Towards Understanding Interactive Sonic Gastronomy with Chefs and Diners

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Figure 1: Eighteen interactive sonic gastronomy designs created in our studies with *SoniCream*.

Abstract

With advancements in interactive technologies, research in human-food interaction (HFI) has begun to employ interactive sound to enrich the dining experience. However, chefs' creative use of this sonic interactivity as a new "ingredient" in their culinary practices remains underexplored. In response, we conducted an empirical study with six pairs of chefs and diners utilizing *SoniCream*, an ice cream cone that plays digital sounds while consuming. Through exploration, creation, collaboration, and reflection, we identified four themes concerning culinary creativity, dining experience, interactive sonic gastronomy deployment, and chef-diner interplay. Building on the discussions at the intersection of these themes, we derived four design implications for creating interactive systems that could support chefs' culinary creativity, thereby enriching dining experiences. Ultimately, our work aims to help interaction designers fully incorporate chefs' perspectives into HFI research.

CCS Concepts

• **Human-centered computing → Interaction design**.

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Human-food interaction, interactive sound, culinary creativity, food design, chef

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1 Introduction

Human-Food Interaction (HFI) [17, 18, 23, 71], a burgeoning subfield of Human-Computer Interaction (HCI), has explored the use of interactive technologies to enrich dining experiences by enhancing the sensory aspects of food, including olfactory [10], taste [63], and visual experiences [68]. In particular, auditory stimuli have been investigated for their potential to influence diners' eating behaviors [99], alter edible perceptions [111], and promote healthy eating habits [81]. For instance, modifying eating sounds (e.g., chewing, swallowing, licking) has been shown to affect texture perception [92], while adjustments to background music, such as changes in tempo and volume, can influence eating pace [93]. Since then, an increasing number of HFI studies focused on the impact of interactive sounds on dining experiences [42, 44, 76, 108], signifying a shift from passive audio reception to active interaction with sounds during meals.

Despite the considerable attention given to how interactive sounds can influence diners' experiences, the engagement of culinary practitioners — encompassing hospitality professionals, food preparers, cooks, and culinary artists, collectively referred to as "chefs" for this study — has been underestimated or regarded as considered dispensable in the development of HFI research [34, 110]. By exploring the dining ambiance [32, 85] and various ingredients along with their qualities (e.g., taste, shape, texture), chefs consistently create a series of multi-sensory, embodied, and emotionally enriched gastronomic journeys [31]. Considering our human-centered focus, it would be beneficial to integrate their food knowledge and creative aesthetics into the progression of sound-related HFI research.

To begin understanding the inherent value that chefs bring to the HFI community, particularly in interactive sonic gastronomy — a culinary practice where sounds are actively triggered by eating actions — we conducted a study involving six pairs of chefs and diners. These participants engaged with *SoniCream*, a device resembling a waffle cone that emits sounds in response to ice cream consumption (detailed in Figures 3 and 5), to craft their food creations. We selected ice cream as our food medium due to its dynamic properties (transitioning from frozen to melted) and its versatility in accommodating various food materials. Additionally, the accessibility and affordability of both ice cream and our device made this initial chef-involved investigation both practical and feasible.

In this paper, we explore the gastronomic experience, encompassing both the culinary creativity (for chefs) and the dining experiences (for diners) within the context of interactive sonic gastronomy. Our contributions and benefits include:

- An empirical study explored the harmonious gastronomic experience by observing chefs and diners engaging with *SoniCream*, inspiring practitioners to create novel food creations through interactive sounds (Figure 1).
- Four themes emerged from our study's findings regarding culinary creativity, dining experiences, actual deployment and chef-diner interplay, providing valuable insights for researchers seeking to understand user experiences in chef-involved HFI research.
- Four design implications are formulated to guide the development of future culinary support systems, aiming to expand the boundaries of chefs' culinary creativity and enrich the dining experience. These implications provide a valuable starting point for designers eager to create such systems but uncertain about where to begin.

2 Related work

Our related work section will first build on an understanding of prior sound-related HFI works, then elaborate insights from prior work on chef participation in the progression in HFI design.

2.1 Prior Works on Sound-Related HFI

Sound is known to enrich the dining experience [80] and sensory perception [88, 93]. For example, cheerful or sorrowful ambient soundscapes can alter the perceived taste of food [74, 90] and beverages [96]. Eating sounds can influence perceptions of crispness and freshness [50], thereby affecting eating behaviors [47]. These prior sound-related works illustrate how sound subtly enriches the dining experience, highlighting the research potential of auditory information while dining. However, such deployments often place less emphasis on interactivity, limiting diners' control over digital sounds and exploring its impact on the overall experience [3, 66].

HFI designs appear to be developed in two significant ways [30]: interactive interfaces **around** food and edible interfaces **with** food. Projects **around** food typically include various utensils, such as mugs [61], forks [42], and dining tables [76] that enable diners to interact with various forms of food (e.g., liquid, solid) and activate dynamic sounds during consumption. On the other hand, some works have designed edible interfaces **with** food based on its inherent properties [19]. For instance, "FoodSkin" established an edible gold foil circuit on the dry surface of cookies [44], activating sounds through contact with the human body. For moist foods, their conductivity was used to create a capacitive circuit with external electronic systems, enabling sound generation [107]. Taken together, these studies contribute to a diverse auditory dining experience by incorporating interactive sounds **around** and **with** food, but overlook the potential to contribute to a cohesive, designed dining experience. We consider the prior work to be establishing initial components, with which we can further investigate the intersection between interactive sounds and user experiences in dining settings.

Some prior projects do consider a more cohesive experience beyond components. "iScream!" expanded our understanding of how interactive sounds affect user experience [108]. This study demonstrated that interactive sounds enable diners to engage with ice cream by facilitating a playful dining experience. "WeScream!" further explored the role of interactive pentatonic scale tones in commensal dining [107], suggesting that collaboratively creating harmonious interactive sounds can enhance diners' awareness of each other's dining behaviors. These works show that interactive sounds can empower diners to fully engage in shaping their dining experiences. However, they also acknowledge the oversight of diverse multi-sensory aspects [91], such as visual, olfactory, and textural elements, and how their synergy influences the dining experience in turn.

These works have inspired us to further explore interactive sounds in dining scenarios and their influence on user experience. In particular, the crucial role of chefs as gastronomy creators utilizing these systems to support their culinary creativity has been overlooked, which may help to fill the research gap in previous works. To explore chefs' engagement with interactive sound, the following section will articulate and reflect on their role in HFI design, advancing the understanding of their contributions.

2.2 Insights from Chef Participation in HFI Design

"*Food is providing the canvas by which chefs can address social, political, and environmental issues through their preferred form of artistic expression.*" McBride & Flore stated this [62, p2], highlighting food's function as a universal language enriched with sensory details that enable chefs to transcend linguistic and cultural barriers to engage with diners [13]. This ability to evoke specific associations and emotions highlights chefs' crucial role in enhancing diners' experiences [1, 89]. With the advancement of HFI, there is growing interest in how interactive technologies can be integrated into chefs' workflows to innovate dining experiences [12]. To begin understanding this integration, we synthesized the HFI literature on chefs' participation and reflected it across five stages (Figure 2). The horizontal axis describes the degree of involvement of a chef (with S1 not involving a chef at all to S5, in which a chef has incorporated HFI into their practice). The vertical axis categorizes the HFI systems into those with and without sounds. We acknowledge that our categorization is rudimentary and provides only an initial, broad overview. However, we believe that it could serve as a useful starting point to illustrate what has been achieved so far and to identify unexplored research areas.

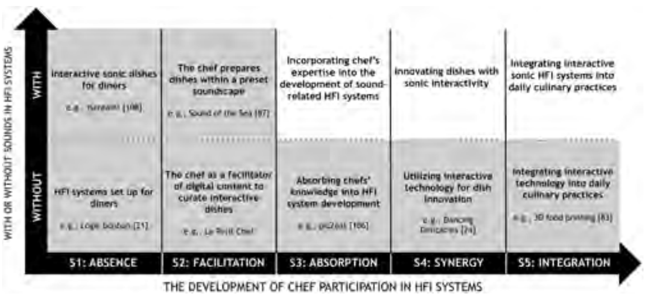

Figure 2: The diagram charts chef involvement in prior HFI systems against the use of sound. Each block describes its concept. Gray blocks have prior work associated with them and include references; white blocks are underexplored but merit further investigation.

2.2.1 S1: Absence of Chef Participation in HFI. In this stage, HFI research primarily emphasizes the innovation of interactive food interfaces. Mueller et al. [71] suggested that interactivity is often integrated into utensils, embedded within the food itself [16], or implemented as edible interactivity [21]. These studies examined the intersection of interactive technologies and eating, aiming to understand how novel interfaces contribute to a positive dining experience. However, these diner-centered interactions often give little attention to the vital roles of chefs as food creators within these systems. This oversight was highlighted by Tom et al. [32], who reviewed the evolution of HFI research in 2022 and proposed the potential benefits of incorporating chefs' perspectives into future HFI designs. Specifically, in HFI studies involving interactive sounds, most implementations prioritized enhancing diners' experiences, often neglecting how chefs could incorporate interactive sounds into their food creations. This gap calls for further exploration into the relationship between interactive sonic gastronomy and chefs' culinary creativity.

2.2.2 S2: Chef Facilitation in HFI. We observed that the increasing integration of interactive technology in restaurants is reshaping the culinary considerations chefs must account for. For instance, audio-visual elements incorporated into interactive projection performances are designed to enhance immersive dining experiences, with chefs synchronizing their culinary pace and dish display to the evolving dynamics of the animations [34, 103]. These systems position chefs primarily as facilitators of interactive dining performances, emphasizing procedural plating or cooking demonstrations. While these technologies elevate the presentation of gastronomy beyond traditional cooking approaches, the fixed and procedural patterns of interactive flows may limit chefs' ability to fully perform their culinary creativity. Meanwhile, these technologies raise concerns among diners about a unidirectional, chef-centric approach to food design, as they can be perceived as overly formal and restrained. This may lead to the impression that chefs are preparing food for themselves rather than for diners [110]. Such a chef-centric mode overlooks the potential for immediate feedback from diners, which could enhance chefs' skills and deepen their understanding of and responsiveness to diners' needs [35]. To address these concerns, Altarriba Bertran et al. [8] advocate transitioning chefs from traditional experts to more open and participatory roles. In HFI research involving interactive sounds, chefs can only use interactive systems within preset sound frameworks to present monotonous gastronomy [87]. These studies prompt us to explore how interactive sounds can be integrated with chefs' expertise to further advance the development of HFI.

2.2.3 S3: Absorption of Chefs' Culinary Knowledge in HFI. HFI research began to benefit significantly from chefs' knowledge in shaping the design of interactive systems. For instance, Van Doleweerd et al. [104] collaborated with chefs to improve the reactivity of edible shape-changing materials, providing guidelines to simplify their application in culinary practices. Similarly, "pic2eat" integrated chefs' culinary expertise in developing interactive 3D food printing interfaces, allowing diners to personalize the taste and appearance of their 3D-printed food [106]. Building on this trend, Altarriba Bertran & Wilde [7] engaged with chefs, proposing a transition perspective for chefs from focusing merely on dish creation to enhancing the overall dining experience. This suggests that incorporating chefs' knowledge into the system development may help chefs to align their culinary practices more closely with diners' preferences. However, how chefs' knowledge can synergize with the generation of interactive sonic systems has not yet been fully explored, which implies that this stage could serve as a foundation for future investigations into integrating chefs' culinary insights into the development of interactive sonic gastronomy.

2.2.4 S4: Synergy Between Chefs and Interactive Systems for Culinary Innovation. Chefs craft visually stunning and flavorful dishes by balancing seasoning, fine-tuning temperatures, artful plating, and incorporating molecular gastronomy techniques [14, 82]. Beyond these methods, interactive technologies have begun to expand the boundaries of culinary innovation. For example, "Dancing Delicacies" [20, 24] integrates chefs' culinary expressions with dynamic droplet trajectories on the plateware, enriching the artistry of gastronomy and offering diners a more engaging approach to interact with their food by rearranging these ingredients. This innovation effectively combines interactive technology with chefs' creativity, transforming chefs into collaborators who elevate the dining experience [8]. Therefore, we envision interactive systems supporting an inclusive collaboration among chefs and diners. This collaboration enables chefs to steer emerging dish innovations and empowers diners not only as spectators of technology but also as active participants interacting with digital content [22].

2.2.5 S5: Integration of Interactive Technology into Chefs' Everyday Cooking. Integrating interactive technology into chefs' everyday cooking presents a promising yet challenging stage in the development of HFI. Currently, technologies like 3D food printing [83] and innovative kitchen equipment [36] have been adopted due to their high levels of automation and seamless integration into chefs' existing workflows. However, incorporating the emerging interactive systems we mentioned in the last four stages into chefs' everyday culinary practices remains challenging, as it often comes with steep learning curves, shifts in collaboration approaches, and challenging traditional workflows [7]. These concerns emphasize the ongoing research's need to better comprehend chefs' feelings, perceptions, motivations, and sense of identification with interactive technologies [29]. Therefore, in this stage, we envision the interactive sonic system as a comprehensive culinary tool — comprising both hardware and software — that seamlessly integrates interactive sounds into everyday culinary practices, much like essential plateware or cutlery.

2.3 Summary

Our review aims to clarify the roles that chefs have played in the progression of HFI, guiding our exploration of how interactive technologies, especially interactive sounds, support culinary creativity to enrich dining experiences. We gained three main insights:

- Existing HFI works that utilize interactive sounds often overlook the potential to incorporate chefs' culinary expertise, resulting in missed opportunities to enrich the dining experience by effectively synthesizing the multi-sensory properties of food with interactive sounds.
- We encourage the consideration of diverse auditory presentations to enrich the artistic expression of interactive gastronomy. In response to the digital gastronomy paradigm [112], we might benefit from exploring how diverse digital sounds can interact with chefs' culinary creativity and diners' dining experiences;
- The five stages — ranging from system-driven dining experiences (S1) and culinary orchestration (S2) to chef-centered food design (S3), followed by a transition to communal interactions between chefs and diners to foster shared gastronomic experiences (S4) — highlight the challenges of seamlessly integrating interactive technology into chefs' cooking routines (S5). This dynamic reflects shifting agency among chefs, diners, and interactive systems [6, 15], a key factor influencing interactive experiences [4, 57]. In the culinary domain, Trubek et al. define "**food agency**" as the ability to actively apply food knowledge, cognitive skills, and sensory perceptions during food preparation and cooking [101]. This concept lays a valuable foundation for our study of sonic gastronomic experiences involving chefs and diners.

This paper, hence, explores the overarching research question: *How do we understand interactive sonic gastronomy that supports chefs and diners in enriching their gastronomic experience?* Specifically, this enrichment is interpreted as expanding and deepening culinary creativity and multi-sensory dining by incorporating interactive sounds, thus enhancing existing gastronomic experiences.

3 the *SoniCream* System

SoniCream is a waffle cone-shaped device (Figure 3) that enables diners to engage in sound interactions while eating ice cream. It consists of five components: (1) an Adafruit Circuit Playground Express (CPX) development board with capacitive sensing capabilities[1]; (2) a mono audio amplifier[2] and speaker[3]; (3) an SD module[4] and SD card for storing sounds in .WAV format; (4) a 3D-printed ice cream cone with light wood materials[5]; and (5) a 3.7V, 2000mAh rechargeable Li-ion battery.

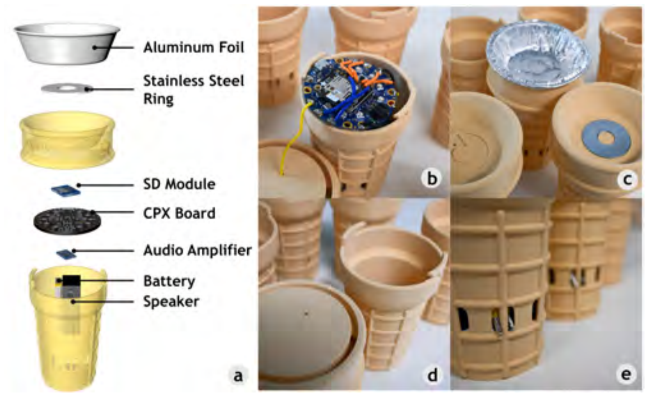

Figure 3: Details of the final iteration of the *SoniCream*. (a) shows the components of the *SoniCream* cone; (b) shows the circuit in *SoniCream*; (c) shows a precisely crafted 1mm pathway in concave to connect the stainless steel ring with the internal circuit system, with aluminum foil placed for supporting the ice cream creation; (d) introduces a combined structure that supports embedding followed by twisting, enabling the integration of the lid and shell; (e) shows the four sidewall holes that allow sound to be released and serve as connection points for alligator clips, creating a circuit through the human body.

3.1 Prototyping the Structure of *SoniCream*

Informed by iterative design [69], our iteration toward the final artifact designs was primarily shaped by the following considerations: (1) **Appearance**: We consider the licking behavior during ice cream consumption as the center of interaction. Therefore, the overall appeal of the artifact should be consistent with an ice cream cone, which can provide compelling visual clues [70] to encourage active licking; (2) **Sound clarity**: the sound must be clear, ensuring smooth propagation from the artifact enclosure; (3) **Stability**: The artifact comprises a shell for containing electronic components and a lid for the ice cream design, both of which must be securely integrated to ensure an uninterrupted dining experience; (4) **Creative space**: We prioritize chefs' capability to actively apply food knowledge and take actions during the engagement with our artifact [101], thereby the structure should provide ample space for

[1] https://learn.adafruit.com/adafruit-circuit-playground-express
[2] https://www.adafruit.com/product/2130
[3] https://www.adafruit.com/product/3351
[4] https://www.adafruit.com/product/254
[5] https://cubictech.com.au/products/esun-wood-pla-3d-print-filament-1-75mm-1kg

chefs to utilize diverse ingredients and craft their food creations. The structure of our exploration is shown in Figure 4.

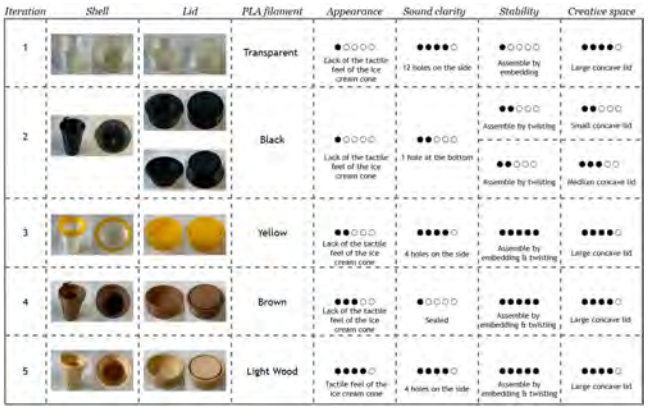

Figure 4: Prototypes of cone structures, showing the progression of materials and assessments of their design qualities.

Through the iterative process, we gained the following insights (with the interactive flow shown in Figure 5):

- Due to the large size of traditional development boards like Arduino or Raspberry Pi, we chose a smaller Adafruit CPX board to support future function development and adjusted the thickness of the internal walls and the angle of the shell sides in the 3D model to ensure that all electronic components could be properly accommodated.
- After multiple comparisons, we chose wood-grain PLA material with low gloss. This material closely resembles the appearance (e.g., color, tactile) of an ice cream waffle cone. Due to its good waterproof performance, it also ensures that the electronic components are shielded from seeping molten ice cream.
- Because the internal speaker is placed vertically, the clarity and amplification of the sound from the side holes are better than those from the bottom holes. Since the speaker volume is sufficient, the number of side holes has little impact on the sound display.
- We used an alligator clip cable connected to the holes, allowing users to naturally hold the cone, forming a capacitive sensing circuit with the CPX board and the human body. Additionally, to broaden the detection scope for ice cream consumption behaviors, we established a 1mm circuit pass-through diameter at the lid to connect a stainless-steel ring. Meanwhile, we applied food-grade aluminum foil on the lid to isolate *SoniCream* from the ice cream, aiming to expand the range and accuracy of ice cream licking detection.
- We adopted a design with a labyrinth seal and a pair of bayonet locking tabs, allowing us to maintain a sturdy lock connection between the shell and lid through embedding and twisting actions while allowing easy disassembly.
- Meanwhile, to support chefs in creating varied ice cream displays, we designed the lid to create a relatively concave creative space, accommodating up to 40g of ice cream and multiple other ingredients.

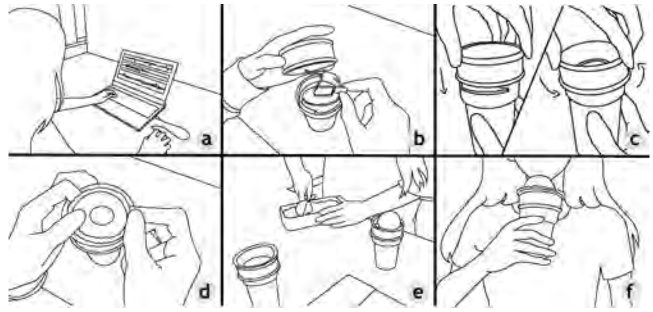

Figure 5: Interactive flow of the *SoniCream*. (a) Exploring and downloading sound options from the online website; (b) Uploading sound files via SD card; (c) Assembling the *SoniCream* through embedding (left) and twisting (right); (d) Applying aluminum foil to the *SoniCream*; (e) Scooping ice cream with the *SoniCream*; (f) Enjoying interactive sonic gastronomy.

3.2 Function Exploration of Capacitive Sensing for Licking

On the one hand, we aim to present a stable system that accurately plays diverse sounds; on the other hand, we begin by considering the unique properties of ice cream to guide our function development. Specifically, different types of food, such as soup and bread, often afford distinct eating patterns [56]. Therefore, we identified licking, a common action when eating ice cream, as the trigger for sounds. Ice cream's moisture and electrolyte content provide conductivity, and saliva turns the tongue into an effective conductor, which can activate capacitive sensors [11]. Our function iterative process to arrive at the final design was primarily guided by the considerations laid out in this section.

3.2.1 Technical Support. We selected the Adafruit CPX board, which can accurately detect subtle changes in capacitance by utilizing its built-in capacitive touch pads. To establish an appropriate threshold for detecting licking behavior, we initially recorded capacitance fluctuations during ice cream licking. These fluctuations suggested the potential for implementing a dynamic threshold that could adapt sound properties (e.g., volume, pitch, velocity) to the ice cream's dynamic state. However, the differences were minimal during ice cream consumption, indicating that a dynamic threshold might introduce unnecessary implementation complexity. In particular, we observed capacitance values of around 700 for freshly placed ice cream and 30 for fully dried ice cream (after 12 hours in a food dryer). Based on these findings, we adopted the average capacitance as the fixed threshold for licking detection. These values represent raw sensor readings with no specific unit. Meanwhile, to address the low volume and sound quality of the Adafruit CPX board's built-in piezo buzzer, we incorporated an 8-ohm enclosed speaker paired with a PAM8302A mono audio amplifier, which significantly enhanced both the volume and richness of the sounds.

3.2.2 Customization. We aimed to provide a ready-to-use device that enables users to customize their interactive sonic gastronomy in various settings. The CPX board supports sound upload via a USB connection. However, we noticed that frequent use of the USB plug for sound uploads could burden users. Therefore, we integrated an SD module to simplify the process of uploading sounds. Moreover, we completed the control loop in the CPX code, allowing users to play sounds sequentially by editing the playback sequence numbers of sound files. Additionally, we used Audacity[6] to convert sound files into the 8-bit PCM WAV format with a sampling rate of 44.1kHz, ensuring compatibility with the CPX.

3.2.3 Sound Duration. We found that individuals could consume 40g of ice cream with 7 to 24 licks in 80 to 120 seconds, indicating significant consumption rate variability. This finding implies that prolonged sound segments might extend beyond the ice cream consumption period. Therefore, we suggest the duration of each sound not be longer than 40 seconds. The *SoniCream* will sustain the playing of the current sound as long as the diner maintains contact with the ice cream, transitioning to the next sound clip upon reinitiating contact. The system will replay the sound loop throughout the eating process until the ice cream is fully consumed.

4 Study

4.1 Participants

We recruited 12 participants (M=27.75, SD=4; four self-identified as men, eight as women, none identified as non-binary or self-disclosed), comprising six professional chefs and six diners (Table 1). They were recruited via social media, website advertisements, and word of mouth. Each chef was randomly paired with a diner, forming six pairs to minimize individual characteristic differences and reduce potential bias in user experience evaluation [53]. These six groups will remain consistent throughout the subsequent ideation workshop and dining process. We established the following selection criteria for our participants:

- Chefs must demonstrate proficiency in creating new cuisines and a keen interest in using interactive sounds to enhance ice cream developments. They are required to have a minimum of four years of experience in the catering industry, as prolonged professional exposure to food is believed to heighten sensitivity to curated interactive sonic gastronomy.
- Diners must be enthusiastic about food and open to innovative food interaction methods. To minimize safety issues in the present exploration, participants needed not to have diabetes, hyperlipidemia, hypertension, chronic pancreatitis, cholecystitis, gastroenteritis, or allergies.

4.2 Study Setup

Auditory perception varies across individuals [46]. In particular, it lacks the standardized norms and conventions in other sensory modalities, such as vision, which makes composition less intuitive [28]. Consequently, traditional sound design processes are frequently characterized as experience-driven, low transparency, and relatively isolated [39], often limiting the potential for creative sound expression. This subjectivity has driven the growth of participatory sound design, enabling stakeholders to bridge understanding gaps collaboratively [33, 73], enhance user experiences [40], and better address their needs [25]. Thus, to explore the intersection of interactive sound and gastronomic experiences, we believe that chefs (as food creators) and diners (as food consumers) should be engaged in a hybrid space for mutual learning and foster constructive dialogue [66]. Drawing inspiration from the differences in **food agency** [101] between chefs and diners in real dining settings, we designed a Food Agency Framework, incorporating four quadrants (Figure 6). This framework aimed to guide our further participatory session, enabling chefs, diners, and researchers to explore, create, collaborate, and reflect together on interactive sonic gastronomy.

[6]https://www.audacityteam.org/

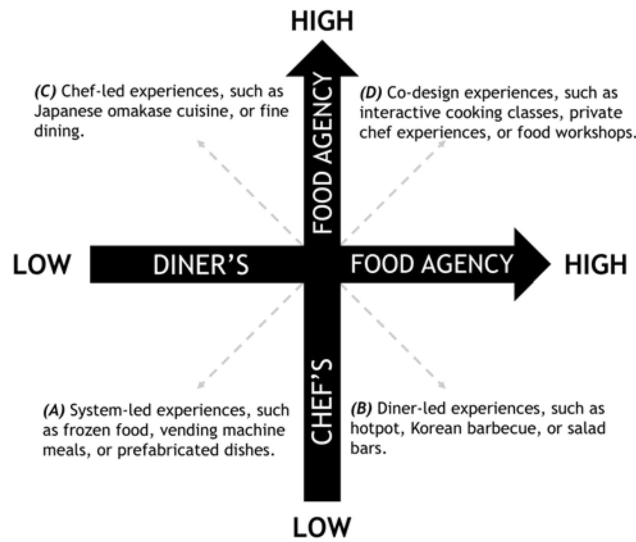

Figure 6: Food Agency (FA) Framework.

- **System-led** is situated in a quadrant where the **food agency** of chefs and diners is relatively low. As technology and automation advance, systems are increasingly assuming control, thereby reducing user autonomy. In this quadrant, they face significant constraints in exercising their **food agency** to craft culinary creations.
- **Diner-led** signifies that diners have considerable autonomy in preparing and cooking their dishes and are primarily responsible for their own dining experience. Chefs still contribute by preparing ingredients, such as chopping, seasoning, and marinating, but their role in deploying food creations is minimal, reflecting lower **food agency**.
- **Chef-led** approaches grant chefs full autonomy to apply their professional knowledge and sensory skills throughout all stages of food preparation, from cooking to plating. The dining experience is closely tied to the chefs' expertise, while diners' feedback can also shape their culinary practice [35]
- **Co-design** represents a collaborative shift in the relationship between chefs and diners, extending beyond the traditional boundaries of the kitchen and dining table. In this approach, chefs and diners share an equal **food agency**, working together toward shared gastronomic experiences.

Table 1: Participant demographics. Note that participants only identified with binary genders (woman (W), man (M)).

Group	Code (Age, Gender)	Occupation	Experience of food-related practice
1	C1 (31, W)	Head Chef	10 years experience in a local fine dining restaurant.
	D1 (20, W)	Undergraduate student	Considers herself a designer and food explorer keen on engaging with novel food interaction.
2	C2 (33, W)	Chef	6 years experience in an Italian restaurant.
	D2 (35, W)	Researcher	PhD in social sciences, considers herself a foodie.
3	C3 (27, W)	Pastry Chef	5 years experience in a private kitchen.
	D3 (24, M)	Graduate student	2 years experience in marketing, has a deep understanding of sounds and consumer decision-making.
4	C4 (26, M)	Japanese cuisine chef	5 years experience in food creation in Japanese buffet restaurants.
	D4 (26, W)	Accountant	Considers herself keen on exploring novel food experiences.
5	C5 (30, W)	Barista	6 years' experience in exploring coffee creation, especially dedicated to scent exploration.
	D5 (24, M)	Graduate student	A graduate student who has participated in food research before.
6	C6 (29, W)	Ice cream designer	4 years experience in managing an ice cream shop and creating novel ice cream products.
	D6 (28, M)	PhD student	Considers himself a food enthusiast who enjoys exploring new restaurants and discovering new foods.

4.3 Study Process

We engaged chefs and diners in two sessions: an ideation workshop [37] and a later dining session to craft interactive sonic gastronomy. Through this two-session format, we aimed to understand how interactive sounds could enrich their gastronomic experiences.

4.3.1 Ideation workshop. We organized a 60-minute ideation workshop and a series of activities before each pair's dining session involving diners and chefs. During the workshop, we applied "design thinking" to the food design process [72], encouraging participants to visualize concepts, rapidly prototype, and collaborate using *SoniCream*. Specifically, a researcher brought the diners and chefs together in the same space to cultivate their diverse visions on interactive sonic gastronomy design [84], as shown in Figure 7.

Figure 7: The process of the ideation workshop. Each of the six workshop sessions involved one researcher with a chef and a diner.

(1) Concept Introduction: In the first 15 minutes, a researcher introduced *SoniCream*, detailing its background and operation through slides and a video. This demonstration aimed to cultivate the participants' initial understanding of interactive sonic gastronomy.

(2) Material, Sound Engagement: Over the next 30 minutes, participants were provided with various ice creams, edible toppings, tools, and access to a free website for sound exploration[7], all alongside the *SoniCream* device. Inspired by the theory of material speculation [105], these edible materials and sounds acted not as mere passive media but as essential elements for cultivating their cognitive engagement [60] in interactive sonic gastronomy. Specifically, we established a structured sequence for participants' engagement: ingredient selection, ice cream molding, sound exploration and downloading, sound uploading to *SoniCream*, and shared enjoyment of their food creations. This predefined sequence aimed to reduce participants' cognitive load [75] and enhance their understanding of each step.

(3) Brainstorming: In the final 15 minutes, each chef and diner was provided with an ideation worksheet as a canvas for sketching their ideal food creations, including flavors and corresponding sounds. This approach was inspired by an HCI storyboard [102] aimed at helping participants contextualize their ideas and expand their creativity beyond traditional culinary boundaries (more information about the ideation worksheet is available in the Appendix A.1). Participants were allowed to take the worksheets with *SoniCream* home to provide additional information. As researchers, we took on a supportive role, helping participants bring their ideas to life and offering immediate feedback on the feasibility of their concepts. We tried to minimize the influence of our biases and aimed to ensure open, effective communication to facilitate the iterative refinement of their creations. During the week following the ideation workshop, researchers prepared all the necessary ingredients and ice cream based on the worksheets they provided to ensure a smooth progression of the dining sessions. However, participants were also encouraged to create their own flavors and decorations (see Figure 8). All the food creations designed in the dining session were based on their worksheets.

4.3.2 Dining session. Following the FA framework illustrated in Figure 6, we conducted six 120-minute dining sessions one week after the ideation workshop, each consisting of system-led, diner-led, chef-led, and co-design phases. These phases aimed to encourage

[7] https://freesound.org/

Figure 8: Preparation of ice cream and edible decorations based on C1's ideation worksheet. (a) Ideation worksheet from C1; (b) C1 is preparing all materials based on this ideation worksheet; (c) The milk needs to be heated to the proper temperature; (d) C1 is using a whisk to mix the ingredients; (e) Some ingredients are added to adjust the ice cream flavor; (f) C1 completes the final food creation and then uploads sounds to *SoniCream*.

participants to actively engage in their creative process, thereby enriching their gastronomic experience. After each of the first three phases, we conducted 10-minute semi-structured interviews [2] to capture the initial impressions and sentiments of diners and chefs. Additionally, we conducted a 30-minute overall interview after the final co-design session.

(1) System-led (10 minutes). We designed a system-led dining session to correspond to quadrant (A) in the FA framework, where both chefs and diners have limited **food agency**. This session limits their ability to apply food knowledge to create interactive sonic gastronomy. Our researchers initially provided vanilla, chocolate, and strawberry as the default ice creams. Additionally, inspired by the 22 playful elements from the PLEX cards [58], we prepared 22 background music tracks (details available in the Appendix A.2) that aimed to cover the range of emotions and experiences music can evoke. Chefs engaged with all the music tracks and assigned them to each flavor using ideation worksheets before the dining session, allowing diners to select a flavor and experience the ice cream. The aim of this phase was to use background music to provide a vivid contrast with interactive sonic dining, and initially enhance participants' sensitivity to sound elements during dining.

(2) Diner-led (10 minutes). To correspond with quadrant (B) in the FA framework, where diners have more **food agency** than chefs, this session allowed diners to customize their interactive sonic gastronomy based on their preferences. The goal was to explore how diners intuitively understand the integration of interactive sounds into their everyday dining experiences. Following their ideation worksheets, diners used their preferred ingredients and sounds to shape their vision of interactive sonic gastronomy and finally enjoy it. Throughout this process, chefs offered instant observations and guidance. Figure 9 displays six creations developed during this phase.

(3) Chef-led (15 minutes). This session aimed to correspond with quadrant (C), where the chef's engagement with *SoniCream* was central to the interaction. We aimed to explore how they utilized their extensive culinary knowledge and aesthetics to curate diverse interactive sonic gastronomy with multiple ingredients, thereby offering diners a meticulously crafted multi-sensory dining

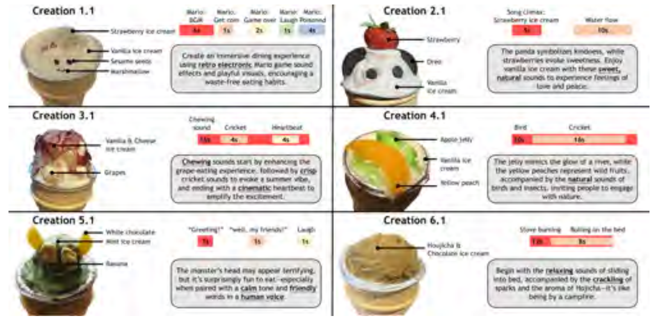

Figure 9: Diner-led interactive sonic gastronomy creations. Each creation shows the details of ingredients (left), as well as its sounds and background (right). The sound segment details include duration, composition, a brief description, and overall vibe highlighted in bold and underlined (This information is also presented in Figures 10 and 11).

Figure 10: Chef-led interactive sonic gastronomy creations.

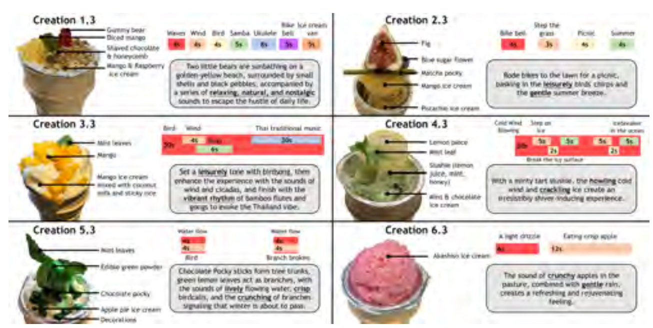

Figure 11: Co-design interactive sonic gastronomy creations.

experience. Diners enjoyed these creations once they were fully prepared. All creations are shown in Figure 10.

(4) Co-design (25 minutes). This co-design session was akin to reflective practice that balances **food agency** to help diners and chefs co-establish unified standards to create interactive sonic gastronomy and enrich each other's gastronomic experiences (corresponding to quadrant (D) in the FA framework). Specifically, based on a shared understanding of interactive sonic gastronomy, chefs and diners began by sketching an ideation worksheet for co-creative collaboration (detailed in Appendix A.1). Then, they fully utilized available resources (e.g., ice creams, decorations, and sounds) to realize their concepts. The diners experienced their co-creations once the implementation was completed (Figure 11).

4.4 Data Sources and Analysis

Our primary dataset comprises notes, photos, and videos from each ideation workshop and dining session. We employed a semi-structured interview method to gain in-depth insights into participants' thoughts, attitudes, and experiences within our predetermined, open-ended questions. During each interview, we documented all creations by chefs and diners, and recorded audio that was later transcribed. The interview questions, designed to align with our research focus, explored participants' immediate experiences with *SoniCream*, the types of sounds they used, their perspectives on achieving a harmonious gastronomic experience, and any notable observations or interactions throughout the process. During the final interview, participants are asked to share their overall impressions of each stage and rank them, with these rankings serving as the only quantitative results included in our findings.

We conducted an inductive thematic analysis [9] using an open coding process to identify relevant concepts and themes. Each data unit consisted of a single coded quote, with the coding process being "data-driven" to reduce bias [65]. Initially, two coders independently familiarized themselves with the entire dataset before coding it separately. They then performed three rounds of coding. In the first round, 33 code labels were generated. During the second round, the coders met to consolidate consistent high-level labels into broader themes and resolved discrepancies through additional coding. In the third iteration, guided by a senior researcher, these labels were iteratively grouped into four overarching themes, encompassing 391 of the 832 data units.

5 Findings

This section presents our qualitative results from the chefs' and diners' engagement with interactive sonic gastronomy, identifying four themes: culinary creativity, dining experience, interactive sonic gastronomy deployment, and chef-diner interplay.

5.1 Theme 1: Culinary Creativity

This theme illustrates how chefs incorporated interactive sounds to support their creativity. This integration has led to the identification of four sub-themes.

5.1.1 F1: Enrichment of food layers. A "food layer" [52] represents the richness of the cuisine, where chefs normally employed a variety of decorations (e.g., Figure 9, Creation 1.2) and spatial arrangements (e.g., Figure 11, Creation 2.3) to craft a visually appealing layout. Moreover, the layered sensations in taste, such as composite flavors (e.g., Figure 11, Creation 3.3), textures (e.g., Figure 10, Creation 6.2), and dynamic proportions among ingredients (e.g., Figure 10, Creation 4.2), also contributed to the complexity of the mouthfeel, as C4 explained: *"I hope the ice cream can contrast with other ingredients, [...] [thereby] creating layers of taste [...] that will not be tired of it."* When it came to interactive sonic gastronomy, we discovered that the real-time audio loop of the *SoniCream* synchronized the diners' eating actions and sound display. Two chefs mentioned that the sound properties (e.g., sharp, stimulating, smooth) implicitly corresponded with the variety of flavors (e.g., sour, sweet, bitter, spicy): *"Ice cream has many flavors [...] which have different intensity. [...] This is similar to sounds, such as different decibel levels, clarity, or naturalness"* (C1). It suggested that the *SoniCream* could incorporate interactive sounds as a novel food property to enrich the food layer. C5 described the liveness of Creation 5.2 (Figure 10): *"I feel like these sounds make all my ingredients come alive as if they have their own souls."*

5.1.2 F2: Auditory-taste narrative. Traditionally, chefs crafted narrative dining experiences through mouthfeel processing and visual plating [55]. For instance, C4 described the taste journey that Creation 4.3 (Figure 11) would bring: *"When you eat the slushie, it feels colder on your tongue than ice cream. [...] Then, an extreme sourness stimulates your taste buds, [...] followed by a strong mint flavor."* With interactive sounds involved, C4 then arranged the sound sequence to coordinate with diners' eating progression to illustrate an auditory narrative, adding: *"The sounds helped me create a story full of ups and downs. [...] I imagine a cruise ship gliding over the icy surface [...] the sound of breaking ice [...] happened when the diner almost finished the slushie and started to taste the [mint-flavored] ice cream below, followed by a strong wind sound to create a chilly atmosphere."* This finding was also reflected in Creation 1.2 (Figure 9) that aims to create a princess dream for a child, *"The small pink glittering sequins [and] the berry flavor is very eye-catching, with the playful lullaby and dreamy string music first leading you into a fairy tale world. [...] The last sound is of a child saying 'Wow!' just like when you hand a child a very gorgeous thing, the first reaction is, 'Wow! that's great!'"* Therefore, the arrangement of sound sequences alongside taste narratives appeared to provide chefs with a medium to convey their culinary expression.

5.1.3 F3: In harmony with food creations. Chefs intentionally used the synergy among ingredients to balance (e.g., Figure 11, Creation 2.3), contrast (e.g., Figure 11, Creation 4.3), enhance (e.g., Figure 10, Creation 5.2), and resonate (e.g., Figure 10, Creation 1.2) across multiple modalities. All chefs described interactive sounds as supplementary to their culinary creations. Therefore, on the one hand, they typically established a correspondence between ingredients and sounds, such as quantity relationships (e.g., Figure 11, Creation 6.3), ingredient implications (e.g., Figure 10, Creation 5.2), taste intensity (e.g., Figure 11, Creation 4.3), and smell (e.g., Figure 11, Creation 5.3). On the other hand, they considered key factors such as main flavors (n = 6), seasons (n = 3), holidays (n = 2), and cost (n = 1) as primary considerations when adjusting the sound configurations to align with the thematic ambiance of their creations. For example, Creation 6.3 (Figure 11) aimed to evoke the feeling of stepping into a pasture. C6 stated: *"Akashiso ice cream has a refreshing smell of grass, but once the sound [referring to the rustling sound of rain] is added to the atmosphere, it becomes completely different. [...] I hope that his [referring to D6] experience can strongly connect to my ice cream theme, so I combine these two sounds as a whole to elevate my creation."* In this way, interactive sounds could be likened to a "seasoning" rather than a "staple" of the dining experience. As C4 confirmed: *"Ice cream is soft, [...] so then I used the chips sounds and crispy syrup to enhance the crunchy mouthfeel."*

5.1.4 F4: Guidance and customization. Some chefs utilized interactive sounds to connect their culinary thinking with the diners' experiences: *"[Interactive sounds can] provide a more purposeful guide. [...] Without hearing the sounds, it's hard to understand what information this design is trying to convey. [...] and lead others into your mind"* (C1). Therefore, C3 attempted to encourage healthier eating through comedic sounds in Creation 3.2 (Figure 10), stating: *"Most people consider ice cream to be a high-calorie sweet treat, so I use [...] one sound serves as background noise to set the relaxed atmosphere [...] another is a theme song of 'Friends' [...] [can make] diners not feel guilty about eating sweets."* Moreover, C2 mentioned that interactive sounds might be an effortless approach to achieve customization, stating: *"In some fine dining restaurants, they always issue questionnaires to collect diners' preferences to customize their dishes. [...] If they have this device, they only need to upload different sounds [...] [then] achieve customization."*

5.2 Theme 2: Dining Experience

This theme demonstrates how the combination of interactive sounds, compelling visual cues, and rich mouthfeel enhanced diners' experiences by enriching their perceptions, leading us to four sub-themes.

5.2.1 F5: Sound-eating conflicts. We discovered that the interactivity of *SoniCream* revealed some conflicts between interactive sounds and eating, which had a noticeable impact on diners' eating pace ($n = 3$) and appetite ($n = 4$). Firstly, interactive sounds could adjust perception by reshaping traditional stereotypes of certain flavors. D4 reflected on the extreme mint flavor (Figure 11, Creation 4.3), highlighting the necessity of using interactive sounds to neutralize its stereotype: *"The mint flavor is so strong, [...] without sounds [...] to make it playful and capture my attention, I would find it hard to keep eating [...] and get tired of it quickly."* Additionally, some participants moved the *SoniCream* closer to their ears to better enjoy the sound after licking it (n=3), or suspended eating while playing sounds to rethink and appreciate their food (n=5); these deviations from regular eating habits caught our attention. D3 described an unusual eating speed when he ate Creation 3.3 (Figure 9), stating: *"In some buffets, if they want you to eat quickly and leave, they play loud music. [...] I ate this ice cream very fast because I found it particularly interesting, so I wanted to keep up with that music [...] this was my own choice to speed up."*

5.2.2 F6: Counterintuitive experiences. Our diners noted that inconsistencies between the real-time perception of interactive sounds and the intuitive mouthfeel evoked diverse mental illusions. For example, D3 described his experience with Creation 3.2 (Figure 10), while accompanied by chewing sounds: *"It felt very strange as if it wasn't me eating the ice cream, but rather someone else, yet the food was going into my mouth. [...] I actually didn't make any real sound while licking."* In the *SoniCream* system, sounds were programmed to play sequentially without overlap, starting with a consistent experience between sounds and mouthfeel, and then leading to a counterintuitive experience as all ingredients blended during consumption. For example, D4 reported an unexpected moment while enjoying Creation 4.2 (Figure 10): *"The timing of the [chips] sounds is a little bit unexpected. [...] When I was eating, I almost laughed because when I bit a nut, there were chirping and pecking sounds [...] as if a bird was pecking at the nut in my ice cream."* These inconsistencies with our dietary instincts have been shown to induce some unexpected sensations [59]. However, our findings did not observe an impact of the inconsistency between visual presentation and sound, possibly because chefs strove to create visually appealing dining experiences, avoiding deliberate disparities.

5.2.3 F7: Mental model trajectory. Interactive sounds while consuming ice cream enriched diners' personal interpretations, symbolizing a dynamic mental model trajectory. Before consumption, for example, D1 described Creation 1.2 (Figure 10) as "*dreamy*," D2 found Creation 2.2 (Figure 10) "*refined and appealing*," and Creation 5.2 (Figure 10) directly brought D5 an intuitive feeling of "*nature and forest*." Interestingly, these interpretations align with chefs' intended expressions, showing that visual information serves as an aperture to initially navigate diners' inside out perception [48]. C4 confirmed, *"You will not be limited by the imagination if there is no decoration, but the advantage of this visual design [. . .] can give diners a hint in advance and the taste they can imagine, or the feeling of the situation they imagine."* The synergy of interactive sound and visual clues further evolved diners' interpretations from simple adjectives to a richer context. For instance, D6 described Creation 6.2 (Figure 10), transforming it from merely tropical ice cream to: *"I was walking on a summer night beach in Japan, and on the way back to my hotel I heard the sound of trees and the river, and fireworks lighting up the sky."* Moreover, C4 demonstrated a progressive understanding of the interactive sonic gastronomy: *"At first, I thought the sound might be insignificant in influencing our eating because [. . .] we [had] never experienced eating with sounds before [. . .]. But as the experiment went on, [. . .] I felt the sound elevated the dish to a higher level."* By documenting this trajectory, we highlight the evolving expectations and understanding of interactive sounds diners developed during the experience.

5.2.4 F8: Tension between interactive sounds and food creations. Our diners mentioned that the tension between interactive sounds and multi-sensory creations fostered their progressively evolving dining perceptions, distinct from traditional dining. For instance, D3 described Creation 3.3 (Figure 11): *"The first two sounds are universal as before [...] However, the most important difference is the later Thai music, with the mango sticky rice ice cream, which makes everything very reasonable [...] and makes me feel as if I am already in Pattaya."* Moreover, the taste also rationalized the sound perception. D3 added: *"The [Thai] music shouldn't start playing while I'm eating mango, as [...] mangoes can be from anywhere, [...] the key is that the music is played after tasting the sticky rice because it has a strong cultural reference."* Meanwhile, this tension also provided a progressively enhanced physical perception, as D4 described Creation 4.3 (Figure 11): *"The ice cream freezes the mint smell on its surface [...] and you can only feel it when you start eating it. With the slushie and the sound occurring at the same time, it feels like being in a cold environment, stimulating my taste buds so much that I can't help but shiver."* Furthermore, D3 highlighted the potential of these perceptions as an alternative to surroundings and environmental elements while enjoying Creation 3.3 (Figure 11): *"Some mental association can also occur in my mind. [...] I can imagine [...] and experience it similarly to the environmental information."*

5.3 Theme 3: Interactive Sonic Gastronomy Deployment

This theme illustrates a series of findings from deploying interactive sounds in dining scenarios, offering new insights from implementations beyond lab-based environments. This has led us to identify four sub-themes.

5.3.1 F9: Interactive sounds versus background music. At the beginning, all participants experienced eating ice cream with background music, which was described as a shared (n=5) and less noticeable (n=6) element while eating: *"If you eat in a restaurant, [...] you wouldn't intentionally focus on whether there is music around you, because it's not prepared for a particular customer"* (C4). D3 added: *"So you can choose to ignore it."* In contrast, seven participants noted that the real-time audio activation from the system placed them at the core of the interaction. Moreover, four participants highlighted the proximity of the sound source to their ears, emphasizing the role of sounds in eating. Interestingly, D6 observed that the natural style of interactive sounds (Figure 10, Creation 6.2), played in conjunction with melodious background music at the ice cream shop, catalyzed a concerto-like experience. D1 imagined: *"If a music restaurant's ambiance is Phantom of the Opera, I hope the meals today will also look like a theatrical performance [...] we use our utensils to make orchestral sounds that are consistent with the opera background. It must be very interesting."*

5.3.2 F10: The freshness and acceptance of interactive sonic gastronomy. Our participants mentioned varying acceptance levels for interactive sonic gastronomy across different dining establishments. Chefs reported a higher willingness to experiment with this innovative culinary experience in thematic restaurants (C1), fine dining establishments (C2), and omakase-style eateries (C6), which are generally more open to novel dining concepts. However, concerns were expressed about deploying interactive sounds in more traditional restaurants. Moreover, during a field exploration at an ice cream shop, we observed that environmental noise significantly impacted the presentation of interactive sounds: *"I think a quiet and private dining place is more suitable for creating this kind of atmosphere, and people will be more focused [...] If you are in an outdoor setting, these sounds might be ignored"* (C6). Additionally, two participants mentioned that deploying interactive sonic gastronomy should also manage diners' expectations and maintain a sense of novelty: *"You might not want to experience it every time because people's pursuit of novelty is always cyclical. [...] [Otherwise,] it might [...] no longer feel novel or creative"* (C2).

5.3.3 F11: Interactive sounds experimentation. In our investigation on sound preferences in dining scenarios, most participants showed a consistent preference for specific types of sounds, such as *steady* (C1), *soft* (D1, D2, C4), *mainstream* (C3, D3), *neutral* (C4, C6), *familiar* (C5, D5), and *elegant* (D4). Conversely, they rejected sounds described as *abrupt* (C2, D2, D4), *extreme* (C1), *disgusting* (D6), *impactful* (C1, C4), and *mismatched* (D2, D6). These findings contrasted with prior studies that used unexpected sounds intentionally to create a playful eating experience [107, 108]. D1 explained, *"Ice cream itself is a comfort food that makes you feel happy [. . .] and every generation loves it. So the sound shouldn't [. . .] [be] disgusting, or [. . .] impactful."* D4 added, *"Taste is the most important part during my eating, [. . .] if a sound draws my attention away from tasting, which could be annoying."* However, some participants thought these preferences stemmed from varying necessities in different dining scenarios. As five participants articulated, negative interactive sounds could be acceptable if they matched the thematic ambiance: *"If you go to a horror-themed restaurant, the surroundings are scary and thrilling [. . .] and the interactive sounds may include screams. [However,] when taste, vision, and sounds are combined, the overall experience can still be positive"* (C3).

5.3.4 F12: Interactive sounds reshape evaluation criteria for dining. Six participants indicated the difficulty in establishing unified personal standards for a harmonious interactive sonic gastronomic experience: *"[While] our benchmarks for the texture or taste are at least the same. [...] But everyone has different sensitivities, preferences, and standards for sounds, so I think this is a challenge [...] to make a sound that everyone finds good to experience"* (C1). For instance, D5, who had a background in deep learning, applied the concept of neural network weights to roughly formulate his evaluation criteria: "*Traditional dining experience = 0.5 * taste + 0.5 * vision,*" while "*Interactive sonic gastronomy experience = 0.5 * taste + 0.5 * vision + 0.2 * sound,*" interpreting interactive sounds as a bonus that enhanced without overshadowing other sensory experiences. Interestingly, this new criterion also led to a new consideration in chefs' culinary process: *"This reminds me of the nervousness and expectation I felt when I first entered the catering industry [. . .] I was concerned about whether my cooking would satisfy the diners at first, but now I'm concerned they won't like the sounds of my cooking [laughter]"* (C1).

5.4 Theme 4: Chef-diner interplay

This theme captures the diverse experiences arising from four different modes of interaction between chefs and diners during their engagement with *SoniCream*. Based on the participants' ranking of these modes (1 - most positive, 4 - most negative; i.e., higher is worse), we obtained the following results: co-design ($M = 1.5$, $SD = 0.76$), chef-led ($M = 1.75$, $SD = 0.60$), diner-led ($M = 2.83$, $SD = 0.55$), and system-led ($M = 3.58$, $SD = 0.76$). These results reveal that most participants consider co-design the most effective mode for enriching their collective gastronomic experience, which informed the development of our three sub-themes.

5.4.1 F13: Diner-led: Diners' engagement and chefs' concerns. The full participation in the diner-led phase brought diners a complete experience. D2 reported: *"I felt integrated into [the process] [...] [and] it met my expectations, [...] not just like tasting, but like a sense of creation and achievement. [...] I can go to any ice cream shop with this device."* The simple approach to uploading sounds allowed diners to craft their experience easily. D1 employed the sound effects of Mario's gameplay to create Creation 1.2 (Figure 10) for eating encouragement, stating: *"I want to integrate myself into a complete game process. This choice made me feel like I was always in the middle of the game, allowing me to experience a sense of fulfillment and continuous scoring. "* However, the diners' lack of professional food knowledge and the challenges of managing the melting properties of ice cream sometimes caused them to overlook visual presentation (e.g., Creations 1.1 and 4.1) and hygiene regulations (e.g., Figure 9, Creations 1.1 and 3.1), which led to anxiety (C1) and frustration (C2) among chefs. C1 explained, *"I am a little bit anxious, because if the diner does not have much cooking experience or is very sensitive to food, [...] it makes me want to step in and help her."*

5.4.2 F14: Chef-led: Diners' exploration and chefs' confidence. During the chef-led phase, two chefs expressed confidence in their abilities to meet challenges. They articulated heightened expectations for their creations: *"Although it can't be said to be a piece of cake for me, I think at least the degree of completion will be higher"* (C4). Meanwhile, the novel sounds from the chefs' creations sparked diners' curiosity: *"The ice cream with sounds [...] did have lots of surprises, like opening a mystery box [...] it makes me want to continue eating and explore what's next"* (D2). However, due to a limited understanding of diners' preferences, chefs preferred using conservative sounds and ingredients to enhance the fault tolerance of their creations: *"I choose steady sounds [...] it seems like everyone can accept them, in line with public preference"* (C4).

5.4.3 F15: Co-design: Participatory practices of chefs and diners. In the co-design phase, our experiment revealed that this co-creative collaborative fostered a synergy between chefs' expertise and diners' preferences to reach a consensus. We observed our participants ($n = 10$) actively crafting collective memories using multi-sensory food creations and interactive sounds, rather than a casual reminiscence. For instance, D3 and C3 reshaped their collective memories of Thailand using interactive sounds: *"The emotional state is prosperous, [...] because we both have been to Thailand [...] so when all these elements come together, they can strongly evoke the emotions of my Thailand memory"* (D3). C3 added, *"I feel the sense of accomplishment in this session is the strongest, [...] it's because we have a consistent understanding of the design concept or background."* However, we observed that in Creation 5.3 (Figure 11), excessive diner involvement led to unintended disruptions in the visual and gustatory design, prompting D5 to reflect, *"I hope to maintain my creativity, but chefs need to help me because they are professional."* In this way, we believed co-design was not solely about who led the creation but about achieving a balance between creativity and implementation.

6 Discussion

Our study reveals that interactive sounds, due to their flexible arrangement, varied configurations, and proactive activation, can serve as a novel element that supports chefs' culinary creativity, enriches diners' experiences, and influences their interplay. This distinction differentiates interactive sounds from ordinary auditory information, allowing to structure this discussion under three key headings. Furthermore, we propose four design implications derived from our study insights and the craft knowledge gained through designing *SoniCream* and conducting this study. We aim to build upon previous diner-focused HFI research related to interactive sounds, and guide designers who seek to create new interactive systems but are uncertain about where to start.

6.1 Interactive Sounds as a New "Ingredient" to Enrich Chefs' Culinary Creativity

Our findings suggest that incorporating interactive sounds as a novel "ingredient", which reframes gastronomy to be not only flavorful but also audibly engaging, can significantly enrich chefs' culinary creativity. This enhancement is achieved by embedding auditory properties (e.g., type, frequency, loudness) into gastronomy (*F1*), enabling multiple sound configurations to align with the spatial and narrative arrangements of food (*F3*), facilitating diverse thematic culinary expressions (*F2*), and promoting auditory culinary experimentation and customization (*F4*). These findings align with prior HCI research on creativity-support tools [45, 49], which uses technology to assist designers in transitioning from divergent to convergent creative processes. Our findings extend this theory by showing how chefs synthesize their expertise and aesthetic sensibilities with existing culinary resources [7, 8, 32] to innovate various food designs [31]. We observed this enrichment appears to stem from the unique traits of the *SoniCream* system: (1) real-time auditory perception triggered by eating behaviors and (2) the alignment of food designs (e.g., layers and themes) with sound features (e.g., sequences and characteristics). These two facets not only expand the boundaries of chefs' creative skills and imagination, but also highlight two key design implications for integrating novel interactive technologies to enrich their culinary creativity.

6.1.1 Design implication 1: Using synchronized perception between interactive technology and eating behavior to enhance food expressivity. Synchronization is defined as the temporal coordination of behaviors [38], with evidence suggesting that when individuals move in sync, it can blur the distinction between self and others [64, 100]. The triggering mechanism in our *SoniCream* system validates these theories, demonstrating that real-time synchronization between sensory inputs effectively blurs the boundary between food and auditory properties. Additionally, we refer to the definition of synchronization in electronic music [77], which corresponds with the internal coding mechanism of the *SoniCream* system (in Section 3.2.3). In this mechanism, the current sound file continues to play without being overwritten by subsequent licking behaviors, emphasizing the continuous and uninterrupted auditory experience during the eating process. This integration expands the expressiveness of food, offering a potential pathway for interactive designers to synchronize interactive technologies with eating behaviors, thereby providing chefs with novel culinary resources enriched with digital properties.

To implement this implication in real dining settings, we recommend interaction designers first consider the unique eating behaviors specific to different types of restaurants, such as the drinking behavior in bars or the licking behavior in ice cream stores. Building on these insights, designers could integrate multiple reconfigurable channels into HFI systems to better align digital technologies with these eating patterns, thereby enabling chefs to program a harmonious dining experience with real-time digital content. However, a significant challenge is preventing dissonance in these digitally enhanced dining experiences. Therefore, cultivating new culinary expertise to adapt to and harmonize with these HFI systems is essential for chefs to craft innovative food creations.

6.1.2 Design implication 2: Aligning interactive technology with food creations to foster comprehensible culinary expressions. Culinary expression, externalizing a chef's inner world onto a perceptible dish, represents another interpretation of culinary creativity, encompassing creative impulse, tangible mediums, and a final harmonious experience [54]. Prior research in HFI highlights that chefs leverage the alignment between basic tastes and affective responses as a key resource for constructing harmonious culinary narratives [31]. This alignment further explored through the lens of cross-modal correspondence, is described as the synchronization of sensory perceptions with expectations [86, 109]. Our study confirmed this understanding, revealing that chefs intentionally utilized *SoniCream*'s concave space to spatially arrange ingredients and food layers, crafting visually and gustatorily coherent themes. Furthermore, by adding interactive sounds, chefs configured various auditory properties (e.g., volume, sequences, duration, and audio overlap) to enhance these expressions. This shift marked a culinary narrative progression from implicit perceptibility to explicit comprehensibility in dining scenarios.

Therefore, during the deployment process, we recommend that interaction designers not only provide ample space to enhance chefs' spatial arrangement of food but also design digital content that complements their culinary expressions. This could involve developing a parametric interface that allows chefs to assign digital content in alignment with key culinary elements (e.g., ingredients, tastes, diners' eating trajectories) while ensuring interaction transparency to facilitate their culinary workflows [26]. However, accurately achieving these correspondences in dining scenarios to foster harmonious narratives remains challenging, potentially leading to misaligned experiences. Although such misalignments (e.g. delays, ambiguity) have been described as unforeseeable culinary improvisations [22] that may enhance the immersion and curiosity of diners [91, 94], efforts should focus on minimizing uncontrollable presentations to support the intended expressions of chefs.

6.2 The Cross-modal Dining Experience Can Enrich Diners' Dining Perceptions

Our findings highlight how interactive sounds mutually regulate and shape cross-modal perceptions through interplay with multiple modalities, such as various mouthfeels (e.g., texture, temperature, taste) and visual appeal, in food creations. This cross-modal perception fosters a counterintuitive experience in dining settings (*F6*). Additionally, the interactivity of sound brings changes in aural awareness and eating paces (*F5*), aligning with prior work that utilizes auditory elements to adjust food perception [47, 50]. Prior sound-related HFI research has shown that these perceptions are often unpredictable, as they are linked to personal experiences [109]. Our findings confirm this insight through diners' various personal interpretations of each creation (*F7, F8*). We extend this understanding by demonstrating that interactive sounds are anchored in chefs' curated culinary narratives, promoting diners' diverse yet theme-consistent mental associations rather than random memory recall. These targeted associations represent a cost-effective avenue for enhancing immersive dining experiences by substituting ambient environmental information, offering chefs a new direction for crafting culinary innovations to engage their customers.

6.2.1 Design implication 3: Leveraging digital content as sensory anchor to navigate thematic mental associations. Prior research highlights that multi-sensory information can trigger memory recall [78] and mental imagery [5]. However, activating such mental associations often requires additional sensory stimuli [67], which essentially reconfigures the limited cognitive resources in dining experiences to prioritize these stimuli as the focal point. This aligns with prior HFI research that regards such stimuli as thematic anchors in culinary artifacts, facilitating the material narratives of dishes [22]. Our findings extend the use of these anchors through auditory interactivity, which empowers diners with an interactive approach to generate digital content and navigate their mental associations within chefs' curated culinary narratives.

These observations indicate that interaction designers could focus on the presentation of digital content — such as its timing, intensity, or content — as dynamic anchors for arranging attentional resources during the dining process. These anchors can enhance diners' immersive experiences and navigate their mental imagery in alignment with chefs' orchestration. This signifies that future dining experiences might not only emphasize diverse flavor experimentation but also incorporate cognitive priming [97]. However, a key consideration is to avoid excessive mental manipulation, which could disrupt the boundaries of diners' harmonious experiences.

6.3 Interactive Sonic Gastronomy Can Forge a New Bond for Chefs and Diners

Recent research has begun to investigate how novel technologies can influence chefs' workflows and diners' experiences [41, 98], aligning with our study's exploration of interactive sonic gastronomy and its impact on the catering industry (*F9*), emerging standards (*F12*), consumer preferences (*F11*), and practical deployment (*F10*). To examine how interactive sounds can enrich a harmonious gastronomic experience, we implemented four participatory phases in our study, each reflecting varying degrees of **food agency**. Our findings suggest that these different approaches can foster dynamic engagement experiences for chefs and diners. Since both chefs and diners demonstrated comparable levels of understanding of emerging digital content, the collaborative mode (*F15*) can facilitate a more rapid, consistent, and mutually enjoyable user experience compared to other modes (*F13, 14*). Additionally, the FA framework provides a flexible and generalized foundation for future investigations into other sensory modalities in dining, such as visual, olfactory, and tactile experiences.

6.3.1 Design implication 4: Balancing chefs' and diners' creativity and implementation for a shared gastronomic experience. The co-design phase of our study aligns with the principles of participatory design [95], emphasizing collaboration between interaction designers and stakeholders to create tools or systems that fully address their needs. Our study extends this perspective by shifting the focus from participatory design of HFI systems to a broader concept of participatory practices in gastronomy creation [110]. This shift challenges the unidirectional, chef-centric model and emphasizes a creative reconfiguration of gastronomic experiences that involves both chefs and diners. This seeks to achieve a harmonious balance between creativity and implementation, rather than the simply binary categorization of task loads.

Therefore, we recommend that interaction designers develop a dining hub that allows diners to contribute creative interaction insights, helping chefs better understand their preferences. This hub would leverage chefs' professional expertise to craft enriched dining experiences through the emerging interactive food interfaces. For instance, the hub could be designed as an app or incorporate generative AI as a transformative medium, fostering a dynamic interplay between chefs and diners. This approach aims to encourage diverse interactions, fostering a collaborative and inclusive dining environment that enhances the shared gastronomic experience.

7 Limitations and Future Works

This study has several limitations. First, we selected ice cream as the primary culinary resource due to its accessibility and compatibility with various ingredients, which facilitated our preliminary exploration of using its moist properties and capacitive sensing for sound triggering. However, this choice limited our exploration to foods with conductive properties, overlooking the potential for interactive sound engagement with dry yet flavorful foods. Future research should aim to design interactive systems that support a broader range of foods to enable more decadent culinary creations. Second, we observed some unnatural interaction flows in *SoniCream*, particularly in downloading and uploading sounds via SD cards. Therefore, developing an application for food-sound interaction could simplify this process, enabling a more seamless culinary experience for crafting interactive sonic gastronomy. Third, our study confined eating behaviors to licking, excluding other interactions such as cutting, dipping, and stirring, which are common in dining scenarios. This limitation highlights the need for further development of systems that can accommodate diverse eating behaviors and trigger interactive sounds accordingly. Additionally, since our research primarily focused on the intersection of auditory interaction, HFI research, and user experience, we missed the opportunity to contribute an additional perspective to the sonic interaction design community. In future sound-related HFI research, one could broaden the scope of our contributions through a more in-depth investigation into the essential properties of sound (e.g., timbre, sound quality, velocity) and participants' inner processes of sound selection.

Notably, our study gained valuable insights from the concept of "developer experience," which captures software developers' perceptual impressions and responses towards development platforms in their work environments [29]. We propose that chefs and software engineers engage in human activities fundamentally driven by intellectual effort and creative ideation [27]. In terms of HFI research, the gastronomy developer experience for chefs should not only include the use of interactive systems for culinary innovation but also incorporate their expertise [12], along with diners' experiences and feedback, which together inform their culinary experiences. Therefore, as interactive technology continues to evolve, this understanding encouraged us to broaden the application of this concept, advocating for more inclusive empirical research into user experiences in interactive systems that support content and creative generation across various professions, including teachers [51], tattoo artists [79], and multimedia artists [43]. We may need to set a general baseline to understand their needs and experiences for future targeted investigations, ensuring that interactive systems can be effectively integrated into their creative workflows.

8 Conclusion

We aimed to broaden the scope of traditional sound-related HFI research by incorporating chefs' engagement via the *SoniCream* system that resulted in 18 unique ice cream creations. Our findings revealed four themes at the intersection of chefs, diners, and interactive sounds, offering design implications for interactive designers interested in supporting chef's culinary creativity to enrich dining experiences. These implications include: (1) enhancing food expressiveness and fostering narrative orchestration to inspire chefs' culinary creativity, (2) navigating mental association trajectory to elevate diners' experiences, and (3) establishing a new mode of chef-diner interplay that balanced creativity and practical implementation for shared gastronomic experiences. As a preliminary exploration, we hope our work lays the foundation for integrating emerging interactive technologies into the culinary domain.

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A APPENDICES

A.1 Ideation worksheets

Figure 12: Ideation worksheets from chefs.

Figure 13: Ideation worksheets from diners.

Figure 14: Co-design worksheets.

A.2 Sound options inspired by PLEX card and system-led creations

Table 2: Chefs' sound options from the system-led phase.

Chef	Ice Cream	Sound Options
C1	Vanilla	Captivation -> Nurture
	Chocolate	Discovery -> Expression
	Strawberry	Relaxation -> Exploration -> Subversion
C2	Vanilla	Eroticism -> Humor -> Relaxation
	Chocolate	Discovery -> Fantasy -> Nurture
	Strawberry	Control -> Exploration
C3	Vanilla	Captivation -> Relaxation -> Exploration
	Chocolate	Discovery -> Fantasy -> Thrill
	Strawberry	Exploration -> Nurture -> Completion
C4	Vanilla	Fantasy
	Chocolate	Completion
	Strawberry	Captivation
C5	Vanilla	Fellowship
C6	Vanilla	Relaxation
	Chocolate	Discovery
	Strawberry	Completion

Table 3: Sound descriptions inspired by PLEX cards.

Plex Card	Sound Descriptions
Captivation	A stable, melodious, and crisp music box lullaby.
Challenge	Tiger's howl.
Competition	A group of people applaud and cheer for you.
Completion	A game sound effect that signifies your success in passing the level.
Control	A brief whistle to call the horse back from afar.
Cruelty	An exaggerated scream of a person whose buttocks are set on fire.
Discovery	The astonished exclamation of a group of young boys discovering treasure.
Eroticism	An ASMR segment.
Exploration	The echoing bird calls in a quiet primal forest.
Expression	A voice clip saying, 'I don't know, maybe it's easy to get a new one.'
Fantasy	A flowing, ethereal, and mysterious string music.
Fellowship	A group of young boys singing together about their friendship.
Humor	A whistling melody.
Nurture	A young girl singing a nursery rhyme.
Relaxation	The ebb and flow of ocean waves.
Sensation	The sound of vomiting.
Simulation	A person mimicking the sound of a hen laying an egg.
Submission	A voice saying 'hello.'
Subversion	A rock electric guitar riff.
Suffering	A desperate scream of a person struggling.
Sympathy	A group of spectators expressing sympathy, followed by applause.
Thrill	A cold and serious countdown.