A Smart Kitchen for Nutrition-Aware Cooking

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A kitchen that intelligently senses cooking activities and provides real-time nutritional information helps facilitate healthy cooking by letting family cooks make informed decisions.

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Recent US and European studies demonstrate that most people prefer home-cooked meals.[1] Home cooking is not only an act of caring for family members but also a daily activity that determines a family's long-term health. Most family cooks are willing to learn healthy cooking practices. However, they often have difficulty accurately calculating calories while cooking,[2,3] which involves these steps:

- Accurately estimate the amount of each ingredient.
- Consult a food calorie table to calculate the overall meal calories.
- Adjust the ingredients so that the meal is nutritionally balanced and doesn't exceed the recommended values.

This lack of accurate nutritional information makes it hard for cooks to make informed decisions, and the effort of calculating calories makes cooks less willing to adjust their cooking style.

This situation creates opportunities to embed pervasive computing in a smart kitchen to facilitate healthy cooking (see the "Related Work in Ubiquitous Computing in Health" sidebar). Our design philosophy is twofold. First, we want to make accurate caloric and nutritional information more accessible to family cooks. Second, we want to avoid instructing them to follow standardized healthy-cooking rules.

On the basis of this philosophy, we designed a smart kitchen that senses cooking ingredients and displays their nutritional information. Using this information, cooks can quickly and easily understand their cooking styles' nutritional consequences, with minimal interruption from the system.

Analyzing Cooking Activities

To design technology that provides adequate feedback for home cooking, we analyzed cooking activities in three homes. We observed experienced cooks preparing typical meals for their families and questioned them when they performed actions of interest. Our observations revealed the following.

First, cooks commonly add ingredients on the basis of experience or preference. The participants stated that they were unsure whether their cooking styles were healthy. They expressed a desire for an onsite nutritionist who could quickly point out unhealthy cooking practices while they were cooking.

Second, cooking requires ongoing planning and thinking about the next step. So, cooks prefer to focus solely on cooking rather than on complex electronic interfaces on refrigerators or microwaves, which can cause distractions and lead to errors. The participants indicated the need for simple, highly relevant information directly related to their cooking.

Finally, cooking consists of intricate decision making in cultural, habitual, and family con-

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Related Work in Ubiquitous Computing in Health

Much research has exploited ubiquitous computing to record health-related information, personal food intake, and calories and to encourage healthy eating. For example, the Diet-Aware Dining Table tracks what and how much users eat on the dining table and then provides nutritional information.[1] Jennifer Mankoff and her colleagues developed an application that tracks the nutrition of foods users have purchased and suggests healthier foods on the basis of an analysis of shopping receipt data.[2]

Other researchers have studied user acceptance of long-term activity-monitoring technologies at home. For example, Jennifer Beaudin and her colleagues found that people might accept activity-tracking technologies that help them learn about their physical and mental condition and how their activities affect their physical and mental health.[3]

Some researchers have focused on letting users record and share their cooking experiences. For example, Itiro Siio and his colleagues automated creation of Web-ready multimedia recipes in a kitchen.[4] By operating a foot switch, users capture images of the cooking workplace; they later annotate these with voice memos and organize a multimedia recipe.

Research has also examined how developers can design digital technologies to enhance the social and cultural aspects of human-food interaction. For example, Andrea Grimes and Richard Harper discussed how food brings people together socially and gives people their cultural identities; our design philosophy also emphasizes this. In addition, they pointed out a new direction for human-food interaction that enhances the food's positive aspects, such as gifting, family connectedness, creativity, and pleasure.[5]

Genevieve Bell and Joseph Kaye proposed a relationship between kitchens and technology that focuses on human experience over efficiency.[6] Our research shares this design philosophy and further explores the cultural, habitual, and family contexts in designing kitchen technology for nutrition-aware cooking. Our previous paper presented the second of the three prototypes developed during our iterative design process.[7] The main article describes all three prototypes and provides insights into technology design for a home kitchen that promotes healthy cooking.

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texts. Although cooks consider a certain ingredient unhealthy, they'll still use it because it's part of their cultural heritage (for example, sesame oil in meals for Chinese women after childbirth), an expression of love and caring (for example, preparing a family member's favorite food), or a family tradition (for example, fatty Dongpo pork at the Chinese New Year's Eve dinner).

Iterative Design

To prototype, test, and refine our smart kitchen, we used an iterative process. We designed and prototyped three awareness displays—the Nutritional Facts Display, the Calorie Display, and the Calorie and Nutritional Balance Display—and conducted a mini-user study to test each one. In each study, the recruited cooks prepared meals in our lab with and without the awareness display. We recorded the cooking sessions and conducted individual semi-structured interviews. All participants were Taiwanese, and we conducted the studies in Taiwan.

Table 1 describes our studies, which involved seven participants, 28 cooking sessions, and six interviews. The qualitative findings collected from the video and interviews provide insights into how each display helped cooks make informed decisions toward healthy cooking.

The Smart Kitchen

We based the three displays on the kitchen prototype in Figure 1, which included two modules:

- The *nutrition tracker* determined the nutritional value, composition, and position of ingredients on the kitchen counter or stove.

TABLE 1
Details of user studies conducted on three prototypes.

	No. of participants	No. of cooking sessions with (and without) the awareness display	Video length	No. of semistructured interviews
Nutritional Facts Display	1	1	31 minutes	1
Calorie Display	3	6 (9)	14 hours, 33 minutes	3
Calorie and Nutritional Balance Display	3	6 (9)	16 hours, 12 minutes	2
Total	7	28	31 hours, 16 minutes	6

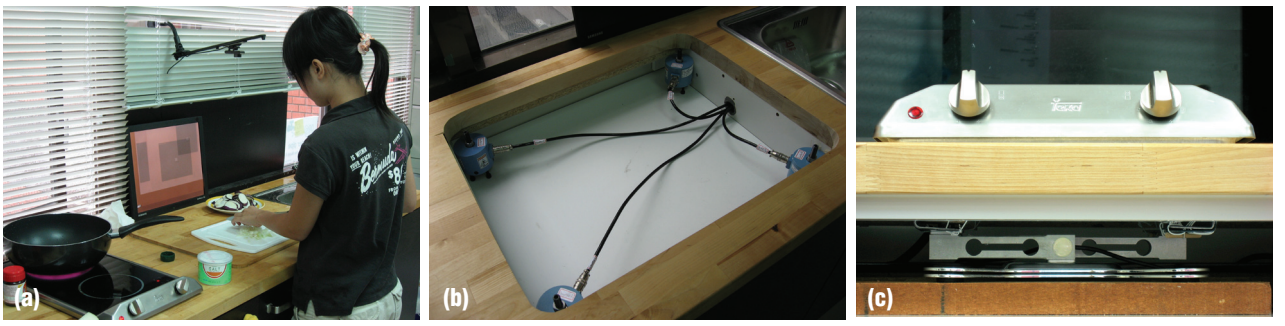

Figure 1. The smart kitchen. (a) An awareness display provided real-time nutritional information during cooking; an overhead camera focused on the surface. Weight sensors were under the (b) counter and (c) stove.

- A countertop display provided nutritional information.

The nutrition tracker provided real-time detection of any cooking action that could change the meal's nutrition, such as adding ingredients to a container or removing them. The nutrition tracker combined weight and camera sensing to estimate nutritional value. We deployed weight sensors under the kitchen counter and stove, where most food preparation activities occur. A camera above the counter filtered out noise from the weight-sensing surface. When the sensors detected a new ingredient on the counter, the system asked the user for the ingredient's name via voice input, for which we used the Wizard of Oz method during our user studies. We then computed the new ingredient's calorie count by looking up its per-gram calorie count in the nutritional database and multiplying that by its weight.

Because this system was based on weight matching, it had several limitations. For example, it couldn't recognize concurrent actions, so users could add only one ingredient at a time. In addition, ingredients had to be inside containers or on cutting boards. Complying with these limitations required user effort that we viewed as the cost of operating the system and that offset the system's benefit in providing nutritional awareness. All participants learned about these limitations at the beginning of the studies. More details on cooking-activity sensing appear elsewhere.[4]

The Nutritional Facts Display

This display provided nutritional information similar to that on food packaging. When the smart kitchen detected an ingredient, the display showed its basic nutritional content, including calories, fat, protein, carbohydrates, cholesterol, and sodium. We designed the system to provide detailed information to household cooks, then let them decide which information was relevant. For example, if a family member was diabetic, the cook would take care to prepare meals with low fat, calories, protein, and sodium. The display provided cooks with real-time awareness of each cooking activity's nutritional effect, such as increased calories.

The display interface had two parts. On the left was detailed nutritional information for the most recently used container of food that could cause a nutritional change (see Figure 2a). On the right was an overview of the containers and ingredients (see Figure 2b). Because this overview mirrored the physical kitchen surface (see Figure 2c), it provided cooks with a direct spatial mapping between the information on the display and the foods and objects on the kitchen surface. Detected containers were represented by small triangles at their mirrored positions on the display. Red and black labels below the

triangles listed the name and weight of each container's ingredients.

The two main design concepts in the display were direct mapping and context-relevant information. Direct mapping let users quickly and easily get information by glancing at the display. It also let them quickly find new nutritional information corresponding to their most recent cooking action by looking at the mirrored location on the display where the last cooking action occurred. We reduced information overload by displaying only the most time-relevant nutritional information related to the most recent cooking action that resulted in a nutritional change.

To test the interface, we had a cook prepare a familiar dish of her choice—spaghetti alla carbonara for four people. The participant then took the cooked food home to her family members. Preparing a familiar dish reduced the participant's focus on how to prepare a meal, allowing her to become more engaged with our system. However, this limited, one-participant study might not reflect all users.

The semistructured interview revealed the following.

First, although the detailed values on the Nutritional Facts Display provided accurate, comprehensive measures of all six nutrition elements, the user found these numbers overwhelming. She couldn't interpret them to determine how healthy her cooking was or whether she prepared the meal according to her family's nutritional needs. So, she expressed a strong desire to receive recommended values based on her family's nutritional needs. This recommendation would not only give her a nutritional target but also help her comprehend the displayed nutritional information.

Second, the user had difficulty tracking the final meal calories because the display showed only the nutritional information for the most recently used container. Because the user cared most about overall meal calories, she suggested adding overall calories to the display instead of less important information, such as ingredient weight, to avoid information overload.

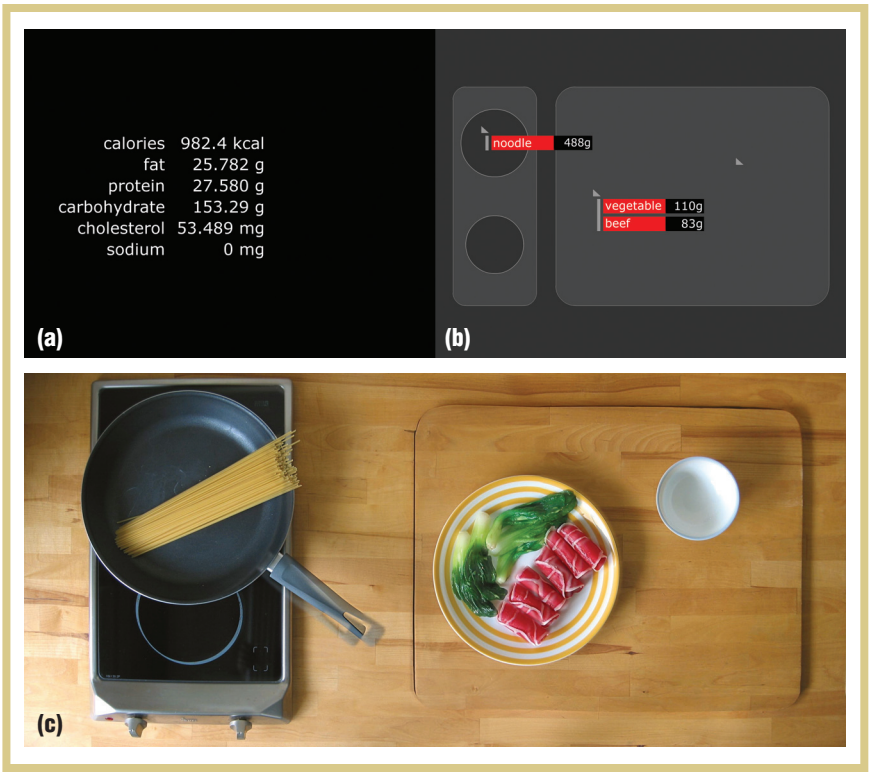

Figure 2. The Nutritional Facts Display, including (a) detailed nutritional information and (b) an overview of containers and food ingredients. The display mirrors (c) the physical kitchen surface.

Third, the user found that the display raised her awareness of the ingredients' nutritional properties and used this information to adjust the amounts of ingredients. For example, she was surprised by bacon's high calories and subsequently reduced the amount of bacon.

Finally, when we asked the user why she took a relatively long time to look at the display, she commented on the difficulty of mapping the displayed nutrition information to the ingredients on the counter. Discussions with her revealed that enhanced spatial mapping to the kitchen surface could make finding information on the display easier.

The Calorie Display

Our next prototype incorporated the user suggestions from the Nutritional Facts Display. Rather than providing nutritional details, the Calorie Display focused only on calories to avoid information overload. The display also provided recommended meal calories and enhanced spatial mapping.

Compared to the Nutritional Facts Display, the Calorie Display had three improvements. The first was size mapping. The display represented each container as a rectangle whose size reflected the container's size. An overhead camera captured the container's size and showed it proportionally on the display. Mirroring the container size reused the direct-mapping technique that proved effective in the previous prototype.

The second improvement was color coding. The display represented the caloric value of the ingredients in a container by not only a numerical value but also the rectangle's color. Darker colors indicated more calories. This

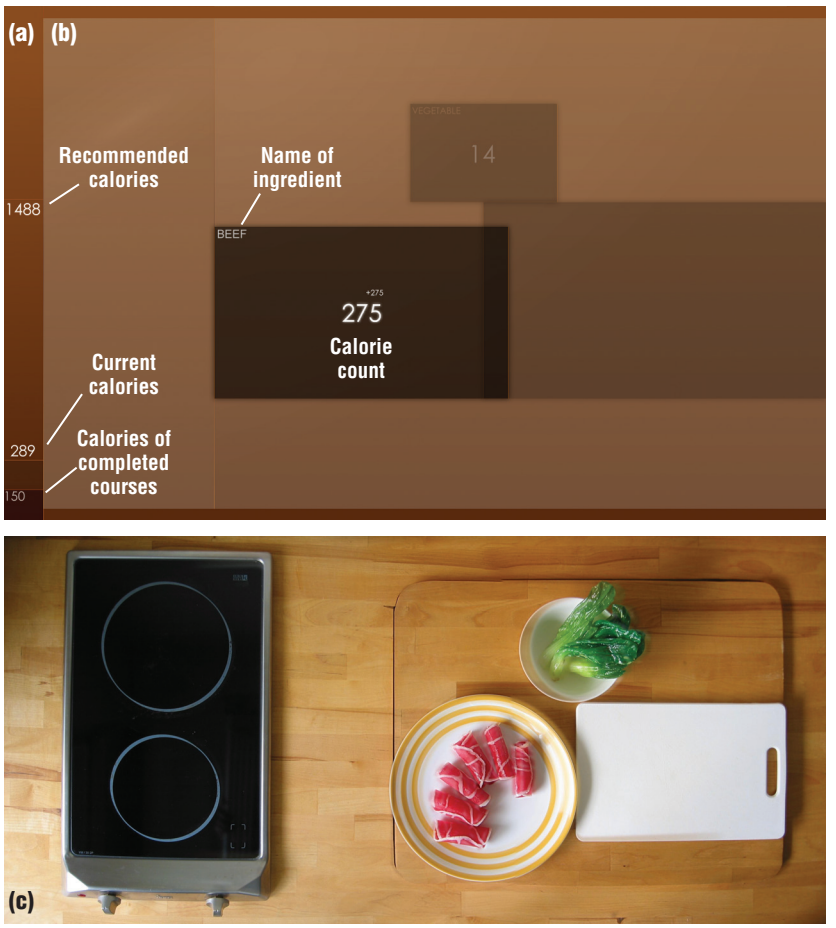

Figure 3. The Calorie Display, including (a) the recommended and current calories and (b) an overview of the calories in the system. The display mirrors (c) the physical kitchen surface.

let users quickly identify containers with a high calorie count and make adjustments.

The final improvement was to the nutritional information. The information for each container included calorie count, ingredients, and calories added or removed by previous user action.

Again, we divided the display interface into right and left parts (see Figure 3). The right showed an overview of the containers and food ingredients in use. The vertical bar on the left showed the family's recommended calories, the current meal's total calories, and the calories of the courses completed and removed from the kitchen surface.

To calculate the recommended calories, we used the Harris-Benedict formula, which is based on the basal metabolic rate multiplied by an activity level.[5] We then derived the meal calorie count from the profiles (weight, height, age, sex, and activity level) of all family members that meal was intended to feed.

We used a budget metaphor to present calorie recommendations. Whenever the system sensed a new ingredient, the calorie budget decreased by the new ingredient's number of calories. As the cook added ingredients, he or she could monitor them to plan the remainder of the meal. We designed the budget metaphor so that the cook could make smart decisions about food ingredients, avoid exceeding the calorie budget, and allocate the budget among different courses.

To test the Calorie Display, we had three adults (two females and one male), each with five years' experience cooking regularly for their families, prepare food using menus they had written in advance (see Table 2). They then took the cooked food home. The participants were between 24 and 58 years old, with a family of three or four members. Over a week, each participant cooked without the Calorie Display for two sessions on two separate days, then with the Calorie Display for three sessions on three separate days.

Observations from the videos and results from the interviews revealed that participants exhibited different cooking behavior when using the Calorie Display. For example, one participant gradually adjusted the amount of ingredients to attain the desired calorie count. She added some spaghetti, glanced at the Calorie Display, and repeated this step until she reached the desired count. Another participant first poured half of the condensed soup into the pan, only to discover that the calorie count was much higher than she expected. She then stopped pouring.

During the semistructured interviews, participant 1 responded that because she was unsure about spaghetti's calorie information, she used our system to accurately measure and decide on the appropriate amount. Participant 2 said that she first added the condensed soup in her usual large increment but was surprised to learn its high calorie count. This suggested that despite differences in cooking habits, participants could adapt the Calorie Display to make informed decisions about healthy cooking.

We observed that participant 3 had difficulty cooking within the recommended calories. Although he could identify high-calorie food ingredients and continually checked the display, he failed to reduce his cooking calories. He explained that healthy cooking con-

TABLE 2
Menus designed by participants for testing.

Participant	Menu
1	Salad (apples, celery, and Thousand Island dressing), salmon, fried eggplant with onion, and spaghetti (with bacon, mushrooms, onions, and milk)
2	New England clam chowder (Campbell's condensed soup), bream roll with bacon and sauce (including ultra-high-temperature-processed whipped cream, onion, white wine, and lemon), rice, vegetables (cauliflower, carrots, and sweet corn), and salad (lettuce and Thousand Island dressing)
3	Shrimp with scrambled eggs, mapo tofu (fried tofu with meat sauce and green onion), asparagus with abalone, Chinese clam soup, and rice

flicted with his preferred cooking habits. Despite information from the Calorie Display, he used certain high-calorie ingredients because his family members loved them. He also added excessive oil to enhance flavor. He said that the display revealed a difficult choice between taste preferences and health. Although his cooking exceeded the recommended calories, he found the Calorie Display informative on finding a balance between taste preferences and health. He commented that he and his family members would need more time to adjust to new cooking habits.

During the interviews, the participants made many positive comments about the Calorie Display. They all agreed that the bar representation and the spatial mapping were easily understandable. One participant said, "After perceiving this information, I would also consider the amounts of ingredients in my shopping." Another participant stated, "This kind of instant feedback helps to remind me of what I already knew about using the condensed soup and some high-calorie ingredients such as UHT [ultra-high-temperature processed] cream."

Overall, our design concept was well received by the participants; however, they requested one feature. They wanted the system to help them cook meals that were not only low in calories but also well balanced with appropriate portions of the five major food groups (grains, vegetables, fruits, milk, and meat and beans). They mentioned that optimizing the calorie count might be undesirable if the meal wasn't nutritionally balanced.

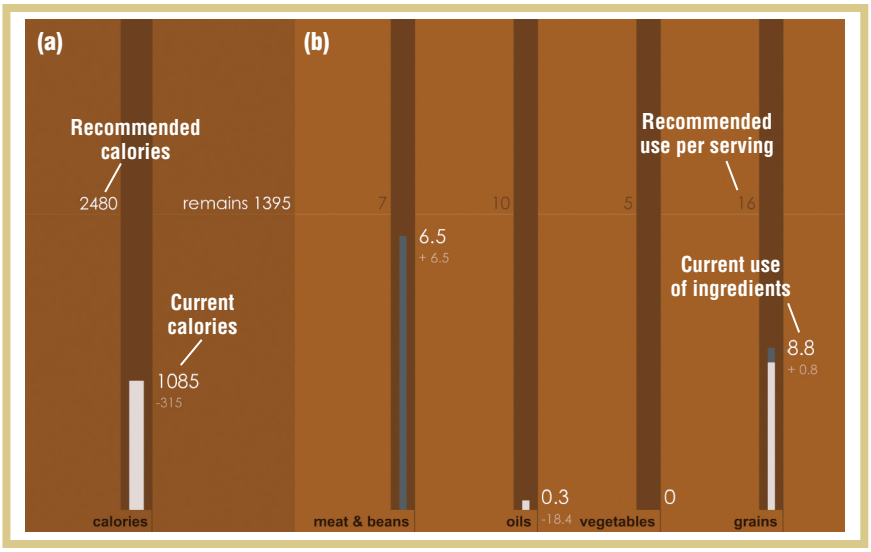

Figure 4. The Calorie and Nutritional Balance Display, including (a) recommended and current calories as well as (b) recommended and current ingredient use in three major food groups—grains, vegetables, and meat and beans—and oils.

The Calorie and Nutritional Balance Display

On the basis of the previous findings, we designed the Calorie and Nutritional Balance Display. Besides calorie information, this display provides nutritional-balance information to help cooks reach the recommended amounts in three major food groups—grains, vegetables, and meat and beans—and oils. To calculate these amounts, we used the US Department of Agriculture dietary guidelines for nutritional balance of food groups (www.cnpp.usda.gov/FGP.htm).

Figure 4 shows the display interface, which again had two parts. The left part showed the recommended and current calories, as in the previous prototype. The right part contained four new bars, each corresponding to a food group and individually marked with the recommended and current number of servings. A serving was a portion representing a certain quantity of food ingredients.

A cook could make better-informed decisions with richer information because rather than focusing on only calories, he or she had a budget for each of the four food groups. By meeting the recommended budget in each group, the cook would reach the recommended

calorie budget and achieve nutritional balance. If a certain food group exceeded the recommended value, the cook could consider reducing the servings in other food groups on the basis of personal preferences to keep the calorie count within the recommended value.

We had three adults (two females and one male) from a nutrition class at the National Taiwan University hospital test the display. Of the three, two were a couple and cooked together in the user study. The nutrition class provided methods of estimating food portions, so the participants understood the concept of servings. The participants ranged from 57 to 63 years old, and each had more than three decades' experience in regularly preparing family meals.

The participants cooked once a week for six weeks. Again, we provided the ingredients, and they took the cooked food home. All of them cooked Chinese home-style meals. They cooked without the Calorie and Nutritional Balance Display for three sessions, then used it for another three. The interviews occurred after the final sessions.

Observations from the videos and results from the interviews revealed two key findings. First, in the three sessions without our display, none of the participants could accurately estimate portion sizes, so they all produced nutritionally imbalanced meals. One participant who cooked an oversized meal said, "I tried to follow what I learned from the nutrition class. Since I didn't know how to accurately estimate the serving sizes of food ingredients, I ended up cooking a meal of a larger portion size than I usually cooked."

With our display, participants could estimate portion sizes accurately and produced nutritionally balanced meals. Often, they added ingredients gradually while glancing at the display until they reached desirable serving sizes. Another common strategy was to consider the ingredients' serving sizes for several dishes during a meal-planning stage before cooking. The participants mentioned that the real-time nutritional feedback helped them apply knowledge from their nutrition class to actual cooking.

With our display, participants could estimate portion sizes accurately and produced nutritionally balanced meals.

Second, the participants found our display useful for not only estimating serving size but also choosing alternative ingredients. For example, one participant used a large amount of vegetables to fill one serving instead of a high-calorie ingredient. He said, "It's better to eat more vegetables because they're healthy." One participant substituted tofu for meat, yielding an equivalent amount of protein and calories.

Lessons Learned

Our iterative design process revealed the following issues related to applying pervasive and persuasive computing in a home kitchen.

Cultural and Habitual Context

Our studies showed significant differences in the social and habitual contexts associated with participants' cooking behaviors. For example, some participants expressed strong preferences about the taste of foods, cultural or family food traditions, family members' favorite dishes, and so forth, whereas others cared primarily about health. Some who were accustomed to high-calorie cooking found it challenging to adjust to large calorie reductions over such a short time period. Participants had different nutritional knowledge and skill levels in healthy cooking.

We believe it's important to design technology that's not judgmental and doesn't punish less-desirable behavior. So, it's important to design technology that people with different habits find useful. Our findings suggested that our design philosophy was well received by our participants.

Changing the Benefit-to-Cost Ratio

Participants commented that the display wasn't that useful after they determined the ingredients' portions because later actions, such as cutting, mixing, and cooking, seldom changed the calories. This phenomenon is due to our system's changing benefit-to-cost ratio during different phases of meal preparation. As we mentioned before, the benefit refers to the user-perceived value of the system, whereas the cost refers to the user effort required to operate the system and comply with its limitations. A higher benefit-to-cost ratio would make our system more appealing.

We can divide the cooking process into three phases. *Planning* involves determining the types and amounts of ingredients, *processing* involves cutting and mixing the ingredients, and *heating* involves cooking them. These phases often repeat several times as cooks prepare different meal components. Our displays offered a substantial benefit to cooks during planning, in which the system determined nutritional and caloric values. They provided less benefit during processing and cooking, when cooks change nutrition and calories mostly by adding seasonings. So, the benefit-to-cost ratio is dynamic, not fixed. When the benefit-to-cost ratio was low, during processing and heating, the cooks received little benefit from the display, which continued to draw their attention with updates on changes to ingredients and containers.

This issue occurs in many complex,

multifaceted human activities in which the pervasive technology confers a benefit at certain times or in different aspects of the target activity. When the technology provides little or no benefit and isn't relevant to the activity, its continuous presence might annoy users. One solution might be to give users flexible, easy control over when to turn the technology off and on.

A future study might investigate our system's long-term effects in actual home kitchens. We're also interested in exploring the use of similar technologies in cooking schools to assist instruction in healthy, tasteful cooking. Finally, another issue is the need to adjust the technologies according to user skill and knowledge level. Such issues pose great challenges for future research.

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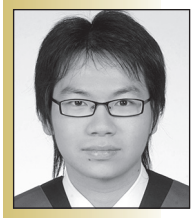

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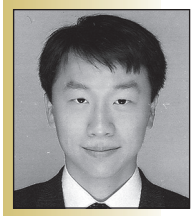

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