Understanding User Needs for Task Guidance Systems Through the Lens of Cooking

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ABSTRACT

To design intuitive and effective context-aware task guidance systems, we must understand users' thought processes and the obstacles they experience when they perform tasks. Though task guidance systems have proven beneficial in many domains for improving task performance and reducing user frustration, there is a lack of general guidelines and design principles for their development. Prior work has shown that recipe-based cooking is a strong medium for studying task planning and execution. In response, we conducted a contextual inquiry study in home kitchens, observing eight different participants' cooking sessions. We used affinity diagramming of our notes and transcripts to identify common obstacles faced by participants and establish user needs in the areas of object interaction, safety, knowledge base, and task coordination. We discuss how these findings can inform the design of technology-driven solutions for task guidance systems beyond cooking.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **HCI theory, concepts and models**;

KEYWORDS

task guidance systems, user experience design, contextual inquiry

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1 INTRODUCTION

Task guidance refers to providing information, such as step-by-step instructions or demonstrating how a task is done, to individuals as they work towards achieving a goal. Task guidance has been used in several domains including aircraft inspection [32], surgical training systems [12], cooking [10, 35], and household equipment operation [37]. Some conventional methods of task guidance for aiding procedures include paper checklists, written or verbal instructions, and visual aids. However, these methods can often lead to tasks and sub-tasks being overlooked [32]. For example, some of the standard errors made with paper checklists include forgetting what the current item is, skipping steps because of interruptions or distractions, failing to return to an instruction that was skipped intentionally, and claiming a task was completed when it was not finished [33].

Technology-assisted task guidance systems, like navigation tools (GPS) or smart-home assistants (Amazon Echo), all aim to enhance procedure following and provide information to individuals while completing a task. Effective task guidance systems can improve task performance and reduce user frustration [9, 32]. The efficacy of task guidance systems is often determined by factors related to the users of such systems, being influenced by aspects like how relevant the assistance provided is perceived to be to the current context, how the guidance is delivered, and when feedback is given [18, 22]. For these reasons, it is imperative to approach the design of task guidance systems from the perspective of the user, ensuring that task support is offered intuitively, effectively, and efficiently.

While task guidance systems are instrumental in various contexts, there are opportunities to establish a set of user needs for developing these systems from a user-centered perspective. Given the wide applicability of task guidance across numerous domains, creating universally applicable user needs poses a considerable challenge. However, there are shared attributes prevalent across numerous domains where task guidance systems can be effectively utilized. These include the necessity for adhering to a sequential, step-by-step methodology, the utilization of specialized tools, and the engagement of various executive functions. Executive functions encompass high-order cognitive abilities such as working memory, inhibitory control, cognitive flexibility, planning, reasoning, and problem-solving [8].

Cooking, which is a commonplace daily activity for humans, is a perfect example of a task that may require following a recipe, using multiple kitchen utensils, and demanding several executive functions from the user [7, 46, 47]. Recipe-based cooking refers to a set of instructions that guide a cook on how to prepare a dish with an intended outcome [4]. In contrast to improvisational cooking [29], which is characterized by a chef altering steps or ingredients to the recipe on-the-fly, recipe-based cooking usually involves sticking to a set of guidelines. Cooking is an activity that can be done by most people and in most homes, and one that does not necessarily require special conditions or equipment besides what can already be found in common kitchens. For these reasons, the task of cooking serves as a favorable testbed upon which user needs for general task guidance systems can be elicited and understood. Examining how humans manage the cooking task provides valuable insights that can serve as the foundation for task guidance systems applicable to cooking and across diverse domains. In this context, it is essential to note that existing technology interventions, such as Majil et al.'s AR cooking assistant [27], while promising, lack the user-centered foundation necessary to develop user needs for robust and adaptable task guidance systems.

Our study aims to contribute to the scientific community by creating a set of user needs for task guidance systems through a contextual inquiry study. The collection of user needs will help designers and creators develop more effective and user-centered designs for task guidance technology interventions in cooking settings and beyond. We conducted a contextual inquiry [3] study with eight participants tasked with cooking a recipe while they were being observed. Each of the user study sessions took place at the participant's home. The participants were asked to cook the recipe as if researchers were not present in the room and to follow the think-aloud protocol [19]. We used affinity diagramming of our notes and transcripts to identify common obstacles faced by participants and design opportunities in the areas of object interaction, safety, knowledge base, and task coordination.

In this study, we make the following contributions:

- A comprehensive set of user needs organized into four key areas of interest. These findings synthesize users' requirements and pinpoint opportunities to enhance technology-driven task guidance systems in the context of cooking.
- An evidence-based argument supporting the broad applicability of our findings in guiding the design of technology-based task guidance solutions across various domains beyond cooking.

2 RELATED WORK

We focus our review of prior work on two categories: (1) task guidance systems and their current limitations and (2) examining existing work in human-food interaction, highlighting the lack of comprehensive user needs for designing task guidance systems.

2.1 Task Guidance

As mentioned previously, task guidance is used in many domains and forms, ranging from aircraft inspection [32] and surgery [12], to cooking [10, 35] and household equipment operation [37]. Some conventional methods of task guidance for aiding procedures include paper checklists, written or verbal instructions, and visual aids. However, these methods can often lead to tasks and sub-tasks being overlooked [32]. For example, some of the standard errors made with paper checklists include: forgetting what the current item is, skipping steps because of interruptions or distractions, failing to return to an instruction that was skipped intentionally, and claiming a task was completed when it was not finished [33].

Researchers have explored various areas where task guidance systems could be beneficial. For instance, Rich and Sidner developed a task guidance system to help users operate household equipment on a daily basis [37]. The authors created this system in response to the problems caused by technology being overly complicated due to lack of consistency in user interface design [37]. Task guidance systems have also been explored in medicine, specifically to help conduct surgery. Escobar-Castillejos et al. reviewed the current state of training and guidance systems in medical surgery [12]. Their study revealed that these guidance systems serve multiple purposes beyond simple guidance; they also offer assistance and facilitate evaluation. The researchers argue that automating evaluation processes through these systems has the potential to alleviate the workload of experts in the field [12].

The results of prior research demonstrate that task guidance systems have diverse applications, from assisting in surgery to aiding in everyday tasks like reading labels and cooking. Task guidance systems have also been shown to improve task performance [32] and reduce user frustration [9]. However, different requirements and preferences must be considered when designing these systems, such as the *expertise reversal effect* [20, 41]. The *expertise reversal effect* states that providing too much information to an expert can be counterproductive, and providing too little information to a novice can be problematic.

To overcome some of the limitations of existing systems, prior work has developed design guidelines for task guidance in specific contexts, including production lines [43], navigation systems [31, 34], and maintenance [38]. The guidelines are motivated by integrating employees into the design process to improve acceptance [43], considering cultural experiences [31], and commercially available systems not meeting the needs of users [34]. Additionally, prior work has shown that most systems are prototypes developed in a lab setting [38]. Despite the progress, the presented user guidelines are still limited to their use context [43] and don't provide guidelines for dangerous situations [31]. Also, users are not always willing to trust and accept new technologies [34].

Additionally, Muller et al. presented how task guidance and technology assistance have been employed in a cooking setting [30]. They explored how people use tablets in their daily activities, which they investigated through multiple research methods, including a contextual inquiry approach. Within their findings, they point at the necessity of including cooking as a critical use case for tablet design and development since they identified multiple opportunities where this kind of technology interaction proved to be a valuable activity to many of their users. Similarly, a study by Brick et al. explored how task guidance and technology assistance can help sight-impaired people around the kitchen [35]. They tested a system that scans images of the food available in the kitchen, processes text in containers, and helps the user by answering queries such as how long to cook something for or if it contains ingredients that they might be allergic to. Finally, a study by Woodward and Ruiz used cooking-related activities to determine how to better present visual information to users in AR headsets, which demonstrated the effect of the location of information on task performance [49].

In summary, primitive methods for providing task guidance, such as paper checklists or visual aids, lack the ability for error correction and safety nets. While prior work has investigated methods for presenting complex instructional information to users, the needs of users with varying levels of expertise are not met. Finally, prior work has identified user requirements for task guidance systems in specific domains. However, these requirements have been limited to their activity context and are mostly focused on technical features.

2.2 Human-Food Interaction

Since we chose to study task guidance in the context of a cooking scenario, it is appropriate and favorable to draw on literature, studying the domain of Human-Food Interaction (HFI). HFI is an interdisciplinary field that examines the intricate dynamics between humans and various elements of the food experience. This includes but is not limited to, culinary activities, nutrition, sensory experiences, social interactions, and, where applicable, the role of technology. As cooking today remains a basic aspect of daily life, there is an increasing interest in developing and advancing technology to make the task of cooking easier for everyone. HFI not only explores the design of interactive systems to help users in a cooking setting, but it also strives to understand users and accommodate their preferences in a kitchen environment. Previous work in HFI has mostly explored corrective technologies, for example, providing clarity when there is ambiguity, and turning inexperience into aptitude rather than just helping improve people's cooking skills [15]. However, as the field of HFI evolves, researchers are exploring novel approaches to enhance cooking experiences and kitchen technologies.

Research in HFI has provided insights into the nature of cooking skills and practices. Short F. conducted a qualitative study of 30 cooks in England aiming to establish a theoretical and empirical-based 'way of thinking' about domestic cooking and cooking skills [40]. Their findings revealed that cooking skills can be seen as either task-centered or person-centered. Furthermore, they found that cooking consists of many different elements, including perceptual, conceptual, and organizational skills. Another study by Van Asselt et al. analyzed videos of 25 participants making a chicken-curry salad at home [45]. The videos were obtained from a previous study by Fischer et al. [13]. The purpose of Van Asselt et al.'s work was to validate the transfer rates and microbial analysis obtained from a previous study [44]. The results showed there was a wide range of microbial contamination levels in the finished salad caused by various cross-contamination practices, shedding light on the importance of safety and hygiene during food preparation.

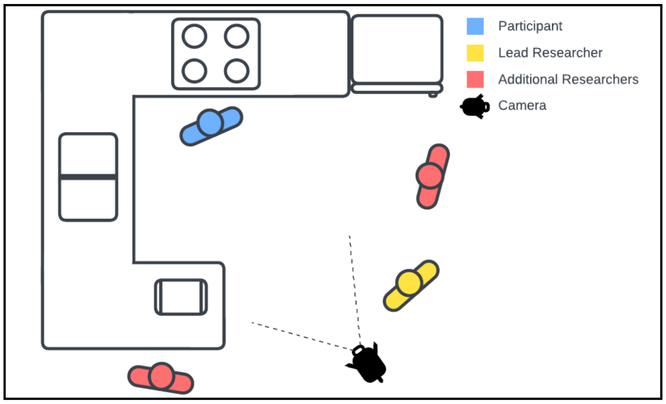
User-centered design is an important aspect of HFI research, particularly when designing cooking aid systems. For example, previous work by Esau et al. conducted a contextual inquiry with 15 participants as part of their study to understand food practices at home, with the end goal of making a voice assistant that conveys embodied knowledge to its users to prevent food waste [11]. Esau et al.'s work showed that understanding how users assess food edibility and make informed decisions can help us develop cooking guidance systems. Their work also highlights the importance of embodied knowledge in cooking [11]. Building upon the significance of user-centered design in cooking technologies, Kuoppamäki et al. delved into the design of kitchen technologies for older adults [23]. Their study presents possibilities for assistive technology to provide physical and cognitive support to older adults while cooking a meal at home, such as supporting the selection of tools around the kitchen, assessing the progression of tasks, or suggesting alternative methods to perform tasks in a way that encourages user adaptability. The researchers derived these opportunities for technology by analyzing the recordings of six adults, aged 65 years and older, as they prepared a meal at home.

Researchers also used the contextual inquiry method as an approach to comprehend the cooking behaviors of home cooks [6], with particular emphasis on calorie awareness. Through this approach, researchers could observe users in their natural context and gain a deeper understanding of their cooking experiences. A different technique was employed by Ricci et al., who conducted research in the realm of augmented reality (AR) task guidance, specifically targeting the utilization of stand mixers [36]. In their case study, the team analyzed the experiences of home cooks through surveys, uncovering user needs and system requirements to help build an AR application that can aid individuals in cooking with stand mixers.

While a portion of HFI research delves into cooking assistance and guidance systems [1, 16, 25, 39], the field's dynamic scope encompasses diverse areas spanning sensory engagement, nutrition optimization, and exploration of the socio-cultural dynamics surrounding food. Various studies have explored design principles and implications within this broader context, highlighting the benefits of understanding users to develop effective kitchen technologies. From assessing food edibility to emphasizing embodied knowledge in cooking, previous work has laid the foundation for cooking guidance systems. However, despite these valuable contributions, comprehensive guidelines for designing such systems are still lacking, considering the full spectrum of human-food interaction. Our study aims to contribute to this knowledge gap by identifying breakdowns and opportunities in which task guidance systems could positively intervene.

3 METHODS AND PROCEDURES

Our user study was conducted using the contextual inquiry method, a user-centered approach focused on understanding how people engage in various activities in their natural context [3], aimed to observe cooking as a holistic experience. Unlike previous studies that delved into users' cooking behavior with specific technologies (e.g., [6, 30]), our approach deliberately refrained from introducing new technology or concentrating on device interactions. The study involved eight participants from the southeastern United States, who undertook the preparation of a *coq au vin* recipe in their home kitchens, utilizing their own appliances and utensils. *Coq au vin* is a dish that consists of chicken, vegetables, and other ingredients braised with wine. The recipe was designed in consultation with a professional chef hired by our team as a consultant. To help us cover an ample range of task planning and execution demands normally present in cooking [7, 46, 47], we asked for a recipe consisting of multiple tasks, parallel activities, and an above-average level



(a) A diagram of the study setup in a participant's kitchen.

(b) An example image from our recordings.

Figure 1: Study setup and recordings

of complexity. The recipe also required the application of specific cooking techniques that might not be familiar to every home cook, such as julienne cuts or blanching pearl onions. Due to its complexity, another advantage of choosing this recipe was its potential to help us identify more opportunities for technology-assisted task guidance in scenarios where the task was difficult or when the user was unfamiliar with the steps to be followed.

3.1 Procedure

We recorded participants and their cooking environment using a high-definition video camera, capturing both the user and their context, as shown in Figure 1. The lead researcher and participants wore audio recorders to capture their voices during each study session. All recording equipment was synchronized with a visual and auditory cue.

At the beginning of each study session, we obtained informed consent and explained the task they would perform to each participant. To minimize the impact of our presence in the kitchen, we instructed participants to cook as if the researchers were not present. Participants were encouraged to use any cooking utensils, procedures, and external tools they were familiar with, all without making any changes to their usual kitchen layout. Researchers maintained a discreet distance, limiting their presence to necessary interactions for safety or clarification. Participants were given a paper recipe to follow, which they were required to use during the cooking session. We also asked participants to follow the think-aloud protocol while they prepared the recipe and executed the various cooking tasks. If at any time the participant stopped speaking, we reminded them to continue to share their thoughts throughout the study. We also asked questions during the study session in order to clarify and obtain additional insights into the participant's actions. For example, one participant picked a specific silicon curved spatula from among other utensils to use to move the bacon around the pan. When asked about the utensil choice, the participant explained that they picked it because it was clean, it would not melt in the hot oil, it had some "spoonage [sic] quality", and it would not damage the nonstick pan. These insights and rationales were gathered for as many of the participants' decisions as possible. In each study session, there was one lead researcher and two additional researchers. The lead researcher monitored the participant's performance and asked the majority of interpretation questions, while the two additional researchers observed, took notes, asked specific clarification questions, and handled equipment setup and disassembly. Researchers' notes included observations and timestamps. Once the study session was completed, we asked the participant additional questions clarifying their experiences throughout the cooking task and finally debriefed them about the study's final details.

The study was conducted in each participant's home kitchen. To increase participants' focus and attention and be aware of safety concerns, we did not allow external distractions such as music or television to play during the study, even if the participant would normally cook with such media playing. Each study session was approximately two hours, including setup and the post-study questionnaire, over 85% of which was active cooking time. Participants did not know what recipe they would work on before the study started; however, one participant mentioned he had cooked *coq au vin* at least once before. Participants were provided with all the ingredients necessary for the study and utilized their own kitchen appliances and cooking utensils. All participants were compensated $100 for their time. Our Institutional Review Board approved our protocol.

3.2 Participants

The study was conducted with eight participants (six identified as female, and two as male[1]) between the ages of 22 and 74 years old (mean 41.9 years, SD = 20.0 years). We recruited participants through word of mouth, with a minimum age requirement of 18 years old. In the post-study questionnaire, we asked participants to rate their cooking skills on a scale between 0 and 100, with 0 meaning they had no experience cooking and 100 meaning they would consider themselves experts. As shown in Table 1, participants rated themselves between 50 and 88 (mean = 64.9, SD = 12.8). No other identifying information was collected.

[1]Multiple options were available, including trans and/or gender non-conforming and 'prefer not to say'.

Table 1: Participant demographics and self-reported cooking skill, on a range from 0 (none) to 100 (expert).

Participants			
Id	Age	Gender identity	Self-reported cooking skill
P1	34	Female	50
P2	Not reported	Female	50
P3	30	Male	60
P4	74	Female	71
P5	66	Male	80
P6	29	Female	60
P7	38	Female	88
P8	22	Female	60

3.3 Analysis

Once all eight of the contextual inquiry study sessions were completed, we performed multiple team interpretation sessions [3] of the notes we took during the studies, which contained exhaustive observations about the participants' actions while cooking, capturing participants' interactions with the recipe instructions, their problem-solving strategies when facing unexpected challenges, and their overall level of comfort and confidence in the kitchen. Every individual observation was transferred into a virtual sticky note on an online platform called Miro [28], making a total of 828 notes. Our team of four researchers, with one acting as a facilitator, met through Zoom to proceed with grouping the sticky notes into overarching concepts using a bottom-up approach with affinity diagrams [26]. Each researcher would individually organize notes in both synchronous and asynchronous iterations. During synchronous sessions, we met through Zoom to discuss initial groupings. Throughout the process, we also worked asynchronously, organizing notes individually and then reconvening to discuss and refine our groupings. As part of the process, we frequently referred to the video and audio recordings to clarify, verify, and expand on the content of the sticky notes. We first grouped the notes into 148 clusters. We then further grouped them into 33 clusters of related themes using the same iterative process. Based on these 33 clusters, we developed 15 user needs. Finally, we grouped these user needs into four overarching themes: *Object Interaction*, *Knowledge Base*, *Safety*, and *Task Coordination*. Fewer than 10 percent of the total number of notes did not fit with the other themes. Often, notes appeared in multiple groupings to avoid over-generalizations.

4 FINDINGS

This section presents our observations from contextual inquiry organized among the four main themes: Object Interaction, Knowledge Base, Safety, and Task Coordination. We also present user needs for a contextual task guidance system based on our findings.

4.1 Object Interaction

This section primarily focuses on understanding how users navigate, adapt to, and make decisions regarding the various objects in their cooking environment. Our findings reveal the challenges users face, the strategies they use to overcome these challenges, and areas where additional support or guidance could be beneficial.

4.1.1 Reactions to working with unfamiliar objects. Participants had mixed reactions when working with objects that they were unfamiliar with. A couple of steps in the *coq au vin* recipe involved weighing a specific amount of ingredients. For example, step 4 tasked the participant with weighing four ounces of bacon. Participants used different tools to accomplish the task. Furthermore, Participant 6 was unfamiliar with their own scale since they did not use it frequently and had to spend some time figuring out how the device worked. This additional work resulted in them taking longer than usual on a simple measuring step. Another example came from Participant 1. They searched for a video that explained how to prepare pearl onions. Once the video was finished, they attempted to follow the steps. They took out the colander to strain the pearl onions, but they had to return to the video when they realized they were unfamiliar with how to properly use it. From our observations, we concluded that **users need help when working with unfamiliar objects.**

4.1.2 Picking the optimal object when multiple options are available. There are multiple ways to achieve a goal. However, some decisions prove to be more efficient in the long run. Throughout the recipe, participants struggled to choose between different-sized bowls, cutting boards, knives, and even the right amount of ingredients. Participants with less cooking experience changed their tools more frequently or were unsure of their choices. We noticed participants chose a tool and later regretted not choosing a different one that would better suit the performed step. For example, Participant 6 grabbed a mixing bowl to hold their ingredients but later mentioned they were unsure if it would be big enough. While preparing the pearl onions, Participant 7 grabbed a little bowl. They then reconsidered their choice and returned the bowl because they realized they would need to boil the onions.

Participants were conscientious when choosing which ingredient they would use in the recipe. When picking out carrots from a bag, Participant 3 found themselves replacing the carrot they had initially taken out because they felt a bigger carrot would be more convenient. As they picked out the thyme stems, Participant 5 chose the longer ones since they could provide more leaves. In a time-sensitive task, participants would impulsively choose whatever was readily available without considering the long-term effects of their choice. This suggests that **users need assistance picking the right object quickly when multiple options are available.**

4.1.3 Finding substitutions when the right tool is not available. In our study, we saw that participants had to improvise if they did not have the correct tool for a step in the recipe. For example, a crucial step in the *coq au vin* recipe involves placing all ingredients in a Dutch oven, a type of lidded cooking pot suitable for use inside regular ovens, and then placing the Dutch oven in the regular oven for 35 minutes. Unfortunately, 6 out of 8 participants did not have a Dutch oven and resorted to using a pan as a substitute. Due to high temperatures, not just any kind of pot or pan can be used to replace the Dutch oven. Placing inappropriate items in the oven could produce toxic fumes or melted cookware. On one occasion, Participant 6 attempted to use a pot with a plastic handle and lid without realizing it would later be placed in the oven. The researchers intervened before the participant placed the pot into the oven, avoiding a possible accident.

A common theme among all participants was using Google to answer any confusion about the recipe. Most of the study participants also used Google for other reasons, but for this section, we will focus on how they used it to find substitutes: mainly to find substitutes for any missing tool they may need. Participant 3 considered using a giant pot for turkey roasting as a Dutch oven and uploaded a picture onto Google to see what it was. The results informed the participant that their pot was not a Dutch oven, but they decided to use it as a replacement.

As participants progressed through the task, the readily available tools would decrease or simply be unavailable. Dirty pots and pans would be left in the sink, and sometimes even preferred spoons would not be accessible. Most participants did not have some specific cooking equipment the recipe called for and had to improvise. Furthermore, based on our observations, **users need to know what to use as a substitution if they do not have the needed tool.**

4.2 Knowledge Base

This section explores participants' experiences in the cooking process, focusing on their interactions with the environment, their understanding of terms and techniques, and how they handle unfamiliar tasks and unexpected events. The findings highlight potential areas where additional support or guidance could enhance users' cooking experiences.

4.2.1 Finding objects around the kitchen. Despite being in their own homes, participants often had trouble looking for a specific tool or ingredient in their pantry. For example, Participant 8 rummaged through their drawers looking for a peeler, and when they could not find one, they ran to their neighbor's home to borrow theirs. Participant 4 also had trouble finding their peeler and searched through their drawers, which took time away from the task. They even considered using a knife as a substitute when they could not find anything until they finally found the peeler. Similarly, Participant 6 did not have a place to store their leftover chicken and had to search through their cabinets and dishwasher for a clean dish.

Participants also forgot where they may have placed an item. After removing the cork of a wine bottle, Participant 5 placed it down on the counter and forgot where they placed it. They mentioned, *"...it was in a different place than what I usually do."*

Knowing the environment proved to be a valuable resource to participants during the task. Participants would take out all of the tools and ingredients they assumed would be needed before beginning the recipe for easy access later on. However, participants still struggled to stay organized throughout the task despite anticipating future outcomes. Participants would forget where they may have placed an item or where they last left a peeler and spend time looking for them. Based on our observations, we conclude that **users need help finding objects in their working environments.**

4.2.2 Understanding the definitions of terms. Due to the complexity of the recipe, participants used Google to define unfamiliar terms and phrases. One step in the recipe called for cutting carrot pieces "on a bias." Cutting on a bias involves cutting an ingredient diagonally against the natural grain. Overall, participants were unaware of how to cut on a bias. Participants 6 and 8 unintentionally skipped this step and cut the carrots across horizontally. Furthermore, Participant 7 did not know what it meant and did not bother looking it up. Only Participant 2 searched for cutting on a bias and learned they had to cut the carrots at an angle against the grain from the results.

Another instance where participants did not know what a term in the recipe meant was after taking out the stew from the oven. The recipe called for adding *beurre manié. Beurre manié* is a thickener made up of equal parts flour and butter. None of the participants knew what *beurre manié* was or how to make it, and they had to search for the definition. Participant 3 searched on Google for articles on how to make *beurre manié.* However, Google mostly suggested videos that they said were unrelated. When they found the right video, the participant watched it to understand the technique, but when they attempted to recreate what they saw, they failed. The *beurre manié* that Participant 3 made looked nothing like what they saw on the Google videos, and they realized they did not follow the instructions strictly, which called for rolling the mixture into a ball.

Participants would also reach out to friends and family for help. For example, Participant 5 asked their partner who was in the immediate vicinity if they knew what *beurre manié* was. The partner mentioned that due to context and some of her French understanding, it should have something to do with butter, and then proceeded to look for more details online.

Likewise, participants were unfamiliar with deglazing, i.e., the method used to remove food residue that may have gotten stuck onto a cooking surface. The *coq au vin* recipe calls for pouring a quarter cup of brandy to deglaze the pot. Participant 2 had no idea what deglazing meant and had to look it up on their smartphone.

Overall, the *coq au vin* recipe used cooking techniques that most participants were unfamiliar with, such as cutting the carrots on a bias or deglazing the pot with brandy. Participants would resort to Googling the terms whenever possible or even asking for some help from their partners. Some participants would even skip a step entirely if unaware of what it entailed. Consequently, **users need help understanding the definition of terms on a task.**

4.2.3 Performing unfamiliar tasks. The goal of choosing a recipe likely to be unknown to participants was to see how they would respond when presented with unfamiliar steps. However, the recipe had an intimidating effect on participants. Participant 1 remarked how the recipe was *"a little fancy,"* and they felt *"out of their comfort zone."* Participant 4 mentioned that they were not used to using recipes and would usually look to see what ingredients they had available to cook.

One step in the *coq au vin* recipe involved peeling pearl onions. Pearl onions are much smaller than regular onions, and an inexperienced chef might think to peel each onion one by one like a white or yellow onion. However, this proves to be a painstaking process. Pearl onions are traditionally peeled using the blanching technique. Blanching involves boiling vegetables for a short period. This allows the pearl onion shell to come off quickly. Most participants were unaware of this technique and manually peeled each pearl onion. Unfamiliar with this technique, participants would frequently complain about the peeling process. Participant 7 said: *"...it is a pain to prepare the pearl onions..."* and then went to get a smaller knife. They prepared the pearl onions by cutting them in half and peeling them, which took a long time. While manually peeling the pearl onions, Participant 4 expressed frustration at the length of time the process was taking. When asked to think aloud, they exclaimed: *"I don't know how much talking I can keep doing about these little onions."* Most participants struggled to handle the pearl onions except for Participant 1, who decided to Google and watch a video on preparing them. Aside from Participant 1, all participants struggled to handle the pearl onions and did not use the recommended technique to peel them. Participant 6 even mentioned that *"there is probably an easier way to do this."*. In the end, some participants mentioned that, if possible, they would have skipped this step.

There are multiple ways to achieve the same outcome. However, there usually is an optimal route. We observed this phenomenon with participants peeling the skin off of pearl onions. Participants who did not know the blanching technique or were Googling how to peel pearl onions would manually remove the skin, which proved costly and inefficient. Therefore, **users need help when performing tasks they are unfamiliar with.**

4.2.4 Things change or don't go as planned. No two kitchens or chefs are the same. Our study made this apparent as participants encountered various unforeseen circumstances and had to improvise when things did not go as expected. One step in the recipe called for allowing the chicken to brown for five minutes on each side. However, five minutes was not enough for some participants because they did not follow the recipe closely. While cooking the bacon, Participant 1 lowered the heat because the bacon was "popping too much". However, they forgot to readjust the temperature after adding the chicken, which resulted in a longer cooking time than the recipe said.

Similarly, the recipe called for heating olive oil until it became fragrant, approximately 90 seconds. However, Participant 6 disagreed when looking at the pan after the time had passed, claiming they felt the oil needed more time.

Throughout the study, participants would take alternate routes when things did not go as expected. If a participant made any mistakes, they would correct their errors until they could return to the recipe. Participants would also modify the recipe without considering the ramifications, which could prove to be costly or require altering ingredient proportions. With this in mind, **users need guidance when things don't go as planned.**

4.3 Safety

This section addresses safety concerns in cooking, including tool-related injuries, challenges in gauging food readiness, precautions with hot objects, and the importance of following food safety practices. It highlights the potential benefits of offering users guidance to improve their safety awareness.

4.3.1 Handling tools safely. Unfortunately, a few participants had minor injuries in the study related to the cooking process. Participant 4 accidentally cut themselves while peeling the skin off of carrots and had to get a bandage which interrupted the task. Later, they began cutting the garlic by curling their knuckles so they would not get cut again, taking extra precautions. Other participants tended to be wary while cutting vegetables. Participant 1 avoided cutting thinner pieces of the onion as they cut through it because of the decreased hold on them. Participants often deviated from recommended cutting techniques [14]. For example, Participant 8 would cut vegetables while holding them in their hands instead of using a cutting board.

Cooking involves risky actions, such as handling knives or other sharp objects. Researchers were conscientious of the participants' safety and would step in when necessary. On multiple occasions, participants were delayed by handling dangerous objects, used wrong techniques to cut vegetables, which can be dangerous, and in some cases, even had minor injuries. Therefore, **users need help properly handling tools.**

4.3.2 Determining whether food is properly cooked. From auditory to olfactory, participants would determine if the food was properly cooked in various ways, using their senses to gauge the progress. Participant 4 would listen to the sound coming from the sizzling bacon to tell if it was cooking. Participant 5 looked to see if the bacon was brown and crispy. While cooking onions, Participant 2 observed the translucence on them to determine if they were ready. The smell was often used to determine if something was burning. Participant 2 had to turn on their fan from the smell of bacon due to the fear of setting off a smoke alarm. Alternatively, Participant 3 decided to use their intuition and waited to see until the bacon was crispy instead of setting a timer. The recipe called for letting the bacon cook for 8 minutes.

These participants had prior experience with the ingredients used in the recipe, which allowed them to rely on their intuition. In contrast, Participant 3 was unfamiliar with cooking carrots and had to use a timer to determine when they were done. As mentioned before, most participants could identify when some food was cooked by smelling it, hearing it, or looking at it. However, this was not the case for everyone. Participant 6 removed the bacon too early, even though she noticed it was a little white. Some of the other participants, even though they could tell when the bacon was done, had a more difficult time telling when the carrots and onions were done. With this in mind, **users need help determining whether food is properly cooked.**

4.3.3 Identifying and working with hot objects. Participants would gauge how to move depending on the current activity of the food being cooked. If Participant 3 got splashed by oil, they would add food slowly. If not, they would add food quickly. Participants took precautions when working with hot objects. Participant 1 expressed fear and stress over hot objects. They also mentioned adding ingredients to a hot pan with oil made them nervous. While adding chicken to the pan, they moved slowly, fearing getting burnt. While working with hot objects, participants also used tongs and spoons. Participant 7 touched the handles of a pot to determine if it was safe to pick up, which could have been dangerous if it was hot enough.

Overall, most participants tried to be careful around objects that could be hot such as pans, the oven, or grease. Sometimes it can be hard to determine whether something is safe to touch, even if they know something may be hot. Because of this, **users need help identifying and working with hot objects.**

4.3.4 Food safety, cross-contamination, and washing ingredients. Improperly cooked food can lead to salmonella and other food-borne illnesses. Participant 2, a microbiology researcher, took extra precautions when handling uncooked food. They consistently removed new cutting boards for each new vegetable or meat during the study. However, most participants tended to use one cutting board for everything, occasionally washing it if it was used to cut raw meat. Most participants were conscientious of handling raw meat and consistently washed their hands after touching the chicken.

Aside from the meat, participants also cleaned vegetables before placing them in the pot to cook. How much they cleaned them was a personal preference. For instance, Participant 4 brushed some mushrooms and not others because they appeared clean enough. However, Participant 8 washed all their vegetables with hot water to avoid contamination.

Overall, most participants were conscious of food safety and cross-contamination. However, even though they did wash their hands, some participants sometimes just rinsed them and did not use soap. One participant handled cooked chicken and was not going to wash their hands. However, they saw some blood in the chicken and then washed their hands. It might be helpful to remind the users when to wash their hands and what ingredients to handle simultaneously to avoid washing their hands and ingredients more than necessary. Consequently, **users need guidance regarding food safety, cross-contamination, and washing ingredients.**

4.4 Task Coordination

This section reveals user experiences in managing time-sensitive tasks and event sequences such as steps in the recipe. The findings highlight the importance of guiding users on planning, multitasking, time management, and task order.

4.4.1 Planning ahead of time. The *coq au vin* recipe required participants to prepare certain ingredients and tools before they were needed. For instance, the first step in the recipe was preheating the oven. This would be too early for some participants since they would take some time to prepare the ingredients. One example was Participant 2, who followed the recipe and left the oven idle since it took them a long time to prepare the ingredients. Alternatively, Participant 1 anticipated their slow preparation and decided to hold off turning on the oven until they felt ready, going against the recipe. They also mentioned they wanted to avoid heating the room too much with an oven since they had a small house.

When dealing with processes that have time-constrained sub-tasks that can be executed independently from each other, there is a possibility of finishing one of the sub-tasks before the others. Unfortunately, this desynchronization event can trigger unnecessary wait times or disrupt the expected state or temperature of food and utensils in a cooking context. In our study, the recipe had multiple opportunities when tasks could be run in parallel; however, it was expected that they would finish at a similar time to continue with the next steps. For example, one recipe instruction asked to preheat the oven beforehand while working with other ingredients. The participants turned on their ovens when the recipe mentioned it. However, due to the time it took most participants to complete the other concurrent tasks, they had the range running hot well past the time required to preheat to the required temperature. Some participants even recognized this had happened and decided to turn the oven off after a while. Acknowledging this, we realize that **users need advice on the ideal moment to prepare objects that must be ready ahead of time.**

4.4.2 Multitasking. Participants tended to perform smaller tasks while they finished a step that did not require immediate attention. For example, while Participant 5 was frying the bacon, they cleaned up around the kitchen. All participants would also use idle time to read ahead on the recipe and begin preparing another ingredient.

Participants also expressed boredom despite the *coq au vin* being a complex and engaging recipe. For example, Participant 1 became disinterested and wished they could listen to music while waiting for the food to cook.

Certain steps in cooking tasks can happen without much human intervention, such as waiting for water to boil or letting the electric mixer run for a specific amount of minutes. Additionally, activities seemingly unrelated to the recipe can add value to the user or even to the ongoing process. For example, activities such as cleaning the kitchen after cooking, calling a family member to ask for help getting a missing ingredient, or finding a utensil were unexpected but necessary to complete the task at hand. Our participants frequently relied on any available downtime to take care of these situations and other responsibilities, which made us realize that **users need to be able to perform activities between tasks and multitask.**

4.4.3 Multiple timers. Participants used any available device to track time while preparing time-sensitive ingredients. Since microwaves and ovens usually have a timer, they tended to be used most often, with 6 out of 8 participants using one or the other. Participant 2 mentioned they *"would usually use Siri on Apple Watch to set the timer but did not have it on them."* One roadblock to participants' tracking time was the lack of multiple independent timers. Most conventional ovens or microwaves are capable of only tracking a single time. Participants were forced to prioritize which process they wanted to time or rely on a single timer for multiple processes. Participant 1 had to stand and watch the oven timer tick for 1 minute for the onions to boil since the oven timer was already used for another process. They had to monitor the timer, which was time-consuming and inefficient.

Occasionally, participants would even forget to set a timer. While cooking the chicken and the bacon, Participant 6 forgot the timer for the bacon but not for the chicken. They remarked how the bacon did not look cooked. Regardless, they removed it from the pan and continued with the recipe with the improperly cooked bacon.

Similarly, time-constrained sub-tasks usually require some time-keeping mechanism to inform the user when to continue with the next steps. In our studies, we observed that our users worked around this issue in multiple ways: by using mobile devices, reading wall or microwave clocks, or ignoring the time and relying on their instincts and experience. However, requiring multiple timers for different activities to run at the same time adds a level of complexity that can generate unnecessary distractions or even induce errors. It is our reasoning then that **users need to be able to track time for different tasks** safely and simply.

4.4.4 Order of tasks. The ordering of steps proved essential in efficiently completing the *coq au vin* recipe. Participants consistently would look ahead at the recipe to see what could be done while they waited to finish cooking something and see what came next. Participants then decided what to do based on their current progress, even checking if they could multitask with another step.

While reading the recipe, some participants even showed confusion about the steps. Whenever participants became particularly confused, they would double-check the recipe to ensure they were on the right step. Before adding the brandy to deglaze the pan, Participant 6 had to stop for a second and look over the whole recipe before continuing since they were confused. They did not understand how the garlic and deglazing steps would tie in together. Participants also showed less awareness of the overall task. Participant 8 did not realize the recipe extended more than one page and had to repeat steps they had skipped.

Since none of our users knew the steps for cooking *coq au vin* by heart, they had to go through the recipe multiple times. For example, users checked the recipe at the beginning of the cooking task after completing specific steps to look ahead and understand what was coming next or to verify that what they were doing was correct. Interaction with a recipe is to be expected when working in the kitchen, which means that **users need to know what tasks they are currently on and what task comes next.**

5 DISCUSSION

To explore the design space of technology-assisted task guidance systems, we conducted a contextual inquiry study to understand people's cooking practices and information requirements. By doing this, we uncovered several user needs that were common across participants. Our results show that there are multiple opportunities in which technology could adequately support cooking task guidance. For example, participants encountered obstacles with multiple steps of the recipe, despite having access to their own technological devices. Additionally, these results have implications for the design of task guidance systems in other domains that may require similar executive functions, such as mechanical assembly lines or medical applications. We focus our discussion on (a) summarizing the key points on users' mental models while executing our task (cooking), (b) how the user needs and the major themes we identified generalize to other domains beyond cooking, and (c) the limitations of our work and findings.

5.1 Users' Mental Models while Cooking

Understanding users' mental models is one of the pillars of the human-centered design process, achievable through multiple observation, elicitation, and design techniques. Prior work has shown that understanding users' mental models is a valuable asset in designing technology intended for their use [21, 42, 48]. In our study, we strove to understand our users' thought processes in a cooking setting. Through the observation process and subsequent findings, we advanced toward comprehending the thought patterns of our users while they were cooking. Broadly speaking, our findings align with and provide more depth to the existing understanding of home cooks' conceptual model, which was previously studied using survey methods in more constrained settings. [36].

Our interpretation of the users' overarching thought process also helped us identify opportunities for technology to intervene and aid them, more specifically in the form of technology-enabled task guidance systems. After conducting the studies and analyzing all our notes and observations, we noticed that some issues were common and relevant to all participants. For example, all the participants needed help with understanding unfamiliar terms and resorted to searching for the definition with their phones or asking a family member if they knew what some specific words meant. Another example comes from adequately handling sharp objects. In the *coq au vin* recipe, the participants were required to utilize sharp objects, such as knives. However, participants often deviated from the recommended cutting technique due to inexperience with the technique or to employ their known practices. Consequently, one of the participants cut themselves when peeling the skin off of carrots. After carefully reviewing all of the user needs we identified, we could group them into four main themes: objects, knowledge base, safety, and task coordination. The four themes revealed areas where users might need more assistance when cooking. Our findings can inform the design of task guidance systems that align with users' actual requirements during cooking. Additionally, they will provide a high-level understanding of the specific areas in which designers should focus the most to deliver a better, more user-centered experience.

5.2 Task Guidance Beyond Cooking

As previously mentioned, we used cooking for our user study because it requires participants to utilize several executive functions [7, 46, 47]. Requiring multiple executive functions is a quality shared across many human activities that might benefit from technology-assisted task guidance systems. Cooking also demands using different tools, working with ingredients that call for various ways of handling and manipulating, disposing of waste and retiring dirty objects, adequately managing the working surface, and operating common but potentially dangerous artifacts. Based on these reasons and our analysis, we present examples of how our findings apply to other application domains. These examples are categorized according to the four main themes identified in our study.

5.2.1 Object Interaction. When designing task guidance systems where the user is expected to interact with objects (e.g., tools) to complete their task, pick the right object for the task, or identify a substitute if they don't have the required object, designers should take into account the user's experience with the objects and the

Table 2: Main themes and user needs summary.

Object Interaction	
1	Users need help when working with unfamiliar objects
2	Users need assistance picking the right object quickly when multiple options are available
3	Users need to know what to use as a substitution if they do not have the needed tool
Knowledge Base	
4	Users need help finding objects in their working environments
5	Users need help understanding the definition of terms on a task
6	Users need help when performing tasks they are unfamiliar with
7	Users need guidance when things don't go as planned
Safety	
8	Users need help handling tools
9	Users need help determining whether food is properly cooked
10	Users need help identifying and working with hot objects
11	Users need guidance regarding food safety, cross-contamination, and washing ingredients
Task Coordination	
12	Users need advice on the ideal moment to prepare objects that must be ready ahead of time
13	Users need to be able to perform activities between tasks and multitask
14	Users need to be able to track time for different tasks
15	Users need to know what tasks they are currently on and what task comes next

available items in their workspace. For example, consider a task guidance system for engine maintenance that supports the use of torque wrenches. The system should support the user's experience with the wrench, presenting instructions on properly setting the thresholds for manipulating the wrench in case they are unfamiliar with it. For instance, a novice may need detailed instructions to operate the wrench, while an expert might only require an indicator showing if the correct torque has been reached. A similar idea was reflected in the system made by Anzengruber et al., who used wrist sensors to investigate torque wrench activities while working, suggesting how to identify errors and provide feedback when using the tool [2]. To illustrate how these user needs could be implemented, the user interface in Anzengruber et al.'s system could include an interactive, step-by-step visual guide displayed via an augmented reality headset. As the user adjusts the torque wrench, the user interface could visually indicate the correct positioning and torque level through color-coded feedback. Green might indicate the correct torque, while red could signal an excessive force, guiding the user to the appropriate action without needing to consult a manual or gauge. Additionally, the user interface could play audio cues to complement the visual feedback; as the user approaches the correct torque setting, audio signals such as beeps or verbal cues could indicate that the desired torque level is achieved. Based on our findings, such a system could also adapt its feedback to the user's previous experience with using the tool. This is a practical example of how our work contributes to a more generalized understanding of how to create guidance systems that can effectively guide users to interact with tools while working through a task.

5.2.2 Knowledge Base. Task guidance systems should be designed to enhance the user's existing knowledge, track the progress of tasks and their steps, and meet the user's need for more information or immediate assistance. As we observed in our study, each step of the recipe requires an understanding of terms, definitions, and procedures to be able to reach the expected goals. Also, adapting to unexpected situations is crucial to error detection and correction. Our findings align with prior research in the fabrication domain, where they have been interested in leveraging knowledge resources to deliver adaptable instructions. For example, Lakier et al. introduced Automatics, a guidance system for assembly tasks that considers the user's experience with a specific tool and supports error detection and recovery [24]. Whenever a user performs an action that causes an error, the system readjusts its guidance to support the new sequence of tasks necessary. Their system also provides support if a tool is unavailable, linking to our argument on Object Interaction. A system that supports knowledge base features, could let users inquire about the location of tools or objects verbally. Upon such requests, the system could guide the user to the desired object by highlighting it with an augmented reality overlay. Additionally, a user could request further details on the current task, and the system could respond by displaying a video tutorial on how to perform the task. Our work supports the importance of including knowledge-based resources on task guidance systems to aid users with achieving goals during a complex task.

5.2.3 Safety. Designers should consider safety-related features when creating task guidance systems, such as properly handling tools or avoiding potentially dangerous situations. For example, Burova et al. explored augmented reality guidance features in the industrial maintenance context in which shock hazards were represented using safety warnings [5]. Consider our proposed user need "Users need help identifying and working with hot objects". A similar need might be extended for a user working with potential shock hazards, which would help designers create adequate guidance systems in that particular scenario. For example, in environments where shock hazards are present, the user interface in an augmented reality task guidance system could overlay color-coded warning symbols directly onto areas where electrical hazards exist.

These warnings could include flashing icons or color changes that alert users in real-time about the proximity to high-voltage equipment or exposed wiring, preventing accidents by ensuring that users are well-informed about their surroundings. In summary, our contribution to identifying user-centered safety needs will assist designers in integrating these user requirements into task guidance systems in areas beyond the cooking domain.

5.2.4 Task Coordination. Task guidance systems should be designed with the goal of supporting the user's evolving temporal requirements and dynamic environment. Our study found that effective task completion depends on a thorough understanding of time-sensitive situations, sequences of events, and adaptability to changing circumstances. Comparable needs and requirements for task coordination have been identified in prior work. For example, Haritos and Macchiarella explored using augmented reality task guidance systems for aircraft maintenance training. They argue that task coordination features in task guidance systems, such as a list of necessary instructions for inspection, could drastically reduce inspection and repair times [17]. Similarly, we observed participants struggling with the order of the steps or having difficulty figuring out the ideal time to start with certain tasks that should happen beforehand, such as turning on the oven at the right time. Some participants tried to be more efficient by doing multiple things simultaneously, but they were not always successful. A task guidance system supporting these types of interactions could feature a task list visible to the user, displaying both current and next steps. This list could dynamically update as the user progresses through tasks, completing or skipping steps. Our findings and prior work suggest that task coordination features should be considered for designing useful and effective task guidance systems.

5.2.5 Combined Effort. Although we have organized our observations into 4 distinct categories, they are not mutually exclusive to each other and are often intertwined in practice. For example, supporting smart tool use can be crucial in preserving user safety and time efficiency, and designing an effective task guidance system in this area requires the combined effort of the main themes identified. Referring back to the Automatics system, an assembly guidance system with tool and adverse event support[24]: a preliminary evaluation of the system showed that it decreased user frustration and allowed them to complete more tasks, which supports our premise that adequate designs can also be based on a combination of user needs.

5.3 Limitations

Our study presents some limitations. Firstly, our study only allowed for one participant at a time, which may not encompass the entire spectrum of activities. For example, cooking as a task can be a social activity that involves multiple participants working collaboratively in the same collocated space, which could change the dynamic of the setting and how different cooks approach the task. Future studies with collaborative dynamics could provide additional insights. At the same time, using a single task, which in our case refers to a single recipe, may not fully capture the variability in different scenarios. For instance, different recipes could present other challenges and opportunities, and future studies with different tasks could reveal additional user needs and task guidance system requirements. Another limitation is that although we conducted the study by visiting the participants at their homes to observe them in a real-life setting, the researchers' presence may have altered their behavior. Unobtrusive methods could complement our findings in future studies. Also, the number of participants in our study, albeit sufficient from a qualitative and exploratory perspective, might not necessarily mean it is representative of the larger population. It is possible that a larger and more diverse sample could strengthen the generalizability of our findings. Furthermore, even though cooking involves various executive functions that apply to other domains, we acknowledge that the focus was primarily on cooking. Different insights and themes may also surface when examining domains outside of the culinary context. Therefore, further research and verification are needed to determine possible additional user needs and how our findings extend other domains for task guidance systems. Lastly, the cultural context in which our study took place could affect practices and participants' behaviors. Different cultural backgrounds may have different styles or techniques when cooking or completing other kinds of tasks, which our findings may not account for.

6 CONCLUSION

Prior work has yet to identify comprehensive guidelines for designing task guidance systems. Therefore, we selected a cooking task and explored practices and behaviors in a contextual inquiry study of eight participants. We aimed to observe and identify breakdowns and opportunities in a typical cooking setting where task guidance systems could positively intervene. We used a bottom-up approach to analyze the notes and observations from our study to synthesize, identify, and understand the major themes. Our contribution is identifying user needs for task guidance systems in the cooking domain and four major recurring themes: Object Interaction, Knowledge Base, Safety, and Task Coordination. We also present an evidence-based argument supporting the broad applicability of our findings in informing the design of task guidance solutions across other domains. Overall, the user needs we identified will aid designers and creators in developing effective, generalizable, and user-centered task guidance systems.

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