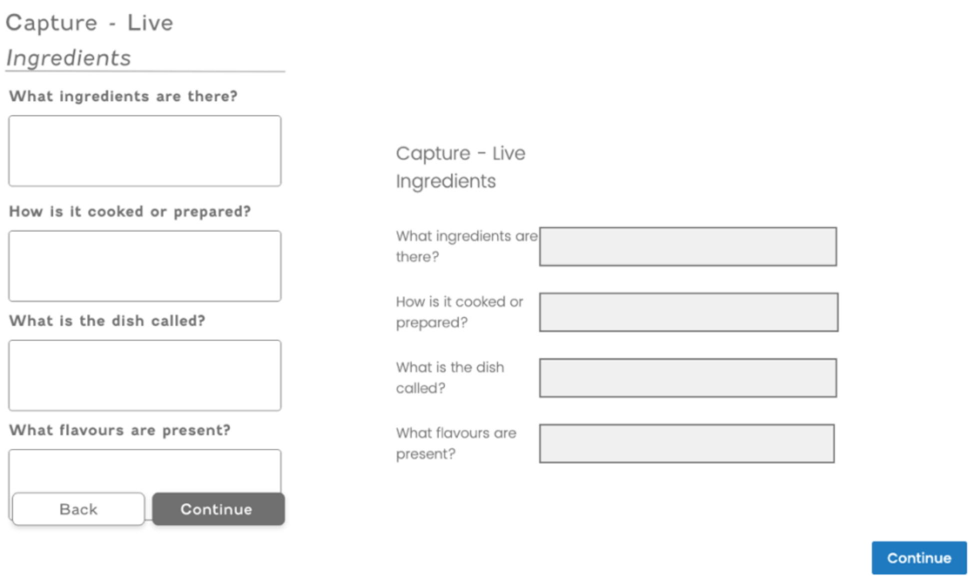


Figure 43 Wizard of Oz of app screen (left) and data entry (right) for Ingredient's screen of the capture functionality of the app

10.3.1.2 Participants

12 participants (8 Female, 4 Male) were recruited to take part in this study using adverts on social media. Mean age was 35.5, with 8 participants aged 26-35. Over half of participants held a postgraduate qualification and 5 had professional experience in app

design and research with the rest familiar with using mobile apps in their everyday life. The skew towards more educated and more professionally experienced participants reflects the characteristics of early adopters of novel food technologies (Gayler et al., 2018). 10 participants were white British or other white background and two with mixed or multiple ethnic backgrounds.

10.4 Findings

10.4.1 Onboarding and App structure

The first functionality of the app covered the onboarding process. Participations felt that the language used was clear (n=8 participants) and that they could, *"have an idea of what a flavour cue was […] there was just the right amount of information"* (P12). However, more challenging for participants were the names *capture*, *create* and *craft* used for the functionalities of the app (n=9). Participants suggested using *edit* in place of *craft* (n=4) and to borrow language from other design tools (n=2). One major issue was the names were not memorable to match the functions (n=8). Alongside more distinct or more familiar names, the use of icons to represent each functionality was proposed (n=4). Real-life examples were also proposed to help understand each functionality in the app (n=3) and the provision of a map or journey explaining to the user *"how everything connects"* (P8).

10.4.2 Capture

Capture is split into two sections, one for the capture of live experience as it happens and one for remembered, past experiences. Some wireframes were shared between the two (e.g., temperature and spiciness) but for some (e.g., taste and smell) variations were explored to test different methods of data entry. Overall participants found the functionality was *"simple and seem to flow as to inputting and building the experience"* (P4). For taste either a linear arrangement or radial arrangement of the Likert scales were presented (Figure 43 Taste experience entry; left showing linear Likert scales and right showing radial scale entry

). Participants preferred the radial arrangement as, *"it makes me feel like all the tastes are there to work with each other. So, by pulling them across and seeing how they* *relate, like we see sweet, and sour are, you can definitely tell what is more than the other. It's in combination."* (P 8, n=4) and that it was, *"a bit more visual"* (P6, n=3). For smell capture participants liked the combination of classifiers of odours combined with a matrix that described smell in terms of simple-complex and weak-strong axes (n=4), "*I really liked the smell matrix [...] I thought that was ingenious"* (P8). However, the classifiers for odours were not seen to cover every smell a participant wanted to describe (n=7). An alternative free drawing option was offered for smell capture, but this was seen as difficult "*to create meaning with each of those patterns"* (P11, n=4). For colour description, some participants preferred picking from a colour wheel as it was more specific (n=2), whilst others preferred labels as it allowed for multiple selection and better supported selection of black, white and dark colours (n=5). A common issue experienced in this functionality was the complexity of the texture scales (n=10). P7 asked, *"the layperson [...] are they going to persevere through 15 different descriptors [in the texture scale]?"*. The texture scale used 17-point Likert scales, something that felt too fine-grain for 7 participants and whilst the provided explanatory text was helpful it did not fully overcome this challenge. Further, it was not clear to participants how to deal with foodstuffs that contained multiple textures or dishes which contained multiple foodstuffs, "*It's not just one dish, it is kind of Sunday roast, which has many different components to it. Do you just choose one of them?"* (P3).

The final screen in the capture functionality was for the reporting of the experience details, participants felt this was an important functionality, but that it should be moved ahead of the flavour description (n=3), "*as you start to describe things, and you really think through those questions, if you may be more open to them, answering some of the other ones as well, because then you're thinking more deeply about, I don't know, like the flavour, the texture, etc."* (P11). This suggestion indicates how the experience details creates user investment into the cue as well as potentially sensitizing them to think more deeply about the specifics of the experience by starting with the more general context and working towards the deconstruction of the multisensory aspects of the experience. The provision for prompted emotional content entry was also proposed as part of enriching the experiential details (n=3) and the requirement for photographing the food in live experience capture was also suggested to be brought forward to avoid people having consumed all the food before the photo is taken (n=4), this point highlights the importance of testing further work alongside the eating practices of the user to understand how the capture and eating interact.

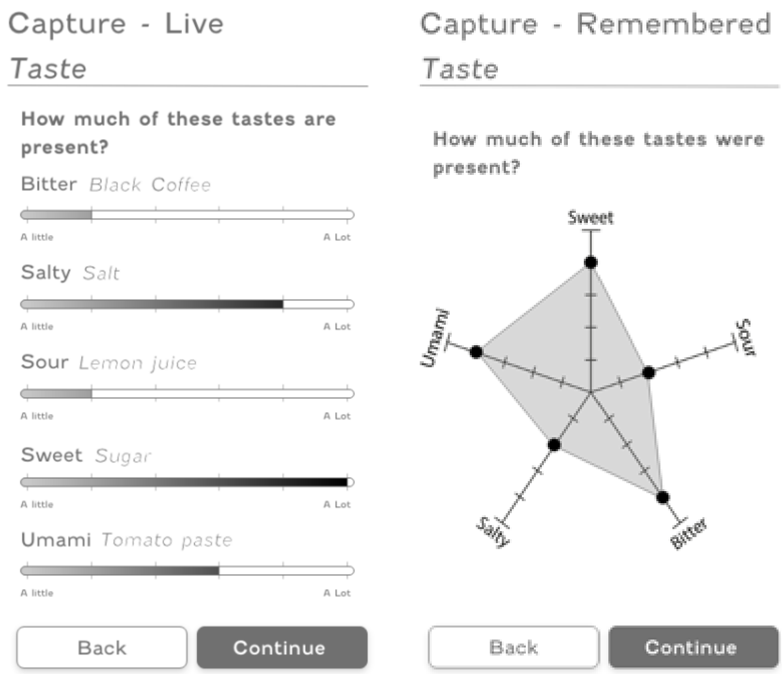


Figure 46 Taste experience entry; left showing linear Likert scales and right showing radial scale entry

10.4.3 Create

The *Create* functionality supported the association of non-food related memories and experiences with a flavour cue. Participants found that the process supported them to produce many connections between the memory and flavour (n=5) but that the majority of these connections were tenuous (n=5), and the structure was highly repetitive (n=10). One highlighted shortcoming was that there was not support for the most obvious response, *"When I think about memory, there are a couple of things I'd distinctly just put down straight away. And none of them are on my list. It didn't work as a process, because what I ended up with it wouldn't be a trigger, it wouldn't work, because I couldn't see the obvious connection at the end."* (P7). However, the process was found to be generative, even uncovering cues for other memories than the one concerned, in this way the process is perhaps creative, but has not been constrained to achieve the initially intended goal.

"So, and because they have asked me a place. So, it led me to, because I put my hometown, it led me to put all of these associations that I have to my hometown, which

are seafood related. So, I feel like, "Oh, I started with this memory", but then I didn't select those food for them, for the cue. [Instead] there was a dish. But also, not that dish in the circumstance, the context, there were other foods that also were in the memory. But they were not in that particular memory" (P1).

Participants suggested that prompts for the content to help direct the kind of responses that were being looked for (n=3) or that suggestions could be made, for example based on taste-emotion mappings (n= 2).

10.4.4 Craft

The third functionality of the app supported participants to select the most salient aspects of captured or created cue data to refine their final cue design. This was "a *nice way to capture what was really important about that experience, like a nice little summary"* (P3, n =4) and "*a good thing to just reflect on although you have put in all the sort of poignant aspects"* (P5). Participants felt that "*the layout of the screen with the headings and words, with the numbers next to them, how they've been scored was easy to understand what you were looking at, and how you could interact them, with the data. And I think, it's pretty clear where [the data] came from as well"* (P5). However, where participants found this more challenging, they described how they were unclear of the value or purpose of this functionality (n=4), *"[it would be better] making the intention very clear in the beginning and sort of helping set expectations around what the benefit of editing or like tweaking your previous flavour cues might be"* (P11). Participants also considered whether it was necessary to add an additional functionality on for this purpose and whether the action of selecting saliency for aspects of the experience could not be integrated into the capture or create stages (n=2).

10.4.5 Overall feedback

Finally, participants also commented on the overall proposition of the app and what barriers to use might exist for them. A main barrier to use was uncertainty around the value of flavour cues (n=4) or their application (n=3), which had also been highlighted as specifically relevant to the craft functionality. In the study participants were told about prior research on flavour cues for emotional and memory-based experience, but felt that the purpose or application of the cues was not sufficiently reflected within the app, *"it'd be good to have some kind of visual, [to] be able to envision it more, I think that would aid the process [...] I think more ideas about how the flavour cue would be of value to me would make me carry on [using the app]"* (P12). This quote captures both how emphasising the application could support understanding as well as motivation for capturing and designing the flavour cue. A second common theme was how challenging some of the tasks within the app were for a general audience, who do not have specific training in food science or sensory evaluation. In the design of this app were several validated scales for sensory evaluation, however these are designed for use following a training process, *"I feel like the way the question is asked is more suited towards like a gourmet, trying to analyse the flavour and the texture"* (P2). One potential way to address this knowledge gap suggested was to use further walkthroughs in the app, "*maybe there is almost like a second set of onboarding [...] that people can engage with that walks them through those processes. A second more active step that you might take, and maybe that provides greater clarity when you're going through and creating or crafting or capturing"* (P11).

Mapping or signposting was referenced both in terms of *"how each section relates to the other"* (P12) as well as to indicate what it is that is explicitly produced at the end of the process and how that is achieved through each step (n=3). At more detailed level further scaffolding for the user's design process was suggested through various mechanisms including prompts (n=5), example outcomes (n=3), grouping of similar terms to aid comprehension (n=3), walkthroughs (n=2) and progress bars (n=2).

The aim of this app is to support individual users to create personalised flavour cues for their memories. As already identified, there are challenges for untrained evaluation of experience. Various scaffolding has been suggested to support this process, but there are also drawbacks to adding structure to the design process, including not wanting suggested mappings for flavours as "*I think (flavour experience) is too personal to do that"* (P4). Another suggestion was to have adaptive approaches tailored to meet the level of detail a participant was able to provide (n=2), "*maybe you could have a minimum number of screens in the app and if someone wants to enter extra information then they can"* (P9). Aligned with consideration of how personalised the design process should be was consideration of more open-ended design approaches. In relation to the free-drawing for smell, 3 participants found this the most creative approach, but participants also found it confusing. Twice participants felt that questions constrained them and didn't support them to be as specific as they wished (for *Create* and recording experience details in *Capture*).

10.5 Discussion

This discussion sets out principles for the effective multisensory experience capture and design applications to support the future development of such tools both for the design of flavour-based experiences as well as multisensory experience more widely. The discussion concludes by highlighting the outstanding challenges for the development of multisensory design tools.

10.5.1 Principles for the effective multisensory experience capture and design apps

10.5.1.1 Consistent, memorable and defined terms are important

When working with flavour one of the more challenging aspects is the confusion between the scientific and colloquial use of terms. *Taste* for example is understood in sensory evaluation as relating to very defined experiences in the mouth based on chemical stimulation of the tongue (Cowart, 1981), however in common parlance it can be used to describe what scientifically is described as the flavour experience (e.g. *a lovely chocolate-y taste*). In this application the terms for the functionalities (*Capture, Create* and *Craft*) were not successful for a range of reasons. Firstly, they added new terms to understand where terms could have been borrowed from existing design tools; secondly, the words were similar, so it was hard to remember and distinguish between them and thirdly, the definitions were not explicit enough to only be related to the title given. Whilst this issue is related to the specific choice of terms used here it does reflect a broader design consideration in that the use of terms must contend not only with a scientific definition but how that term is understood in common usage.

10.5.1.2 Give examples through vignettes

One way of supporting the understanding of key terms is the use of vignettes which demonstrate in a concrete and applied manner what something means or what something does. Examples of successful applications of vignettes to support the explication and communication of complex internal and subjective experience can be seen in recent work into depression (Sas, Hartley, et al., 2020).

10.5.1.3 Using prompts and example answers to sensitize participants

Similarly, to the above point, findings suggest users would value having prompts or example answers to questions within the capture functionality that could help sensitize them to the kinds of language or responses that would be useful. This was particularly noted in the text entry boxes, where participants felt prompts could help them find the right language to describe their intentions. An alternative was to explore how text entry boxes could be replaced with multiple choice options that allowed selection from a predefined list. However, a move towards defined options should be weighed against the desire for specificity.

10.5.1.4 Connect the capture and design processes to the application

One recurring challenge for participants in this study was understanding how the process undertaken was to connect to an outcome or application. Whilst the app connects the visceral, sensory experience with a target expression of the memory to be cued (Schifferstein, 2011), it did not support users to connect further to use case (or 'product vision' (Camere et al., 2015)).

10.5.1.5 Support specificity but not descriptions that are so detailed as to become arbitrary

A recurring theme across functionalities of the app was the desire for users to be as specific as they could be about their experience. They preferred the ability to select multiple labels for colours and to choose the exact colour from a wheel rather than giving a simplified response that was quicker. However, they also highlighted that questions that were too fine-grained (e.g., the 17-point Likert scales for texture) or had terms that were beyond their comprehension were not helpful for them to record their experience. This suggests tools should be considerate to the capabilities of individuals to describe their experience and to support exactness without prompting descriptions which users feel unable to give. One solution is to increase the support for understanding complex terms, another is to reduce the overall complexity of scales whilst supporting more open-ended descriptions.

10.5.1.6 Explore novel methods for experience reporting and communication

The smell description was explored by the combination of existing odour classifiers and novel ways of presenting the odour through icons or visual imagery. Various methods were proposed from the use of predefined icons as part of a matrix or the use of free and supported drawing tools to use shape, colour and size to help describe the smell. This approach was informed by prior work into visualising taste experience (Obrist, Comber, et al., 2014) and tangible objects for describing experience which were designed not to have inherent meaning but to be able to be used to create meaning by users (Isbister et al., 2006). The application of the smell iconography worked best in a limited way in concert with the classifiers taken from literature and indicates that pairing together more exploratory and multimodal responses with validated scales may be a way of combining together the aesthetic and psychophysical descriptions of sensory experience that support shared understandings (Wilkes et al., 2016).

10.5.1.7 Memory is semantic, sensory experience is visceral

In the capture functionality of this app, users record their visceral sensory experience before detailing the description of semantic details of the memory or moment. In the create functionality this was reversed, and the description commenced with the memory and then went to the sensory experience. The second approach is aligned with previous work on models for multisensory experience (Camere et al., 2015; Schifferstein, 2011) and was preferred by users, who felt that starting with the memory gave meaning and motivation to the sensory recording which otherwise could be seen as pointless or laborious. Making use of the fact that meaning is embedded in the memory (the specific 'target expression' (Schifferstein, 2011) for this app) can support the function of the visceral sensory experience description and result in higher rates of completion and more user satisfaction with the process.

10.5.1.8 Support most prominent connections first, processes should be responsive and flexible

The *Create* functionality of the app allowed creative association between the memory and flavour cues. However, the process is not responsive to the answers given nor does it support the most obvious connections first. Therefore, the process often generates many low saliency connections which were demotivating and inefficient for the users. Whilst many approaches to multisensory design emphasise completeness in considering each sensory perspective (Camere et al., 2015; E. Harris et al., 2019; Schifferstein & Desmet, 2008; Schifferstein, 2011) they are aimed at designers whose training allows they to intelligently assess the potential of different explorative activities and thus can choose the most promising first. In this app, users should not be required to have a wealth of design experience or knowledge about what is likely to result in a strong connection. Instead, users should be prompted to explore connections in the most efficient manner, this could be informed through recording patterns of previous associations to weight interactions towards common interaction patterns, and over time they may become adaptive to fit the user themselves.

10.5.1.9 Build in iteration to move back and forth between the experience and the design

Not catered for in this app, but a key feature of previous studies with an analogue co-design process was the iteration of designed flavour cues by making, eating and evaluating to tweak the designs. Through this process there is also the potential to further sensitize participants to the flavour experience, using repeated use and engagement as a way of the user learning more about their sensory experience (E. Harris et al., 2019). The original ratings could be used as a benchmark against which the outcome is seen as too high, too low or just right. The importance and necessity of iteration should be communicated to users, through this lens they should be encouraged to see the design process as not a linear and isolated process in which a cue is created and then never changeable but instead an ongoing exploration to move the created cue (or *sensory effect* (Fuchsberger et al., 2013)) closer to the intended experience (*sensory impression* (Fuchsberger et al., 2013)).

10.5.2 Challenges remaining

10.5.2.1 Choosing validated scales for trained evaluators or simplified tools for non-experts

This app made use of several scales for the sensory evaluation of food products (Bellisle, 1999; Carden et al., 1999; Crisinel & Spence, 2009; Ervina et al., 2020; Furia, 1973; Meilgaard et al., 2006; Sammons et al., 2016; Szczesniak, 1963), often designed for use by trained evaluators. In particular the texture scales (Meilgaard et al., 2006) proved challenging for the untrained users in this evaluation. There is an open question about whether simplified or more concise evaluation tools may be more effective than those used here. Prior work on collaborative design between material scientists and designers has attempted to integrate aesthetic experience with psychophysical evaluation to create richer and thicker descriptions of the experience of materials (Wilkes et al., 2016). Future work should explore how to simplify scales or use those designed for untrained evaluators, it could also consider the use of multiple tools to allow different ways in to describing experiences and support learning through sustained engagement (E. Harris et al., 2019).

10.5.2.2 Dealing with both complex multiple part dishes and single ingredients

There is an unresolved challenge in dealing with descriptions of multiple part dishes, where sensory qualities may vary across different parts of the dish and as such single descriptions that are an average do not actually represent any one constituent part of that dish. One approach would be to identify distinct parts first and then describe each in full, however this could make the design process very long. Another maybe to prompt the consideration of the dominant part of a dish, although this loses some uniqueness and similarity to the experience in question.

10.5.2.3 Supporting users to report the saliency of sensory fragments and confidence in their rating

Within the *Craft* functionality of the app, participants could select sensory fragments (e.g., their rating for bitterness) that were particularly salient for the flavour cue. The intention of this was to support users to curate cues that were highly salient with only the most important details included. However, participants found assessing the saliency of the fragments challenging. Similarly, participants reported sometimes being unsure (either from confusion or that they simply could not detect or remember) when entering data about an experience, at present there is no way to reflect confidence in the given ratings. Future work should explore how saliency and confidence could be considered to ensure the most accurate descriptions are used to create cues.

10.5.3 Applications for the Flavour Designer App

This app was designed within the context of creating flavour-based cues to support the recall of memories in older age, building on prior work with an analogue co-design process (Gayler et al., 2021b). However there are many more applications that this app could be used to support, these included creating memory-based meals for use in space travel (Obrist et al., 2019), designing foodstuffs for use in playful experiences (Altarriba Bertran et al., 2020), supporting emotional experience with food (Gayler et al., 2019; Velasco, Michel, et al., 2016), or interpersonal emotional expression and coregulation (Gayler et al., 2020), supporting rich craft practices with food (Vannucci et al., 2018) or how food can be used as a tool for exploring and understanding more about sustainability and ecological systems (Markéta Dolejšová & Kera, 2016; Kuznetsov et al., 2016). Each could be easily catered for through swapping out the experience details section (i.e., changing the *target expression*). In this way the app can be utilised to support much wider adoption of food as a resource for interaction design by overcoming the barriers of designing for an individual's subjective experience, instead making this a feature of any interactive experiences where the subjective experience supports personally meaningful interactions.

This final study creates a tool which can be used by both researchers and designers to further explore the design of interactions based on flavour experience. However as of yet there are further steps needed to move these wireframes forward towards a completed functional app. It creates an accessible tool which draws on the design knowledge generated through the interviews in Study 2 and the co-design process in Studies 4 and 5 and aims to promote further experiential uses of the 3D printing of food as suggested by Study 1. The next chapter, the discussion reflects on the findings of each of the studies here to consider how this thesis has answered it research questions and advanced knowledge through the exploring and design of multisensory interactions with 3D printed food.

11 Overall discussion

This thesis is comprised of 7 studies which together explore and design for multisensory interactions with 3D printed food. Starting with the 2 exploratory studies (Study 1,2), insights on technology, food and experience were generated that fed into the 4 design and co-design studies (Study 3, 4, 5, 6). Study 3 explored taste as a commonly shared experience in lab settings and Study 4, 5 and 6 moved towards designing for flavour as a personal experience in naturalistic studies. The final study 7 is a technology design and evaluation study of an app interface for designing flavour as a personal experience in naturalistic studies. Through combining Research through Design and material approaches the work in this thesis asks how experience with food *might be* if the experiential qualities of food are reimagined for new purposes. This discussion revisits the main findings and research questions in order to highlight the novel contributions of the work.

11.1 Findings of this thesis

11.1.1 User perceptions of technology for the 3D printing of food

Study 1 explored the attitudes of 3 different groups of potential early adopters of technology for the 3D printing of food (Gayler et al., 2018), exploring the technology aspect of this thesis. 50 participants were surveyed to assess food technology neophobia (Cox & Evans, 2008) and social representations for novel foods (Onwezen & Bartels, 2013). The study found lower food technology neophobia and higher adherence to technology in the sample compared to the validating populations, suggesting these groups were good candidates for early adopters. Participants' perceived risks focussed on the long-term health impacts of eating 3D printed food. Findings also indicated that experientially-led approaches would be most easily accepted, a key finding for Studies 3, 4 and 5 into emotional and memory focussed applications.

11.1.2 Taste-Emotion Mappings and Food Experience Design Strategies from the Perspective of Chefs and Food Design Practitioners

Study 2 worked towards food experiences beyond mundane dining, exploring the food and experience aspects of this thesis. It reported on interviews with 18 chefs and food designers to understand the validity of taste-emotion mappings in the design of ecologically valid experiences and approaches to designing experiences with food.

Sweet-positive and bitter-negative mappings were confirmed, and nuance was added especially with respect to intensity (Gayler & Sas, 2017). Sour, salty and umami were found to exhibit mappings differing from lab-based findings. Experience design approaches were also uncovered for sensory experiences, narrative and memory-based experiences, comfortable and uncomfortable experiences and how balance and contrast were utilised (Gayler et al., 2021a).

11.1.3 Taste Your Emotion : An Exploration of the Relationship between Taste and Emotional Experience for HCI

Study 3 drew on the insights from Study 2 and explored the potential of technologies for the 3D printing of food through an experimental approach to investigate the relationship between taste and emotional experience (Gayler et al., 2019a). For this, 4 interactions were designed to mediate between humans and computers via taste and to gain knowledge into the validity of taste-emotions mappings in interactive scenarios. Findings indicate that the taste-emotional valence mapping (sweet taste-positive emotion, bitter taste-negative emotion) extends beyond lab studies into real-life inspired scenarios, and that the taste-emotional arousal mapping in real-life inspired scenarios holds true for highest arousal emotions (intense taste-intense emotions). The findings led to three design implications for novel taste-based interfaces drawing on the identified mappings, the design of flavour-based interfaces, and the use of taste for evaluating user experience.

11.1.4 Material Food Probe: Personalized 3D Printed Flavours for Emotional Communication in Intimate Relationships

Study 4 introduced a novel *material food probe* design method to uncover opportunities for both design-with, and design-around food in the context of romantic relationships (Gayler et al., 2020). It reported on the design of personalized flavours for emotional expression and coregulation, highlighting how they drew from both remembered flavour experiences and new ones creatively generated. These flavours, and the experiences of engaging with them, were explored through a three-day exploratory study in couples' homes, where they became integrated into everyday intimacy rituals. This study combined *development work* with *action research* (Frayling, 1994), and was actively engaged in imagining in the real world (as a *Field* study (Koskinen et al., 2011)) how the 3D printing of food *could be* used for HCI. The findings open up design opportunities for novel food-based interactions via the further development of *material food probes* including bodily-actuated emotional regulation through food.

11.1.5 "It took me back 25 years in one bound": Self-Generated Flavour-based Cues for Self-defining Memories in Later Life

Having explored the design of personalised flavour cues for emotional experience, this study leveraged the olfactory aspect of flavour experience to design flavour-based memory cues (Gayler et al., 2021b). Study 5 recruited 12 older adults to take part in a three-stage study, drawing on methods from Study 4. Findings indicated that food-based memories in the study more strongly reflected the relational self, were more evenly spread across the life-time of participants, related more to positive emotions and were sensorially richer. Through the design process, patterns in how flavours were associated with non-food memories were uncovered, highlighting the dominance of proximal foods, but also reflecting a diversity of approaches. In the evaluation, flavour-based cues were found to generate a stronger feeling of travel back in time than compared to word cues alone and were associated with intense positive emotions and greater levels of gustatory and olfactory details. Effective cues were based upon on a strong match with the original experience, distinctiveness and positive emotional congruency.

11.1.6 The Design of a Multisensory Visual Probe Kit to Support Personalised Flavour Design

A key aspect of both Study 4 and 5 was the ability for individuals to participate in the design of bespoke flavour cues for emotional and memory-based interactions. Probes played an important part in this by sensitizing participants to their experience of food by equipping them with language and tools for questioning and expressing these experiences. Study 6 details the design and development of the probe kit through expert workshops with 8 HCI experts and interaction designers to deployment in Studies 4 and 5 and iterative development. These probes contribute to *methods for material explorations* (Fernaeus & Sundström, 2012). Each aspect of the development and iteration of the kit is outlined, and shared themes identified. These include the role of difficulty and challenge, the creation of new perspectives for users of food experiences and how participants were engaged in sense-making and narrative construction. The discussion reflected on the value of embodied design approaches for the creation of the kit, how challenge could be leveraged as a design consideration, the overcoming of mundanity in food experience and the value of these probes to wider multisensory HCI. The discussion finally proposed the concept of *flavour design worlds,* which draw on *taste worlds* (Bartoshuk, 1978) and *design worlds* (Schon, 1992) to detail the value of recognition and interpretation of individuals flavour worlds within the design of food and flavour-based HCI. Flavour design worlds represent a *method for communicating material properties* as part of material approaches to design (Fernaeus & Sundström, 2012).

11.1.7 The Design of a Mobile App for Capturing Multisensory Experience and Designing Personalized Flavour Cues

The final study addresses the challenges associated with scaling up of personalised flavour experiences both for research and commercial applications. Through three focus groups with a total of 12 participants initial wireframes were evaluated for *Flavour Designer,* an app that digitises the capture and design of multisensory flavour cues. Findings report on the app's three functionalities, principles for future multisensory experience capture and design applications and remaining research challenges.

Having summarised each of the studies' findings in this thesis, the next section returns to the research questions set-out in Chapter 1. It articulates what new knowledge has been generated through the research and design activities of this thesis. It highlights how new insights have been uncovered which extend prior work across the use of food to create novel experiences in HCI, the use of 3D printed food for multisensory interactions in HCI and the design methods necessary to support the exploration and design of such experiences and interactions.

11.2 Revisiting Thesis' Research Questions: Designing novel HCI experiences with food

RQ1 - How can food be used to create novel multisensory emotional and memory-based interactions in HCI?

This question aimed to identify and explore novel forms of food-based experience in HCI, extending prior work. The findings of this thesis indicate that food can be used in different ways to support emotional and memory-based applications. Firstly, emotion-based interactions are supported by taste through the approach taken in Study 3, i.e., using basic tastes to understand and express emotional content in interactions with computers. This further incorporated learnings on taste-emotion mappings from Study 2 i.e., that sweet and bitter tastes could be used for expressing positive and negative valence emotions in naturalistic settings. Moreover, it became clearer there was an opportunity to move towards multisensory flavour experiences with food to extend the potential of designing emotional interactions. Study 4 findings reports the design of personalised flavours for communication and coregulation of emotions between partners in romantic relationships (extending the expression and understanding of emotions in study 3). Having established a method for creating experiences through personalised flavours, Study 5 explored how this approach can be extended to investigate memory cues for older adults.

These findings build on prior work that so far has been focussed on design *around* food (Barden et al., 2012; Ferdous et al., 2016; Gross et al., 2011; Wei et al., 2011) or *with* food (Gayler et al., 2019a; Murer et al., 2013; Obrist, Comber, et al., 2014a; Vi, Ablart, et al., 2017), this thesis attempts to combine both approaches to design novel experiences. Through drawing on design with food experience from a broad range of perspectives and embracing personalised co-design approaches it is also better matched to tackle the challenges of working with subjective experiences of food and flavour. This question draws mostly on methodology related to *material research* (Frayling, 1994), and particularly on sensory experience (Fuchsberger et al., 2013) to support *material explorations* (Fernaeus & Sundström, 2012) that address the *details, wholeness, material and textures* (Wiberg, 2014) of food as a material for design. The *Lab* approaches (Koskinen et al., 2011) that were drawn upon to answer this question equally prioritise sensory experience with cognitive experience to *"more fully engage bodies"* (Koskinen et al., 2011) and create richer interactive experiences.

A key aim for this thesis was to uncover how food could be used as a material for novel experiences. To build on the richness of available food experience, the literature review (Chapter 2.1) and interviews with chefs and food designers (Chapter 5) addressed work on food integrating both academic exploration with applied knowledge and practice. From this a series of Ashby-inspired (Ashby & Cebon, 2011) charts were developed building on previous approaches to taste (Obrist, Comber, et al., 2014). These charts focus on the use of food for emotional, temporal, narrative, communicative and embodied experience (Chapter 11.4.2, Gayler et al., 2021a), for each chart, several design implications are identified. The emotional, communicative and narrative charts inform the design and exploration of emotion (Studies 3&4, 11.2.2) and memory-based interactions (Study 5, 11.2.3).

11.2.1 Emotional experiences with food

RQ 1.1 What is the relation between food and emotions and how it can be harnessed in HCI?

Informed from the emotional chart (Chapter 11.4.2), emotional experience with food was explored both as a universal experience (Studies 2&3) and a personalised one (Study 4), drawing on two different qualities of food: namely, taste for emotion mappings and flavour-based emotional associations. This supports the use of food as a multisensory design resource for affective interactions in HCI adding to prior work on food as data output or reward (Khot et al., 2017; Patekar & Dudeja, 2018; Yun Wang et al., 2016). Whilst taste-emotions mappings have been studied extensively in lab-settings (Bredie et al., 2014; Obrist, Comber, et al., 2014a; Park et al., 2011; Rousmans et al., 2000; Yamaguchi & Takahashi, 1984), this thesis added to the knowledge about their use in real-world contexts. Food designers and chefs supported sweet-positive and bitter-negative mappings, suggested mapping sour to surprise and also gave detail on how extreme low or high intensity of any taste was mapped to negative experience (Gayler & Sas, 2017). This was built upon by the application of taste to support understanding of emotionally related content by the user and the expression by users of emotional responses to stimuli (Gayler et al., 2019a). The validity of taste-emotion mappings in applied contexts is contrary to previous suggestions (Desmet & Schifferstein, 2008).

As well as taste, personalised co-designed flavours can also be used to support the expression and coregulation of emotions (Gayler et al., 2020). In Study 4, complex multisensory flavours were co-designed with, and used by couples, extending previous work on how food could be used as a communication medium which focussed on the visual experience (Khot et al., 2017; Patekar & Dudeja, 2018; Wei et al., 2014). This thesis proposed the potential for future emotional flavour design to combine both preferred and positively mapped flavours with functional qualities of some foods such as nervine herbs (Abascal & Yarnell, 2004) to increase their impact.

In summary, emotional experience through food was explored and designed for through taste and flavour qualities. Mappings with taste were effective and also reflected in some of the flavour designs. Very high and low intensities of taste and flavour were related to negative emotion. One consistent quality of emotional experience with food was the greater support for positive, rather than negative experiences. This in part may be due to the lack of appetite for users to consume foods that taste 'bad' or are associated with negative outcomes. This thesis proposes the use of multisensory experiences to account for this short-coming of taste experiences or make use of knowledge of individuals thresholds and vary intensities to make otherwise pleasant and readily accepted foods experienced as negative emotional content.

11.2.2 Memory experiences with food

RQ 1.2 What is the relation between food and memories and how it can be harnessed in HCI?

This thesis presents findings that suggest the use of food in the form of flavour cues to support memory recall. When used flavour-based cues resulted in recall which was more visceral, sensorially rich and supported stronger recollective retrieval compared to word cues alone. Importantly this showed that flavour-based cues functioned in a similar fashion to olfactive cues (Chu & Downes, 2002; Herz, 2004; Herz & Engen, 1996), they may in certain contexts be more accessible, more available or more suited to the processing knowledge of their users than other olfactory stimuli such as fragrances. However as with food it maybe be possible to consider other sources of olfactory stimuli such as flowers. Importantly, flavour-cues were found to cue non-food related memories as well as food-related ones. Meaning that they are not only useful for cueing memories in which food was already a significant part. This suggests that food may be a suitable material for any memory, regardless of its content, more broadly expanding the impact of food on memories. Food or flavour cues may be selected for the advantages in terms of dynamic recall and emotionality offered in comparison to visual and aural modalities (Dib et al., 2010; Frohlich & Murphy, 2000; Isaacs et al., 2013; Le et al., 2016; Sas, Davies, et al., 2020; Sas et al., 2013; Sas & Coman, 2016).

This thesis provides some guidance towards the design of most effective cues including the importance of the encoding-specificity principle (Tulving & Thomson, 1973), for which multisensory richness or creative cue construction were proposed as two approaches through which distinctiveness of cues could be achieved.

Answering the first research question allowed this thesis to identify opportunities for designing emotion and memory-based interactions with 3D printed food. These built on the potential of taste and flavour qualities of the food to support emotional experiences and flavour qualities to support memory-based experiences.

11.3 Leveraging 3D Printed food for multisensory HCI

RQ2 - How can 3D printed food be utilized in multisensory human-computer interactions?

This thesis now considers how the 3D printing of food as a technology can be used to deliver food experiences in HCI. The findings of this thesis support the use of 3D printing of food to support both interactions based around taste (Study 3) and flavour experiences (Study 4 and Study 5). Whilst Study 1 indicates that early adopters are most likely to be already engaged with 3D printing or technology in some way the success of systems with older adults (who typical are less familiar with technology) suggests potential for broader appeal if the right applications can be found. Study 1's findings support such applications as being experiential rather than functional, nutritional applications. Further, Study 4 explores how 3D printing of food may be adopted into the everyday routines and rituals around food. Study 4 reports on the use of the technology as part of focal intimacy practices, providing a meaningful application of 3D printing of food. Study 5 also discussed other applications such as recreational reminiscing or the use of flavour cues in therapeutic contexts which should be explored in future work.

Previously technology has been used to integrate flavour experience within interactions with computers, including electronic taste stimulation (Ranasinghe, Karunanayaka, Cheok, Fernando, Nii, & Gopalakrishnakone, 2011), pumping liquid flavour (Khot et al., 2015; Vi, Ablart, et al., 2017) and 3D printing solid foodstuffs (Khot et al., 2017; Wei et al., 2012). This thesis makes use of liquid 3D printing of food to create a range of interactions for emotion and memory-based experiences. The format of the printer supports a wide range of flavours and thus the design of personalised flavour experiences. This thesis also explores how printers are likely to be adopted and used within domestic environments by early adopters, finding that rather than nutritional or functional benefits (Kouzani et al., 2017) applications should focus on experiential benefit such as emotional and memory experiences that were studied. Both *Lab* and *Field* approaches (Koskinen et al., 2011) were key to supporting *development work* (Frayling, 1994) with technology for the 3D printing of food. In controlled settings, designed interactions with printed food could be used to understand emotion-based human-computer interactions, and in user's domestic environments, designed interactions could be created to understand how the technology interacted more widely with lifestyles habits and environments.

This thesis has detailed two approaches to how qualities of 3D printed food could be leveraged in HCI contexts. Firstly, Study 3 (Chapter 6, (Gayler et al., 2019a)) showed that tastants could be effectively created and used for HCI applications through 3D liquid printing. Secondly, a multisensorial flavour approach was taken in Study 4 (Chapter 7, (Gayler et al., 2020) and 5 (Chapter 8, (Gayler et al., 2021b)). These studies relied on 3D printed food to deliver designed taste and flavour experiences, moving beyond the appearance-led interactions previously explored (Khot et al., 2017). The 3D printing of food effectively recreated the personalised flavours as designed by participants in Study 4 and effectively supported olfactive memory cueing in Study 5. The same liquid 3D printing technology was used both for the tastant and flavour cue production, representing a range of applications, from unimodal and universal experiences to personalised multisensory ones.

11.3.1 Food-based HCI in everyday life

RQ 2.1 How could new interactions supported by 3D printed food be experienced and used in everyday life?

In the systematic literature review, two approaches to designing experiences with food were identified, those of *improving existing food practice* (Chapter 0) and those of *creating new food practice* (Chapter **Error! Reference source not found.**). This thesis provides an example of food practice extension with the detailing of the value of 3D printed flavour cues for focal intimacy practices. Importantly, the novel technology did not disrupt existing valuable practice but was able to integrate with and extend it. This was due in part to the nature of material food probes as an immediate way in which to offer a laboriously crafted gift. It supported lightweight snacking experiences loaded with experiential richness (Pradana & Buchanan, 2017), something also present in the flavour-based memory cues in Study 5 (Chapter 8, (Gayler et al., 2021b)). The format of the printed food led to consideration of the cues within recreational or therapeutic settings, where the ability for food to be delivered unsolicited could supporting the overcoming of social isolation or memory impairments that are associated with aging.

11.3.2 Users and contexts of use for 3D printed food

RQ 2.2 For what people and in what contexts is 3D printed food feasible to support user experiences?

This thesis identified the potential early adopters of 3D printed food as those who were tech-literate and previously aware of 3D printing or food technology (Gayler et al., 2018). The aversion of less tech-literate and older users was reflected in some scepticism about the technology by the older adults in Study 5 (Gayler et al., 2021b), however this did not have a significant impact on their experience of 3D printed food within the study context. One of the highlighted values of 3D printed technology in terms of personalisation was drawn upon successfully in Studies 4 and 5, not only about catering to the preferences of an individual but also being consciously crafted, deepening the value of personalisation as a result of DIY (Sas & Neustaedter, 2017). This personalised design was extended through Study 7 which explored how an app could support the design of personalised flavours.

Answering the second research question supports this thesis to deliver emotional and memory-based interactions for users that hold value for their everyday lives. It identifies users and contexts of use as well as providing design implications for the integration of the 3D printing of food into everyday rituals and specific HCI use cases such as expressing and understanding emotional content in interactions with computers or assisting users to recall memories in meaningful and rich ways.

11.4 How to design interactions with 3D printed food

RQ3 - What approaches can support the design of interactions with 3D printed food?

One of the main contributions of this thesis is the development of design processes that support the creation of personalised flavour cues for emotion and memory-based interactions. Study 4 and 5 detailed a co-design approach based on sensitizing and engaging users in the creation of their own personalised flavours for use in interactive contexts with others and for themselves. This co-design process relies on the sensory probes, whose design, development and evaluation are reported in Study 6. The probes provide one solution to the problem of engaging end users with the complexity and nuances of their felt experiences. To further advance the potential for the methods and insights from Study 4 and 5, Study 7 reports on an app supporting user to create personalised flavours. Taken together these methods support the further research with flavour-based interactions in HFI and hint at how such knowledge might be made available to wider audiences through the development and refinement of digital tools.

These methods are necessary for the advancement of work with food in HCI as it is an emerging field and there is little in the way of existing design tools. To date most work has focussed on expanding the design space through playful (Altarriba Bertran, Duval, et al., 2019) and speculative approaches (Markéta Dolejšová et al., 2020) rather than working with food in specific applications. There is more work beyond HCI in the design models for multisensory experience with products (Camere et al., 2015; Desmet & Schifferstein, 2008; Obrist & Velasco 2020 ; Schifferstein, 2011) but these approach experience as something that is universal and have not yet overcome the challenges of differences in perception between people. What is offered here are tools and approaches to designing personalised experiences that build on previous work to support applications of food in new interactive domains. Answering this question worked towards the creation of *"shared vocabularies"* and "*multifaceted understandings"* (Wiberg et al., 2013) both at the universal and individual level. Methods were designed with the intention of "*working back and forth between details and wholeness, materials and textures"* (Wiberg, 2014). What was created aims to further explore materials both for general knowledge and within the specific contexts of individuals interactive contexts. The tools also support the communication of material properties, and again this works both at the level of generalised principles (i.e., experience design charts) and at the level of unique users (i.e., co-design approach for couples and older adults).

11.4.1 Design processes for food, 3D printing of food and the consumption of food

3.1 What design processes mediate between food (material), 3D printing of food (technology) and the use and consumption of food (human practice)?

As of yet there are very few methods and tools to support the design and co-design of experiences and interactions with food in HCI. One opportunity for working with 3D printed food identified by early adopters was the potential for personalisation. This thesis addressed this by exploring how co-design approaches could support individuals to successfully craft personalised flavours for specific interactive purposes. This co-design was underpinned through the construction of *flavour design worlds* aided by the multisensory visual probe kit in Study 6 (Chapter 9, (Gayler et al., 2021d)). The probe kit aimed to sensitize users to the breadth of food experience as well as equipping them with the language to effectively participate in the co-design. The probe kit supported users to better appreciate food experience through disrupting and destabilising (Wilde et al., 2017) existing experience in the user's normal environment. Through these probes the value of challenge was detailed, as well as the need for varied approaches to balance the disruption with the support for user's confidence in expressing their own food experiences.

Cultural probes also informed the *material food probes* used in Study 4. These probes drew from *technology probes* (Hutchinson et al., 2003) and *material probes* (Jung & Stolterman, 2011) to create personalized flavours that could be deployed with a 3D printer for food to understand how they were adopted and used within user's home environments. Material food probes supported the exploration of how different flavour qualities of food could be designed with and then used within user's lives. Through the co-design process the probes were embedded with meaning but the usage was open to user's interpretation and allowed the uncovering of how they could fit with focal intimacy practices (Borgmann, 1987), inspiring future design work.

The co-design of personalised experiences has already been indicated as a factor supporting adoption and key to the functioning of flavour-based experiences. Both Study 4 and 5 provide examples of how users could make meaning through different flavours, creatively constructing flavours to represent events or abstract ideas, or associating foods via preference or experience. This process also showed how multisensory experiences could be designed through the deconstruction and reassembling of the sensory experience, building on previous approaches (De Giorgi et al., 2011; Merter, 2017; Schifferstein, 2011). Further this process has been adapted into a proposed app design (Study 7, Chapter 10) to support scaling of this process so that individuals can undertake it without the support of experts. This supports the wider adoption of the process for a whole range of digital and non-digital food-based interactions.

11.4.2 The Design Space for Food in HCI

RQ 3.2 What design principles can support the design space for such novel interactions?

This section aims to map the HCI design space for food, and to indicate the gaps that open up future design opportunities. One of the key attributes of experiences afforded by foods are their complexity. This provides a challenge in terms of mapping these attributes in a coherent manner such that future designers can feasibly make use of them. This research has drawn out properties of experience which are particular to the experience of foods such as the temporal format, the embodied experience and the connection with emotion. In order to document the findings, a model from materials selection and engineering has been adopted, namely that of Ashby diagrams (Ashby & Cebon, 2011). The Ashby diagrams are tools used for material selection through presenting many material qualities simultaneously. Previously they have informed illustrative mapping approaches for aesthetic (Ayala-Garcia & Rognoli, 2017) and sensorial (Rognoli, 2010) qualities of materials. The charts also draw upon the visualisation of taste experiences that was pioneered by Obrist (Obrist, Comber, et al., 2014), which suggests the temporal, affective and embodied aspects of taste experience. These classifications are extended both through addition of communicative and narrative experience but also by application to wider food and flavour experience. The charts presented here compare two qualities along two axes, however unlike the Ashby diagrams these charts are not quantitative but illustrative, not suggesting an optimum compromise but uncovering possibilities for experience. Below are the created charts for emotional, temporal, narrative, communicative and embodied experience, these are not exhaustive, but they serve to account for the outcomes of the knowledge so far on the use of food for experience. The themes for each chart were derived by card sorting the experience fragments identified in the systematic literature review (i.e., *Sharing* *food* and *Dining contexts*) and findings from Study 2 (i.e., *Nostalgia cued by childhood foods* and *Anticipation*). Insights or papers can appear across multiple charts as they connect to more than a single type of experience.

The themes generated represent a new perspective on designing with food in HCI by focusing on the types of experience that are made available. Through working with food as a resource for design in this way it highlights the different interactions made possible. In drawing out the potential design space for each theme it not only emphasizes the potential for building on existing knowledge of food but can reflect on gaps in the design space (for example the current lack of mundane, low arousal food experiences in the *emotional* chart). In taking this approach, the aim is to provide not only an overview of current work in the field as previously conducted (Bertran et al., 2018) but extend insights towards design knowledge to support the wider application and engagement with food in HCI. Similarly there have been attempts to outline the range of experiential possibilities for taste (Obrist, Comber, et al., 2014) or colour (Velasco, Michel, et al., 2016) which are limited by their unimodality. The charts presented here incorporate a range of sensory insights into food experience with social and cultural factors, by doing this it provides a fuller picture into food as a resource for design. Whilst themes such as emotional and narrative experience have been the explicit focus of some HCI research (Bruijnes et al., 2016b; Gayler et al., 2019a; Gayler & Sas, 2017a) what is presented here brings together literature and insights from interviews to more fully appreciate the scope of emotional or narrative experience that can be designed for via food. Other themes such as communicative, embodied and temporal experience are new framings of how food can be used within HCI, again aspects of these forms experience are present in current work but as of, yet it has not been the explicit focus of work.

11.4.2.1 Chart Construction and Anatomy

The charts in the following subsections are a form of organizing the insights collected in the systematic literature review and interviews. Each chart is supported by a brief description of its structure, outlining the axes chosen and how they frame experience for that chart. Then there is discussion of the content of the chart, connecting together the range of insights and considering how they can inform design. Within each chart are blobs representing experience fragments or types of experience within the overall theme. Each of these fragments is colour-coded to relate to a key which describes the role of the food in supporting such a form of experience. As such these charts work to present a range of possible experience and connect it with the role food plays in supporting that experience. To further support referencing and further learning each experience fragment is annotated with references for where further detail can be found. These charts have been designed to support both quick browsing as well as a sustained particular interest in a single area.

The charts are designed to be illustrative of the connection between food, experience, and technology. They are intended as visual references for future design work, such that as someone intending to create an emotional experience, the way in which food could support that can be quickly seen and the particular qualities of food which will support the designer's aims identified. In this way the design is inspired by visual mappings of taste (Obrist et al., 2014) and Ashby diagrams (Ashby & Cebon, 2011). In particular the way the charts are intended to be used draws on the process of materials selection that Ashby diagrams support, specifically the identification of the 'right' material for the design problem based upon a mapping of that materials properties. The qualities of food can appear across multiple charts, for example taste being used both for emotion (through mappings) and temporal experiences (sour palate cleansers in the flow of meal). The charts intended to map as much as possible of the knowledge of design with food, including the multiple ways in which one quality can be put to use.

The charts were constructed using the following process.

1. The chart themes were identified based on the systematic literature review
2. The fragments were generated under each chart theme
3. The qualities on each chart axis were decided to best illustrate the range of ways in which food could support a specific experience within that theme.

11.4.2.2 The fragments were placed in relation to the axes, illustrative of their relationship. The area of each blob represents the range of experience relative to the axis. A smaller blob has smaller range of

experience it can supports and vice versa.Proposed Chart Use in Design

These charts are proposed as design tools and such have been made available in formats to support designers' ideation and co-design activities while designing for novel experiences with food. They are available as printouts, each chart is made available to be printed twice on one sheet of paper, once with the experience fragments, once without. This allows designers to draw onto the provided axes new technologies or to explore the gaps in these design spaces and their generative quality to inspire more radical designs. For each chart there are a series of sensitizing questions provided that help shape and inspire designers. Files can be downloaded from www.fooddesign.co.uk/charts.

11.4.2.3 Emotional Experience

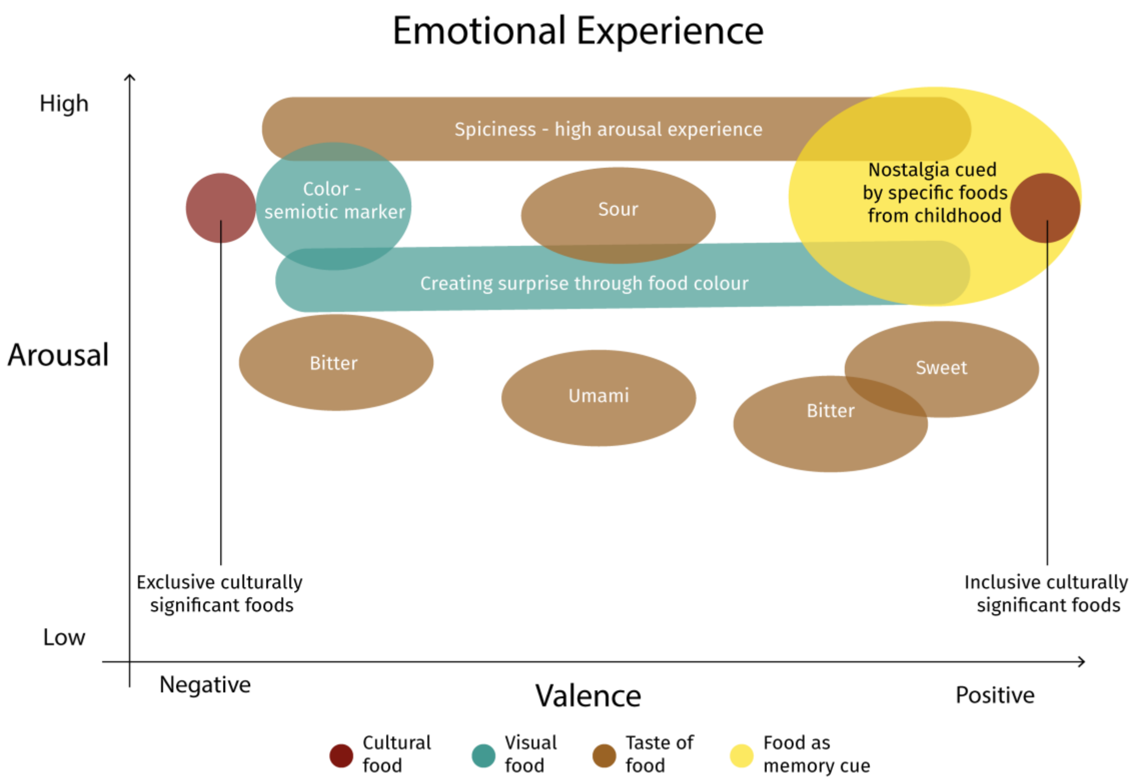


Figure 47 Chart of Emotional Experience

11.4.2.3.1 Chart Design

Valence and arousal were chosen as the axes for this chart, following on from the work of Russell's circumplex model (Russell, 2003). Through this chart, the aim is to promote the understanding of how food can be used in the design of specific emotional experience. Negative and low arousal experience is in the bottom left of the chart, high arousal and positive valence in the top right. This extends the prior work on affective experience of tastes as previously mapped (Obrist et al., 2014a).

11.4.2.3.2 Emotional Design Insights

All of the emotional food experience fragments collected from interviews represent mid-to-high arousal emotions, reflecting previous work with chefs on taste-emotion mappings in applied contexts (Gayler & Sas, 2017a). *Taste of food* provides the most flexible method of eliciting differing valence and arousal with food. *Visual food* and *Cultural food* offer a range of high arousal emotions dependent on context and the user experiencing the food. *Food as a memory cue* is shown to offer strong positive experiences, often connected to personal, childhood memories.

11.4.2.3.2.1 Extending taste-emotion mappings

In the literature review a set of papers reported emotional experience (Gayler & Sas, 2017a; Satterfield et al., 2008; Velasco, Michel, et al., 2016), which Study 2 extended in specific scenarios of use. While taste-emotion mappings have been much explored in psychological research, most often sweet and bitter tastes (Bredie et al., 2014), in this thesis were found more nuanced understandings of these mappings based on real-life use. In the chart (Figure 47) there are two bitter taste areas, one as negative valence as expected following the psychology literature, and interestingly, one as positive. This positive experience of bitter derives from a feeling of maturity gained by overcoming this initially negative response. This creates the opportunity for an acquired taste over a lifetime (Gayler & Sas, 2017a), opening interesting avenues for evolving interaction dynamics over repeated interactions. A comparable, reflexive experience was reported for sour, having an initial repulsion that gives way to pleasure over a few moments (as seen in (Obrist et al., 2014a)). Similarly, it was found that sour was associated with positive memories from childhood, recapturing that experience when tasted again as an adult (see 5.3.1). Emotion is one of the most enticing ways in which food can pave the way for user experience design. The specific role of personal or culturally meaningful foods to elicit emotions only adds to the potential.

11.4.2.3.2.2 High arousal and positive valence

There can be seen two similar qualities on the map in *spiciness* and *surprise-colour*, both are relatively high arousal experiences with differing valence. In the case of spiciness, personal preference for spicy foods as well as level of spiciness dictates the quality of experience. Designers can therefore benchmark for individuals and create positive or negative experience by staying within or transgressing thresholds. Designing for surprise through food colour (Velasco, Michel, et al., 2016) can again afford both positive and negative experience through shaping the anticipation and actual tastes. The negative experience designed through colour was more explicitly described in 5.3.1, in which negative emotions could be conveyed through either an unexpected or meaningful choice of colour.

11.4.2.3.2.3 Low arousal and negative valence food experiences

Overall, there is little in the way of negative valence experience of food, as research into the emotional experience with food in everyday life suggests a bias towards positive valence experiences with food (Desmet & Schifferstein, 2008) , yet in (Wei et al., 2012) there was a subtle use of the affective communication for remote co-dining, this possibility was speculated on further in *Food Internet Communication* (Abeyrathne et al., 2010). Low arousal is not well documented for food experiences research (Gayler & Sas, 2017; Q. J. Wang et al., 2016). Emotional experience could be combined with communication (where food mediates the expression and comprehension of emotions between people (Gayler et al., 2019a)), or self-influence (through the leveraging of the emotional impact of food to cheer up or calm down (Gayler et al., 2019a)). As suggested by the work on emotions and eating (Desmet & Schifferstein, 2008) there remains a question of how eaters may wish to engage with food they know, or believe, will elicit negative experiences. As discussed, with the acquired taste for bitter, there is potential for a complex experience to evolve, and to change the relationship between eater and a particular food. Alternatively, negative food experiences may provide a way of designing tools for reflection or catharsis through supporting re-experiencing and re-embodying negative emotions as part of processing them (Luria et al., 2019).

11.4.2.3.3 Sensitizing Questions

- If specific emotional experience is to be created, is there an existing taste mapping?

- If there is no taste mapping, can the experience be supported through combing multiple multisensory stimuli?
- How often will the mappings be used? Will the mapping change meaning over time or with repeated interactions?
- Are the acceptability threshold of tastes or spiciness for the user(s) known? Can they be used to create a range of positive and negative experience?

11.4.2.4 Temporal Experience

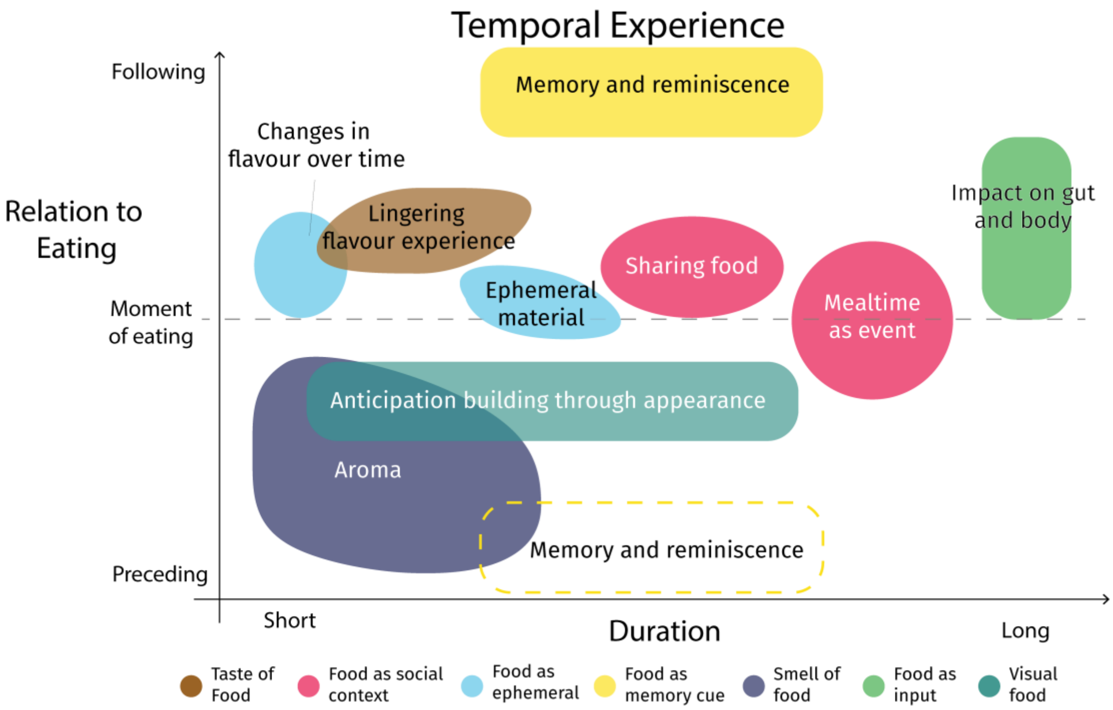


Figure 48 Chart of Temporal Experience

11.4.2.4.1 Chart Design

This temporal chart (Figure 48) is arranged around the moment of eating as midpoint on the y-axis. Experiences that occur before a food is eaten are shown below and experiences following a food been eaten are shown above. On the x-axis, the duration is arranged with shorter term experiences to the left and longer-term experiences to the right. These frames measure temporal experience in a relative (relation to moment of eating) and absolute manner (duration), supporting designers to make choices about when and for how long food experience can be useful in shaping an overall interaction.

Again, these draw on prior work on temporal experience of taste to inform the approach (Obrist, Comber, et al., 2014).

11.4.2.4.2 Temporal Design Insights

A large percentage of the experiences here are focused on the central horizontal band that marks the moment of eating. Experience fragments here range across both long and short duration experiences and involving a range of biological and chemical transformations (*Food as ephemeral material, Taste of food* and *Food as Input*) to *Food as social context*. Highly prominent, prior to eating, is the utilization of the *Smell of food* and *Visual food*, both multisensory cues for the eating experience itself. *Food as memory cues* provides an experience after the moment of eating but also connects to previous food experiences, creating a common thread between repeated experiences over time.

11.4.2.4.2.1 Manipulating duration of food experiences

Food is often associated with shorter temporal experiences (Döring et al., 2013), and perhaps the food experience most representative of them is *lingering tastes* which can be used in several ways. Firstly, the material qualities of food, with more viscous liquids or stickier solids staying longer in the mouth. One can imagine how this could create a direct experience of temporal metadata, such as recentness of update, or duration of a video file. Secondly, flavours are experienced over a short period of time and lend themselves to short term variety in experience, for example, varying emotional communication within an interaction context (Gayler & Sas, 2017). Finally, duration manipulation can be inspired through the case of *memory and reminiscence*, the calling back to previous experiences in the moment of eating can be seen in a recent work on 3D printed food use in romantic relationships (Gayler et al., 2020).

11.4.2.4.2.2 Social influence on temporal experience

The moments when someone decides to eat, provides a space for forms of social interaction. Perhaps the most interesting temporal explorations reported in relation to this arise from the KIZUNA system (Nawahdah & Inoue, 2013) and the balancing table (Mitchell et al., 2015), both in different ways connected the behaviours of individuals, creating an impact on the eating speed of the diners. For designers, this poses an extra route to curating temporal food experience, through influence of social presence. A food experience can be made faster through a dining partner eating quickly, and eating slowly for a longer experience. Little explored so far is the potential for avatars or perhaps music to curate food experiences, and particularly slower ones such as those involved in mindful eating.

11.4.2.4.2.3 Diet as an experience space

The emergence of citizen scientists hacking their diet (Dolejšová & Kera, 2016, 2017) has focused on the outcomes of the metabolization and digestion of food, in particular they directly experience the outcomes of their inputs as part of an experimental practice. In this way foods are almost treated like drugs (particularly in the case of soylent) in that the moment of consumption is almost a non-experience but the priority is the impact and effect of food once it is digested. Promoting healthy eating can often rely on the deferment of gratification in the moment, for a healthy body in the future, and the tension between this present experience and future experience requires careful consideration from designers.

11.4.2.4.1 Sensitizing Questions

- Is a temporally specific experience to be created? Which qualities of food support the precision or time period required?
- Can the temporal experience be manipulated through environmental stimuli or interactions with other humans or human-like agents?
- Are longer or repeated experiences being designed? Can design influence how the food consumed will impact on the body, shaping long term experience and potentially having knock-on effects?

11.4.2.5 Narrative Experience

11.4.2.5.1 Chart Design

To describe narrative experience, the social quality of the narrative is compared with the duration of the experience (Figure 49). This chart considers how food or the contexts around it could be designed to achieve these different individual or shared experiences. It also aims to understand how experiences that diverged from an episodic meal structure could be achieved and how to create longer terms experiences that extend beyond typical 'short-term' food experiences (Döring et al., 2013).

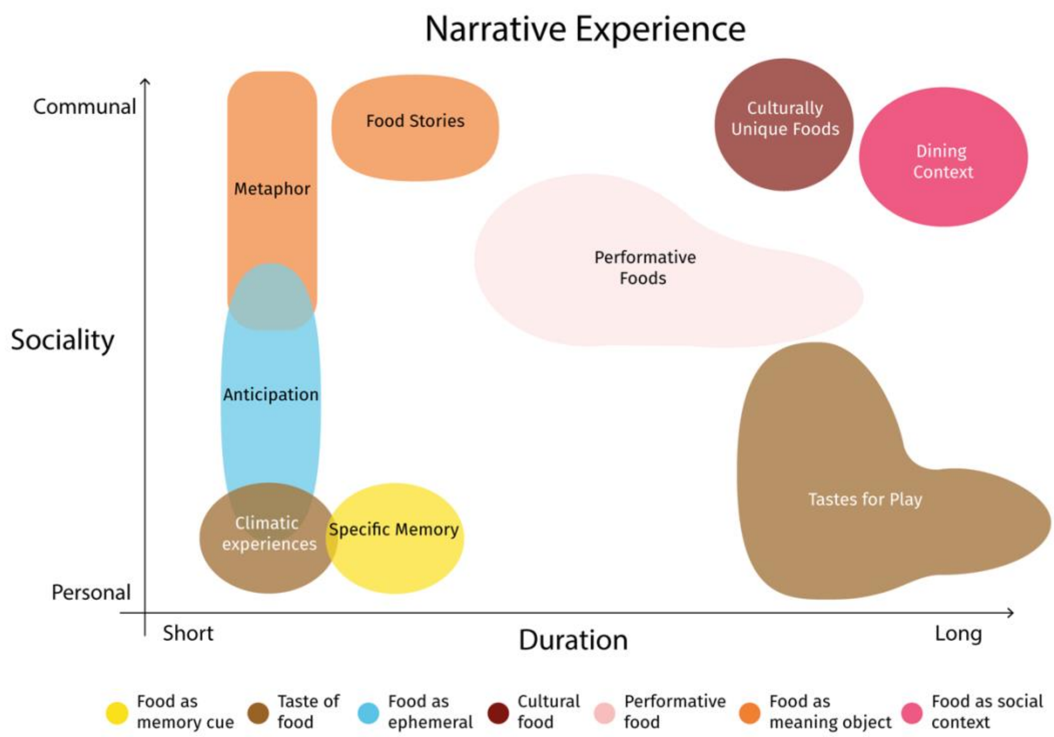


Figure 49 Chart of Narrative Experience

11.4.2.5.2 Narrative Design Insights

In the narrative chart (Figure 49) there are a cluster of internal experiences that are short and personal, related to the inward sensation of eating (*Taste of food, Food as ephemeral, Food as memory cue)* whilst more communal short experiences come from *Food as a meaning object*. *Taste of food* was also supportive of longer, personal experiences through play. Communal, mid- and long-term experiences arise from *Performative food* and more contextual perspectives of *Cultural food* and *Food as social context.*

11.4.2.5.2.1 Crafting food stories that connect

The sharing of food was harnessed to support the sharing of stories. *StreetSauce* (Dolejšová & Lišková, 2015) embedded the narrative of marginalized women in a sharing context, leveraging the sharing of food to encourage the sharing of personal stories. What it lacked was perhaps an attention to the metaphorical potential of food (as the recipes were not designed to have consistent meaning). In future work, designers could use metaphors for food's colour, form, taste and context, which are likely to be most effective when designed with holistically but also as a space in which counterpoints can be found. There is potential to learn from religious rituals which use food as parts of historical retelling (e.g., unleavened bread in the Jewish faith) to create full narratives which use food as bodily connection to a narrative, kept alive through repeated sharing and engaging with the food.

11.4.2.5.2.2 Responsive animated food for narrative experience

Animated foodstuffs (foods that are designed to move through space) are only related to one of the reported studies (Vi, Marzo, et al., 2017), so their potential requires further exploration. Within narrative, the ability for food to become responsive to users' interaction is particularly intriguing. If food was able to run from a grasping hand or to flock together with other foodstuffs it is able to express some forms of change between interactions. One can imagine a system for tuning a guitar in which a piece of food transforms according to the frequency of a string being plucked. It could begin as an out of tune, spiky blob and slowly smooth and round to a perfect circle which can be picked up eaten alongside the exact 'sweet' tone.

11.4.2.5.1 Sensitizing Questions

- What qualities can be drawn upon that are meaningful to the user(s)? Can these meanings be layered to reinforce the impact or juxtaposed to create complex experiences?
- Can the food be manipulated, or the users manipulate the food so that its movement towards the body and mouth becomes meaningful and even create a sense of character for the food?

11.4.2.6 Communicative Experience

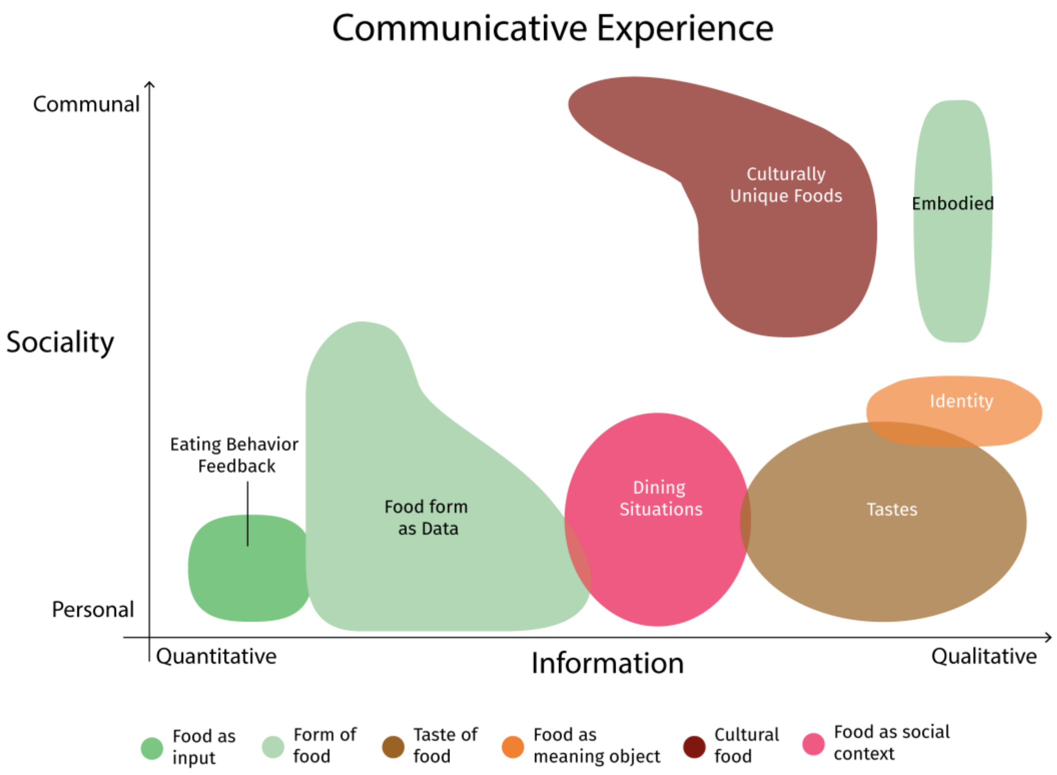


Figure 50 Chart of Communicative Experience

11.4.2.6.1 Chart Design

Here the y-axis shows the sociality of the experience from personal to communal. The x-axis shows the form of information communicated from quantitative to qualitative. The intention is to support the selection of the optimal format for the delivery of message based on the information content and its audience.

11.4.2.6.2 Communicative Design Insights

The above chart (Figure 50) explores food as a medium for communication. Personal and quantitative information can be communicated via *Food as input* and *Form of food* (in this case as data output). More qualitative experiences arise from *food as social context* and *cultural food*. *Form of food* also plays a role in communal, qualitative experiences through embodied experience. *Taste of food* and *Food as meaning object* offer personal, qualitative experiences. One noticeable gap is for communal-quantitative experiences.

11.4.2.6.2.1 New relations between food and data

So far, the connection between data and food has remained at the level of form, the other qualities that can be manipulated (such as taste) could and should be considered as a way of creating a greater impact for the data communicated. Food is a complex material to work with and each time it is experienced, all the varying qualities it holds are communicated. For example, in *Edipulse* (Khot et al., 2017) all messages are printed in chocolate, a congratulatory prize if you reach your exercise goal, but what if it communicates you have missed your target, the chocolate seems incongruous in this setting, perhaps a bitter taste, or a 'healthier' foodstuff should be used instead.

11.4.2.6.2.2 Personalization amongst shared experiences

The fact that *Culturally unique foods* allow a selective experience elicitation through the same medium (some people have one reaction, some other people have a different, opposite reaction), offers an intriguing way to curate experiences. These foods afford for specific communities to have shared experiences in a crowd, through their shared preference setting them apart from the rest, who dislike or are indifferent to the experience. Affective communication can be supported through personalized flavours, the mappings between tastes and emotion have some shared connections but these can be tailored more to reflect individual experience and in doing so their design and use can help reinforce their meanings, for example when used between couples in romantic relationships (Gayler et al., 2020).

11.4.2.6.2.3 Food as a tool for empathy

An intriguing additional layer to the above uses occurs when considering personal preferences or shared experiences, which can be expressed through the delivery of tailored taste experiences. This can extend the idea of *identity* construction and integration described in *Foodmunity* (Gross et al., 2011). Considering the context of a romantic relationship, if someone offers some food to their partner to express their feelings, the act of that then being consumed by their partner is poetic. The taking and eating of that food (representing the other's feelings) is an acting-out of the idea of empathy between the two people as one takes the other's feelings into their body.

11.4.2.6.1 Sensitizing Questions

- How can relationships between data and food extend beyond visual representations? How can this data become experiential for the user?
- How can personally meaningful and relevant experiences be created within group situations? Can taste preferences or culturally-specific foods be used to support this?
- How can food be used to build understanding between people? Can the symbolism of food or the rituals and contexts of sharing food be used?

11.4.2.7 Embodied Experience

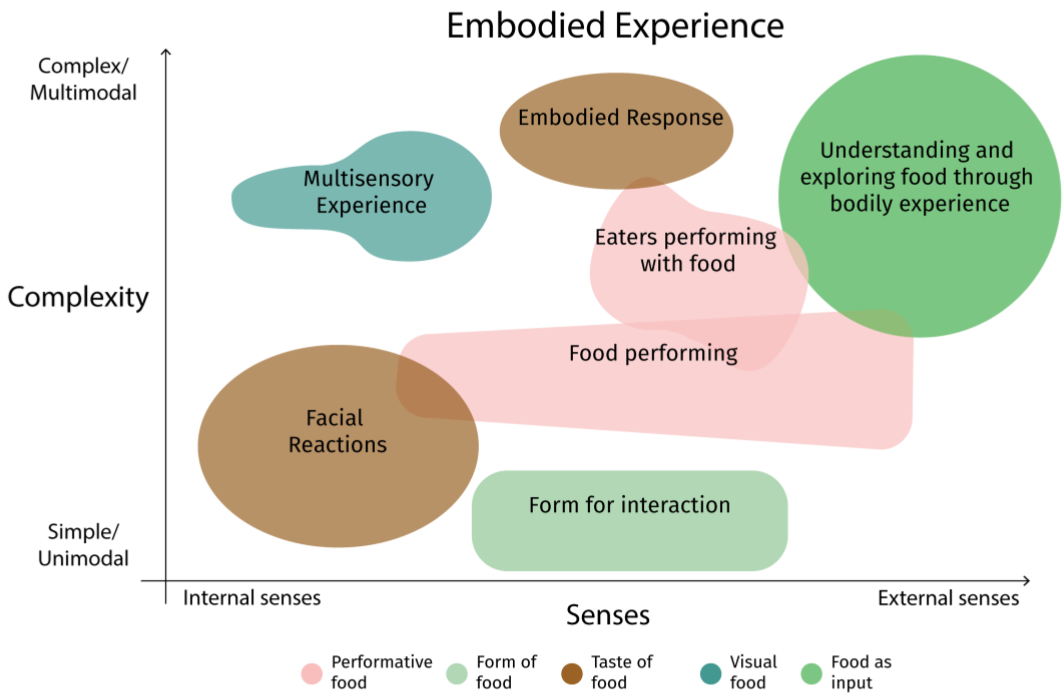


Figure 51 Chart of Embodied Experience

11.4.2.7.1 Chart Design

Sensory complexity is shown on the vertical axis, running from simple, unimodal experience at the bottom to complex, multimodal experience at the top. The horizontal axis has a similar scalar quality in relation to bodily experience, with focused localized experiences to the left and whole body and whole system experiences to the right. These embodied experiences add to taste-based ones previously identified (Obrist, Comber, et al., 2014).

11.4.2.7.2 Embodied Design Insights

This chart (Figure 51) shows a general trend of more whole-body experiences arising from more complex, multimodal stimuli. *Visual food* indicates one digression from this trend, offering a more localized yet complex experience and *Form of food* a simple method for more bodily engagement. *Taste of food* localized through facial reactions, but the later embodied response is more complex. *Performative foods* engage more of the senses and more of the body and *Food as input* allows access to the whole of the body through impacts on multiple sensory pathways.

11.4.2.7.2.1 Physical structure and physical interactions

Food as place making for social interaction has been a key tenet of early HCI research on food (Gross et al., 2011; Mitchell et al., 2015; Nawahdah & Inoue, 2013; Wei et al., 2012). In thinking about movement and food, this has been extended through examples of food for interaction. The structure of the food can interact with the mouth (e.g., sharp foods that may cause some degree of lasting pain in the mouth), similarly trigeminal sensation maybe used (through spicy food) to create a lingering experience. At the point the experience is to be ended, a 'palate cleanser' may be used, such as citrus to cut through umami, or cold foodstuff to counter a hot mouth. The involvement of robots in feeding for disability (Jiménez Villarreal & Ljungblad, 2011) are designed to support a move towards an already established method for eating but could be used to imagine new forms of bodily interaction and consumption. The ability of the feeding machine to become an agent within gaming, assistance or caring capacities should not only consider the functionality but also the ability of food to provide epicurean pleasure.

11.4.2.7.2.2 Mouth as space for HCI

The mouth is an obvious site for exploring the relation between food and our bodies. In the interviews, participants cited the reactionary effects of certain tastes as part of the experiences they try to design, from lip-puckering sour to the burning sensation of spice. The literature review uncovered work exploring the design of food affording for different experiences (Burbidge, 2012). The bodily experience localized to the mouth is mostly centred around taste, trigeminal sensation and touch. An opportunity to extend the mouth-based interaction to other parts of the food can be seen in the collection of foodstuffs that transform or animate as part of a performative action before they are consumed.

11.4.2.7.2.3 Body as a space for HCI

The embodied experience of food consumption sets it apart as an interactive medium. Whilst haptics allows designers to create technologies responsive to the body, food allows us to consider both surface sensations but also to create sensations within the body itself. The *digestion and metabolization* section gives insights into how food performs here. In 5.3.1 there was reporting on the influence of tastes and particular substances on eater's emotions. This perhaps can lead to the consideration of which tastes grab attention (as has been explored for smells (Dmitrenko et al., 2018)), or how substances within food alter the perception and mood of an eater, thus shaping interactions that follow (5.3.2 and 5.3.3). In this sense, food is an opportunity to open up the insides of the body as sites for interaction but also as a tool for learning about how we might design devices that enter into the body. Of course, internal body devices already exist, examples being pacemakers and digestible drugs, but the experience of such invasive devices, and the interactive opportunities they could offer have been little explored. Food however can be a promising first step to explore internal body interactions.

11.4.2.7.1 Sensitizing Questions

- How can the physical structure of the food be leveraged to embodied interactions between the food and user?
- How can the mouth be made use of as a space for experience design?
- How can the body be made use of as a space for experience design?

11.5 Summary of Chapter

This discussion has reviewed the main finding from 7 studies which report on the exploration and design of multisensory interactions with 3D printed food. The findings contribute to new understandings of how food can be used to design experiences in HCI, how 3D printed food can be leveraged as a technology to this same end, and detailed methods to support designers and researchers to further work with food in the future.

The key contributions of this thesis are the design of novel personalised flavour cues as part of emotion and memory-based interactions with 3D printed food and the development of design and co-design strategies that support personalised flavour design with non-experts.

Below, the wider contributions are summarised:

- Identified experiential use of technology most readily accepted and that tech-literate audiences are most likely to adopt 3D printed food.
- Expanded taste-emotion mappings from those known in lab settings and highlighted their influence in real-world contexts.
- Explored the role for taste in communicating positive and negative information, identifying use in emotionally charged contexts as most suitable.
- Designed prototype experiences with 3D printed food as part of interactions with computers.
- Uncovered the value of positive emotion associated flavours for coregulation.
- Developed a prototype experience of 3D printed food to support emotional communication between partners.
- Developed material food probes that offer immediate tokens of affection that are laboriously crafted and described their value for focal intimacy practices.
- Identified both food and non-food memories as suitable for food cueing, with positive emotional memories as most suitable.
- Identified common associations between non-food memories and chosen flavour cues and that reproduced flavours were most common as cues for memories.
- Created flavour cues that supported emotional and visceral memory recall experiences.
- Created a design approach for working with memories and flavours with older adults
- Created and iterated a design tool to support the sensitizing of participants in multisensory design activities.
- Designed wireframes for an app that supports the capture, reproduction and creative conception of flavour cues for memory.
- Developed charts to identify the qualities of food experiences and support the design of novel experiences through design implications and sensitizing questions for emotional, temporal, communicative, embodied and narrative experiences with food.

Answering this third and final research question allows the thesis to provide tools and processes that can be adopted for future work. The charts both document existing work to connect future designers with existing approaches as well as highlight opportunities for exploration of new ways in which food might be used to create enjoyable or useful interactions with technology. This thesis explores two such opportunities in relation to emotion and memory-based interactions. It also presents methods that can support the codesign of personalised flavours for use in such interactive contexts. These aim to overcome some of the challenges of work with personal experiences by engaging each individual in a standardized process to sensitize them towards and then create within their own flavour design worlds.

12 Conclusion

12.1 Limitations

12.1.1 Longitudinal studies with 3D printed food

This thesis reports on one deployment of 3D printed food in users' homes. Whilst this allowed the outlining of some details about how it was adopted into lifestyles and existing food practice; it was not possible to discern the impact novelty had on driving use and how users may have truly adopted and adapted the technology over time. There are two challenges to conducting such a longitudinal study: the production of foodstuff and the maintenance of the printing device. Firstly, the foodstuff used with the nūfood printing needs to prepared fresh. To support further developments, either users must be able to prepare food for printing themselves or suitable preservatives used in the preparation to allow them to be kept for longer periods of time. Secondly, we used the nūfood printer in this is still a prototype and not yet on the market, meaning reliability was a problem for longer deployments. Further technological advances are needed to ensure successful research in longitudinal studies.

12.1.2 Sustainability of 3D printed food

Current climate and environment crises are deeply linked to the impacts of food systems across the globe (Vermeulen et al., 2012). The 3D printing of food may offer some benefits, such as reducing food waste by using non-prime fruits and vegetables in its mixes, adding value to them through the printing process. However before wider use there are considerations to be made about the levels of energy and water are needed for the 3D printing of food. This thesis proposes the use of small samples for experiential purposes, rather than the larger quantities needed for nutritional purposes. Care should be taken to consider whether growth in the use of food to support interactions with computers does not drive higher additional consumption but instead replaces some current eating habits with more meaningful and mindful ones. There is reason to believe this is possible, as was seen with the integration of 3D printed food into focal intimacy practices around dinner, where the food acted as a form of desert or appetiser.

12.1.3 Idiosyncratic vs Universal experiences with food

One key feature of the research reflected in this thesis is that it moved from design explorations with universal taste-emotion mappings to personal flavour cues. This move was undertaken based on the decision that it could result in the richer design outcomes, that could engage with a wider range of interactive contexts, i.e., expanding emotional expression and understanding to emotional communication and coregulation as well as supporting memory recall. Whilst this offers a suitable direction for exploration it had associated challenges, such as the need to develop ways of working with non-expert users as co-designer partners in creating and crafting personalised flavour cues or the expert knowledge needed to craft cues through preparation and cooking practices that were required to create the specific flavours that were described. Despite the development of the tools in this thesis personalised flavours require a degree of know-how to produce the flavour cues derived from food processing and food experience design.

12.2 Future work

12.2.1 Flavour-based memory cues for therapeutic uses

As suggested in study 5, there is potential for food to offer a valuable tool in combatting memory impairments associated with aging. Not only has food be associated with the functions of olfactive cueing but conscious dietary design has been shown to deliver wider benefits to older adults in studies on nursing and gerontology (Ingrid & Moene, 2016).

12.2.2 Temporal, narrative and embodied HCI with food

In the experience design charts are outlined many opportunities for design which were not possible to cover within the scope of this thesis. In particular the opportunity for experiences shaped through the temporal, narrative and embodied qualities are worthy of further research.

12.3 Thesis Conclusion

This thesis reports on 7 studies and a systematic literature review that explores and designs multisensory interactions with 3D printed food. Through interviews with chefs, food designers and potential early adopters, the potential for the design of interactions with 3D printed food is uncovered. Studies then explore the use of 3D printed food in interactive scenarios both in the lab and in user's homes for emotion and memory-based applications. A novel co-design approach is presented for the creation of personalised flavour cues, involving the use of a bespoke probe kit and resulting in a proposed design for an app to digitise the process as part of scaling up this activity. The discussion highlights the novelty of this work in designing effective interactions based on taste-emotion mappings, supporting the creation of personally meaningful flavour cues for emotional expression and coregulation in couples and the design of flavour cues to support memory recall that is more visceral and emotive than compared to word-cue recall. Through this work several new tools and design approaches are described supporting both the increased exploration of food in HCI and multisensory experiences more broadly.

13 Personal Reflections on Thesis Research

Following my viva voce in which this thesis was examined I was encouraged by examiners to provide a section on my personal reflections on working on this thesis. I hope this may add some perspective to what it was like to conduct and write about the research in this thesis.

I have found food to an amazingly interesting yet tricky subject of research, my work started with a close examination of the sensory experience of food, but it was apparent to me that I could not do the research I wanted to by keeping a laser focus on this particular aspect of food experience, and ignoring the wider potential for food. In part this was based on my principles and beliefs as a researcher and designer and on a critique of some existing works with food in HCI. I understood the value of separating and examining individual aspects of experience (be they sensory, emotional or social) but I felt that when considering how food is used by people in the real world it is not simply as a sum of these individual aspects but that there are interactions and interplays between them and as such it was necessary to have as holistic as possible understandings of food informing my work. Whilst my aim was to consider the totality of food experience and how to design with, at times this was not possible and perhaps inadvisable, as reflected in comments from supportive reviewers throughout my PhD and at my viva that the breadth of work in this thesis is challenging, at times too broad to tell a singular story. Whilst I understand that perhaps a more singular and coherent argument could have been made through a more focused approach this would have shied away from the core understanding I was developing through working with food. Namely that by engaging in the breadth of experience, richer, more exciting and interesting design opportunities unfold. I am pleased on the day I write this reflection, very near the end of my research to have done the research this way. To me it always made sense to work with food like this, my challenge was to explain and argue for that through my work and findings.

I would also like to reflect on the set-up of the research as a partnership with industry. I gained a lot from working on my research across different academic and industry environments. However, there were major challenges in getting the technology to support the research in the way it had been planned. The ability to see a way through to completing the thesis and to doing the research I want was something I feel I gained and want to thank Dr. Kalnikaitė and in particular Prof. Sas for their support in this. I would encourage any prospective students planning to work with novel technologies to consider how much they personally will be able to deal with technical challenges, what back-ups and supports are available and what is the access to that technology. These ideally should be written down and well discussed between all partners up front as it can be much more challenging to set these relationships once the ball is rolling.

Finally, I want to wish all future HFI researchers the best in their research. I hope what I have done is an appetiser for your own main course of work. Bon Appetit!

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