Machine-Assisted Cooking

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ABSTRACT
We present the observations, processes, and results in designing a machine assisted cooking interface for novice chefs. We present detailed observations from our user experiments and the resulting evolution in our interface design. We describe the final interface that is the result of this process, and list important features that contributed to its success. We conclude with the current state of our work and our plans for the future.

INTRODUCTION
For decades now, food options in America have been primarily unhealthy. Unhealthy food options have grown from fast food restaurants to web-based delivery services. It has become increasingly easy to eat unhealthy food, and this is a problem for people who want to make a change. In this regard, there is a need for healthier eating. There are several ways to address this issue, one of which is to simply make your own food. To enable those who are motivated but inexperienced with cooking, the process of learning to prepare a home cooked meal must first be well understood. Most people today learn to cook by following a recipe book, or reading recipes online. To better understand the process of learning to cook, as well as understand good cooking practices, we observed three subjects with varying cooking experience cook a meal following a recipe with which they were unfamiliar. Our observations showed that even experienced cooks exhibit symptoms of cognitive overload, which lead to mistakes, frustation, and in one case, a loss in motivation to cook. One major cause of such symptoms is poor recipe instruction. Consequently, the primary focus of this work is to improve the experience of learning a new recipe by improving the design of recipe instruction.

Our examination of popular recipes showed such recipes are typically geared toward people who have sufficient experience cooking. The typical recipe lists out ingredients needed and either gives a paragraph describing what needs to be done, or a coarse list of steps that need to be carried out. Based on cognitive-load-theoretic principles, and work done by Mayer [citation], the cognitive load while cooking from recipe instructions may be reduced by reducing the amount of information displayed at any given time, called chunking. The use of interactive media is a natural way to chunk information.

Work on adaptive graphical user interface techniques [9, 10, 20] shows that such techniques decrease search time. We make use of adaptation by emphasizing the current step being carried out in the cooking process. We also emphasize the ingredients needed for that step.

Our observations show that cooking is very much a process over which multiple tasks are executed simultaneously. The need for a performant user interface is therefore important. We measure the base-line performance of our interfaces using Fitts' law [citation]. In general, attention was given to maintaining sufficiently large target hit areas (hit area is greater than actual UI elements), maintainging consistent target positioning (spatial consistency of menu item positions), and minimizing the overall amplitude required to navigate between steps (natural scrolling).

The major experimental feature of our interface is the use of Semantic Zoom (SZ) [citation]. We believe the use of semantic zoom leverages adaptive interaction techniques to emphasize relevant information while maintaining accessibility to logically adjacent information. We present our findings on the effectiveness of our SZ interface, and

There were aspects of recipe instruction that have evolved from the traditional paragraph-based way of describing a recipe. Recipes now list instructions in steps, and display a separate list ingredients. These designs use the inherent structure in the process of cooking, which seems natural. This is also a very common layout pattern with which people have grown accustomed to. Retaining some familiarity to this layout is important for reasons that go beyond the scope of this paper.

RELATED WORK
Cognitive theory has been extensively studied in the field of instructional interface design. The majority of work is based on Baddeley's canonical model of working memory as a limited buffer for visual and auditory information [4]. When the buffer is overloaded, possibly by performing tasks that involve an ordered series of physical and mental activities, new information can fail to be processed [4, 15]. Mayer expands Baddeley's model to form a cognitive theory of multimedia learning [14]. In his model, information processing is divided into a verbal (not necessarily auditory) channel and a visual channel. Again, each channel has a fixed information-

processing capacity and can be overloaded. Mayer presents a series of principles for designing instructional multimedia aimed to reduce cognitive effort required from the learner for one or more channels [13].

Over the last decade, similar principles have often been used in the design of multimedia systems for academic or conceptual instruction (e.g., Moons et al. [16] or Wong et al. [23]). However, unlike academics, most activities, cooking included, require less intellectual effort but require coordination of motion and sensation. The requirements on the channels of information processing thus differ. Paas and Sweller [18] argue that "biologically primary" skills passed through evolution require less cognitive effort than explicitly learned, often culturally driven "secondary" skills. Based on time of historical emergence, movement-based activities like sports and cooking should be more primary than many fields of academics. On the other hand, Post et al. [19] find that gesturing while watching grammar-instruction animations interferes with learning, and grammar could arguably be a primary skill. Moreover, interference from over loading could be bidirectional, for it is well established that secondary in-vehicle activities such as phoning or texting compromises driver's ability to react to road conditions, leading to injuries and fatalities [5].

Several questions arise, yet few studies have directly investigated the cognitive load effects of teaching tools in non-academic situations. In a rare study, Khacharem et al. [12] investigate the cognitive load effects of animations used for soccer instruction and find that novice players process both static images better than animations and slow animations better than fast ones, whereas expert players learn more effectively with fast animations. Their results suggest that speed and motion from instruction alone can add additional tolls on cognitive load, but these instructions were conveyed offline, as opposed to during gameplay.

The body of literature on cooking instruction is similarly patchy. Recipe recommendation and generation are well documented in the literature [8, 22, 21]; many such systems have been built but do not assist users in making the recipe. Few formal research investigates the cognitive load of cooking, and few systems seek to address the possible overload. Kraft's iFood Assistant [2] and Quasar Computing's Cook Assistant Lite [7] seem to share our goals, but their design choices and user test results, if any, are not documented.

Though not a formal academic study, the *Modernist Cuisine* series of Myrhvold et al. [17] uniquely takes a more intellectual approach to recipe presentation. To ease the cognitive load of cooks, the authors radically redesign the structure and order of presentation of print recipes: they alter the textual and graphic formatting to highlight key ingredients, times, and tools, they break down recipes into smaller, logical, often parallelizable units with clear time estimates, and explain the underlying principles behind steps. This work comes closest to our goals. In this work, we seek to formalize the design patterns used here and adapt them to a multimedia interface.

PROCEDURE

We used an iterative process to develop our design. We began with preliminary paper prototypes to gather our initial thoughts on the interface. Then we conducted experiments of novice cooks following non-interactive online recipes that they had not previously encountered (see Figure 1). With these observations in mind, we iteratively refined our paper prototypes and developed a first digital prototype system. We then observed novices using the prototype, and used our observations to refine our system.

Figure 1. Observing Subject 1

INITIAL PAPER PROTOTYPES

The initial genesis of this project came when we noticed there was not a significant transformation of recipe presentation by means of technology. Initially, we developed several low fidelity paper prototypes in order to gain early insights into a design. Figure 2 shows an example of our paper prototypes overviewing a recipe interface, and Figure 3 illustrates a single step of the recipe interface. Initially, we envision to add features such as text-to-speech instruction, timer for managing multiple simultaneous tasks, reminders to check oven and stove temperatures, and many other features that can be assisted by advanced technologies. However, as we progressed our experiment, we realized there were more fundamental issues in traditional recipe presentation. The next section describes our experience observing novice chefs cooking, and presents fundamental challenges in traditional recipe presentation.

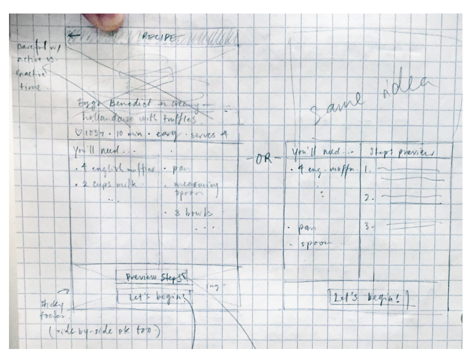

Figure 2. Recipe Overview Interface

USER STUDY #1

For the first experiment, we observed three subjects. The experiment was conducted as follows: each subject was asked

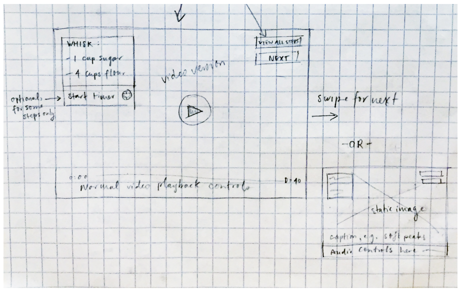

Figure 3. Recipe Step Interface

to cook a dish that he/she had never made before. We asked subjects to narratively describe the process that they are taking. The subjects' responses, behaviors, and surroundings were documented and occasionally recorded on pictures and videos.

Subject 1

Subject 1 had very little experience in cooking. His primary source of meal was delivery or prepackaged food. For the experiment, the subject was asked to cook Ravioli with Creamy Sun-dried Tomato and Basil Sauce [6], which the subject had no prior experience in cooking.

One of the first things we noticed upon observation of the subject was the organization of ingredients. Prior to cooking, the subject put out all ingredients that were listed in the recipe and measured their accurate portions. Even though all ingredients were measured accurately *in the beginning*, he roughly guessed portion of ingredients using mugs and bowls *while cooking*. After preparing all ingredients, he started boiling ravioli with sliced tomatoes. There were minor confusions on how much water to put in to cook ravioli and what shape tomatoes need to be cut but these issues were easily resolved based on the subject's prior experience and analyzing the final image of the dish.

Every time the subject completed a task (e.g., slicing tomatoes), he looked at the recipe, found the position of the task he has just completed in the paragraph, and read the next step. Over the course of cooking, he looked at the recipe more than 20 times where each reading took a good amount of time trying to find the position of the step he has completed in the paragraph. The subject remarked, "I have to constantly read over the paragraphs to see what step I am currently on." One interesting observation is when the subject did not look ahead. The subject mistakenly used all ingredients when some were needed again in later steps. The subject commented: "My assumption is, unless it is specifically stated to save some for later, put all ingredients in. It would have been helpful if recipe is structured in a form that is easier to see what ingredients are coming ahead." While closely reading individual steps were well-comprehended, coordinating such task while multitasking did not work well at all. Evidence of this was given when the subject was missing steps.

After cooking, we found that all ingredients (including the ones that were no longer needed) were kept in open air as shown in Figure 4. The ingredients were kept open and outside for an additional hour even after the completion of cooking.

Figure 4. Ingredients were kept open and outside

Subject 2

Subject 2 was a relatively experienced cook. The subject was asked to make Spaghetti Squash Gratin [3]. She had experience roasting spaghetti squash, but had no prior experience preparing this recipe.

She spent about one minute reading instructions and realized that Roasted Spaghetti Squash ingredient required significant preparation. After preheating oven and heating water, she read instructions again to scan for instructions that could be done while the oven preheats and the water boils. After preparing for all ingredients, she read the entire recipe again, from beginning, to re-evaluate her process. The subject continuously multitasked while cooking (e.g., prepped flour while waiting for liquid solution to reboil). Timer was used only for ingredients that may burn (e.g., warming milk). While cooking, she continuously read the recipe to to reassess her own mental process for cooking the recipe.

Similar to Subject 1, Subject 2 repeatedly read/scanned entire recipe, often standing idle, contemplating how to go about executing recipe. Time spend reading the recipe ranged from 30 to 90 seconds. Unlike Subject 1, Subject 2 took more control over reading the recipe instruction, and did not completely rely on the presented ordering of the recipe. Furthermore, Subject 2 reviewed past instructions to determine if she has made any mistakes. While observing the subject, we realized there was a significant gap between the number of steps carried out by the subject and the number of steps.

While whiskering flour into liquid solution, she encountered unexpected situation where flour started clumping. Later, she realized that the amount of sage she used was incorrect. Similar to Subject 1, Subject 2 read individual steps of recipe multiple times, however coordinating instructions while multitasking led to mistakes in keeping track of active ingredients.

Subject 2 was relatively comfortable improvising instructions for current needs. For example, when pot called by recipe was too small, she improvised by mixing spaghetti squash and liquid/flour mixture in a larger container.

Subject 3

Subject 3 also had some experience in cooking. The subject was asked to make Mushroom Ravioli with Goat Cheese from scratch [1]. The subject did not have prior experience making the dish and unexperienced working with dough.

Subject began by skimming both recipes. He commented that he likes to "parallelize" when cooking to minimize time spent, and to do that, he needs to read all steps a few times to process them and decide what to do first. Noting that the filling needed to cool before being wrapped, and that the dough preparation really only had 20 minutes of downtime, he decided to first prepare the filling and then move on to the dough.

The subject referred back to the recipe at least twice in each step, often once every couple of ingredients (and some steps had many ingredients), to double check the quantity and amount of time necessary to process each. Each time he checked the recipe, he only glanced at it a second or two, skimming for key numbers.

Making and rolling dough was a challenge, because the subject had never before worked with pasta dough. Here, he still followed the recipe step by step, but referred to it more to understand how to work the dough rather than what to put in it. As a result, each recipe check was longer and more involved; he read the sentences of the recipe and scrolled back and forth to check the pictures.

Next came filling and wrapping the ravioli. He first unsuccessfully skimmed both recipes looking for specifics on the optimal ratio of filling to dough, as well as how large to cut the ravioli. He then Google searched quickly, before deciding that it was useless since nothing was to scale and decided to just use "gut" and his prior experience with Chinese dumplings. He did not need to consult wrapping instructions after that point.

The last step written on the recipe was to boil the ravioli. This he did without consulting the recipe. He did wonder aloud when the ravioli would be done but decided that he'd just wait until a bit after they floated, like dumplings. As per his "parallelization" tactic, he set the water on a boil when he still had a few more ravioli to wrap so that he could get moving immediately when the ravioli were ready. He commented that it would be faster to have started boiling the ravioli in batches, while more of the ravioli were still unwrapped, but that it was unimportant because boiling time was so short.

Evaluation

As a result of these observations we found that existing curation of a recipe was very difficult for the novice users to comprehend while cooking. Subjects repeatedly read and scanned the entire recipe. Novice subjects had a lot of difficulty remembering the current step within the paragraph and spent significant amount of time keeping track of current and upcoming steps. Additionally, there were poor connections between recipes that were parts of one dish. These observations were further corroborated in our interface evaluation.

Based on these observations, we decided to focus on the curation of recipe instructions and ingredients.

SYSTEM DESIGN

After gaining this background knowledge, we developed a new interactive prototype that focused on curation of recipe instructions. From the user study, we found the difficulties of identifying current step in traditional recipe design. In our proposed interface, we included a feature that highlights the current step. We expect highlighting the current step will reduce the cognitive load of users, because they no longer need to scan the entire recipe to identify the step they have just completed. The position of the highlighted box remains consistent throughout the instructions. We further discuss the details of this feature in the later section. While highlighting the current step, our interface also presents the summary of previous and next steps. We have found that reviewing previous and future instructions is important for successful cooking but the traditional recipe design makes it difficult to quickly review the steps. For that, we design our interface to only include the summary. An example view of our proposed interface is shown in Figure 5.

In order to compare effectiveness of different recipe interfaces, we developed three interactive web-based interfaces: traditional recipe interface, step-by-step interface, and our proposed interface. Figure 6 shows the traditional recipe interface curated as a list. Step-by-step interface is commonly used for cellphone-based recipe interface. As shown in Figure 7, it presents a single step at a time and allows user to click next or previous to navigate the instruction.

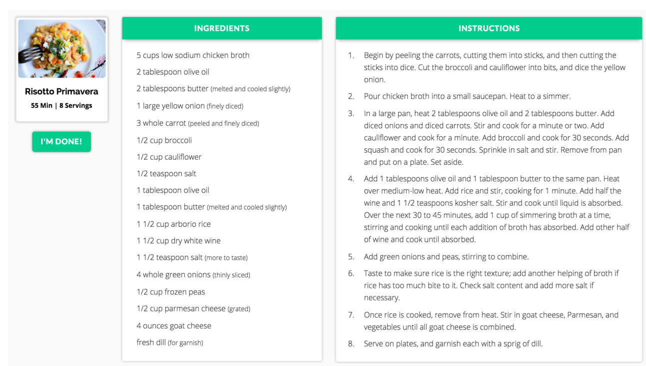

Figure 6. Traditional interface of a recipe

USER STUDY #2

Three subjects are observed and interviewed for this study. Each subject was asked to test three interfaces (Control, Step-by-step, and our proposed Responsive interface). We curated three recipes (risotto primavera, mushroom lasagna, and baked eggs with spinach and mushrooms) that the subjects did not have prior experience making. Subject 1 tested traditional interface with risotto primavera, step-by-step interface with baked eggs, and our interface with mushroom lasagna. Subject 2 tested traditional interface with mushroom

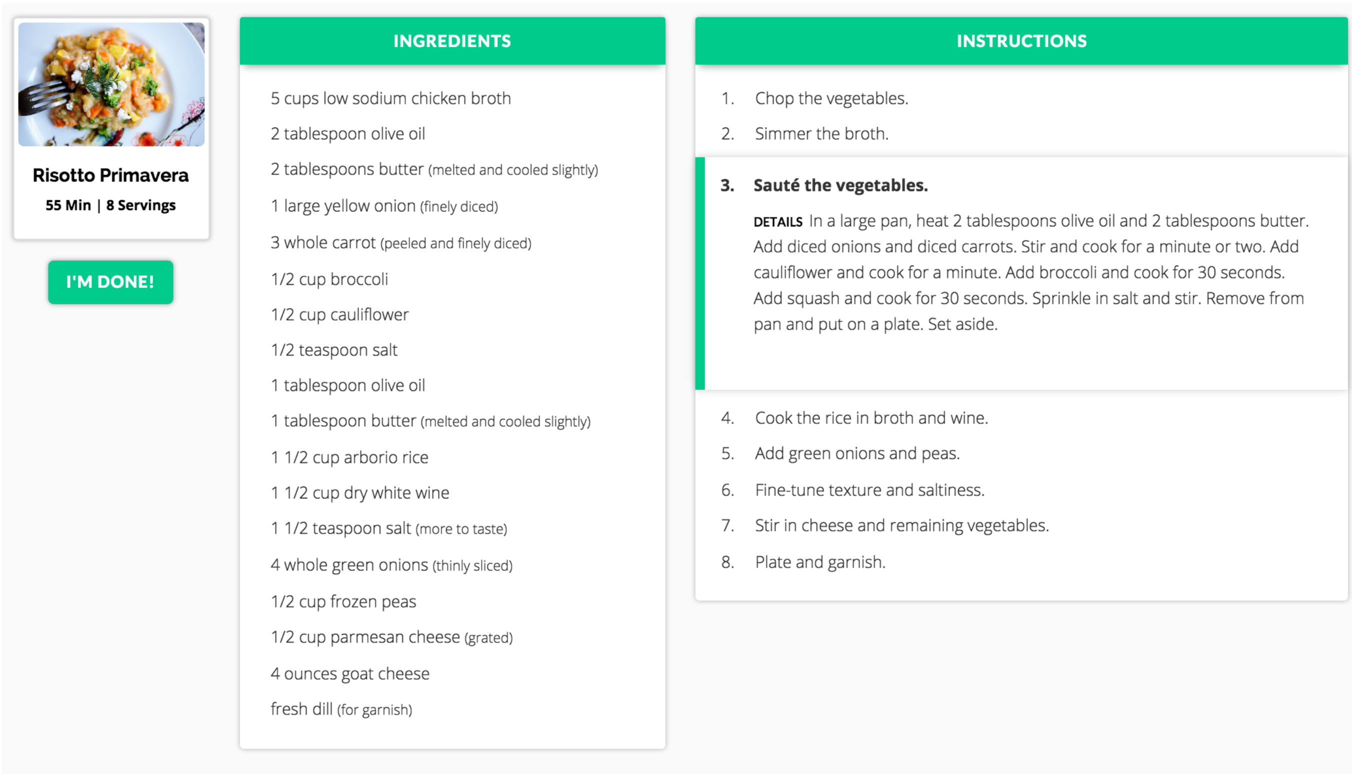

Figure 5. Example view of our proposed Responsive interface

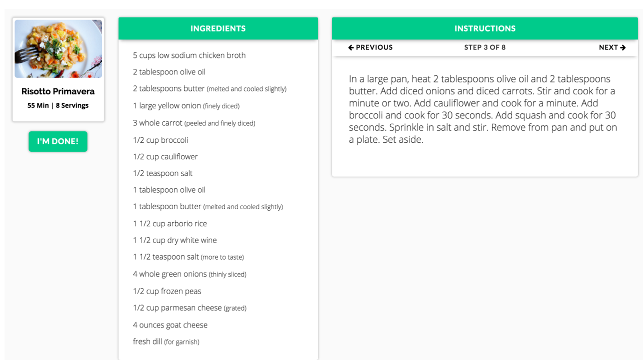

Figure 7. Step-by-step interface that is commonly adopted for cellphone applications

lasagna, step-by-step interface with risotto primavera, and our interface with baked eggs. Subject 3 tested traditional interface with baked eggs, step-by-step interface with mushroom lasagna, and our interface with risotto primavera. We measured time spent on completing individual steps as well as the entire instructions. Similar to User Study #1, subjects narratively described the process that they were taking and the subjects' responses, behaviors, and surroundings were documented. Subjects completed NASA-TLX [11] worksheet after each interface, and at the end of the experiment they selected their most preferred interface.

Subject 1

Subject 1 tested Control, Step-by-step, and Responsive, respectively. The first recipe for Subject 1 was baked eggs with spinach and mushrooms using the traditional interface. Similar to User Study #1, the subject accurately measured the ingredients in the beginning and estimated amount of ingredients used in each step while cooking. The subject stumbled on couple jargons such as 'indentation' and 'baking eggs.' The subject said his insecurity kicked in when he read the instruction, "If baking eggs in this skillet, make 12 large indentations in mixture ... " because he did not know what baking eggs and making indentations mean. The subject said that the traditional interface presented too much information at the same time and remarked: "This interface seemed like an essay."

The second recipe was mushroom lasagna using Step-by-step interface. This interface also included ingredient highlighting feature that emphasized active ingredients in a step. We describe this feature in details in the following Section. When the subject first saw the interface, he expressed excitement because "clear separation of steps made for easier digestion and awareness of what he needed to do without worrying too much of overall picture." He also stated: "Even though the second interface was also in paragraph format just like the first one, it didn't have as daunting of a feel since it was just one." The subject also suggested that it would be nice to break down the paragraphs even smaller with more steps, although it would make it more challenging to go back and forth when doing simultaneous procedures. Throughout cooking, the subject had difficulty interacting with the interface because

Step-by-step interface only showed a heap of information and was not easy to figure out intermediate steps. We found that ingredient highlighting made important information salient and removed extraneous information. The subject found ingredient highlighting very helpful. He remarked "the highlighting of ingredients list as I went through the steps was wonderful because I could just focus on the few on table that I needed at the moment."

The third recipe was risotto using Responsive interface. This interface emphasized instructions for current step and highlighted ingredients for current step. The subject had much easier time multitasking using this interface. The subject said "I liked that each step was clearly spaced out just like in second interface. But what made the third interface even better was I could see all the steps in one place rather than having to click back and forth multiple times to go from say step 2 to step 5 with interface 3. I could look at step 5 and then go back to step 2 with just one click." Because the subject was able to see summary view of the recipe, he said "it sort of offered a little blurb/summary of what was being achieved in that step." The subject selected Responsive as his most preferred interface.

Subject 2

Subject 2 tested Responsive, Control, and Step-by-step, respectively. The first recipe for Subject 2 was lasagna using Responsive interface. When first started the recipe, the subject scanned all the steps and went back to the first step. In the first step, the subject flipped to next step to have a sense of what could be done in parallel. The subject stated "I was going up and down because I was trying to parallelize process." The subject found ingredient and instruction highlighting helpful but too coarse. He could not figure out which ingredients to prepare before others, or estimate how long each preparation process would take. Additionally, the subject suggested "If the interface showed time or the number of pans you need per step, then that would be very helpful."

The second recipe was risotto using the traditional interface. Looking at Control interface after Responsive interface, the subject remarked "this interface is definitely much harder." The subject commented that the list of paragraphs was an information overload. The subject was worried that he might miss a step or an ingredient so he read the recipe multiple times before he started. Similar to our observation in User Study #1, the subject said Control interface was "difficult to follow along" and "never knew where he was in the recipe." For Responsive interface, he only had to press up and down arrows when trying to read ahead, but with Control interface, every time he wanted to look next or previous steps, he had to scan the entire paragraph to see where he was, which was "more irritating." While cooking, the subject noted images or videos in each step would be helpful.

The third recipe was baked eggs with spinach and mushrooms using Step-by-step interface. The subject liked visually having 'next' and 'previous' cues. In the previous test, when the subject first opened Responsive interface he immediately went to clicking 'Done' button to go to the next step. However, in Step-by-step interface, he did not make that mistake due to visual saliency of 'next' and 'previous' buttons. He commented "arrow keys are normally for power users." Interestingly, we also noticed that the subject had a sense of completion when he clicked 'next' button after completing each step. In terms of instruction and ingredient highlighting, similar patterns were observed as for Responsive.

Subject 3

Subject 3 tested Step-by-step, Responsive, and Control, respectively. Subject 3 first made risotto using Step-by-step interface. The first instruction of the recipe was to chop vegetables so the subject first chopped vegetables and moved to the second step. The second step was to boil broth for cooking rice. The subject reported that she could have chopped the vegetables while boiling the broth, and said "I guess I could have looked at step 2 to see if there was anything I could have started in the next step." This was arguably a flaw in the design of Step-by-step interface. The interface only showed current step, which limited cognitive load but it did so at the expense of knowledge. Hence, it led to longest total cooking time compared to Control and Responsive interfaces. The subject made heavy use of ingredient highlighting. While going back and forth in executing a step, she looked at screen for ingredient measurements, then went back to preparing the ingredients. She remarked: "I liked the highlighted ingredients because ingredients were broken down into chunks instead of having it all sitting there in front of me. It was easier to read." Ingredient highlighting feature was reducing search time of ingredient measurements and allowed the subject to focus on preparing ingredients.

The second dish was baked eggs with spinach and mushrooms using Responsive interface. The subject found summary view in Responsive interface informative. She commented "it was a nice way of conceptualizing what I was about to read as a whole; so I didn't have to read all the details. Otherwise, I would have to skim through the steps to get the main idea of the step." Similar to Step-by-step, she found ingredient highlighting useful as she could focus on ingredients that were bolded, instead of looking at all the other ingredients. Similar to Subject 2, she wanted to have a feature that listed materials used for each step. The subject selected Responsive as her most preferred interface.

The final recipe was lasagna using Control interface. After using Step-by-step and Responsive that had ingredient highlighting feature, the subject complained that the control interface did not have the feature. The subject commented that compared to Responsive and Step-by-step, Control interface is very plain as it was non-interactive. The subject selected Control as her least preferred interface.

Evaluation

From User Study #2, we found that most subjects preferred Responsive Interface over Step-by-step and Control. Compared to Step-by-step interface that only showed a single step at a time, we found that presenting the summary view of the recipe in Responsive interface provided users a sense of control. All subjects expressed that ingredient highlighting in

Table 1. Number of times user has switched between steps

	Risotto	Egg	Lasagna
Control	-	-	-
Responsive	6	10	34
Step-by-step	14	25	37

Step-by-step and Responsive helpful in keeping track of ingredients per step while staying out of their way. From the observation, we identified that Responsive interface reduced load of extraneous information presented at any given step. This observation was further corroborated with our quantitative data shown in Table 1. For each recipe, the number of times a step has changed can be interpreted as the amount of cognitive load the recipe demands. Table 1 shows the number of times user has switched between steps. For each recipe, Responsive interface led to smaller number of step changes than Step-by-step interface.

User feedback indicated that Step-by-step interface chunked information and missed important future steps that slowed subject down. On average, subjects took 94.5 minutes to cook a recipe using Step-by-step interface compared to 89.8 minutes using Control interface. For a given recipe, we expected Responsive interface to take least total cooking time compared to Control and Step-by-Step, but this was not evident from data as Responsive took 92.7 minutes on average.

Initially, we included NASA TLX survey to get user feedback on different interfaces. However, we realized that the survey ended up reflecting reactions to recipe, not interface. We observed that subjects had most difficult time making lasagna. As expected, lasagna had the highest rating for mental demand (risotto: 2.67; eggs: 3; lasagna: 3.67) and frustration (risotto: 2; eggs: 3; lasagna: 3.67) in NASA TLX survey. Referring back to Table 1, the number of times a step has changed indicated the amount of cognitive load the recipe demands. As lasagna was identified as the most difficult dish, it had the highest number of clicks, eggs had the second highest, and then risotto for both Responsive and Step-by-step interfaces.

FINAL DESIGN ITERATION

For the final design, we improved Responsive interface based on our observations and users' feedbacks in User Study #2.

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- Most subjects requested presentation of cookwares along with instructions and ingredients. In this iteration, we incorporated the feature of cookware curation.

- All subjects looked at the photo of the finalized dish to decided on intermediate steps that were not elaborated in the recipe. Most subjects commented that having a picture in each step would greatly help them understand latent instructions. With their request, we added images in each step.

- In the final design, we clearly added 'next' and 'previous' button. In previous Responsive interface, those buttons were not visually presented bur rather implied.

DESIGN OBSERVATIONS

In this section, we describe added features of our final design, and some factors that led to its relative success.

Instruction Highlighting

Instruction Summary View

Ingredient Highlighting

Cookware Listing

Native Scrolling

CONCLUSIONS AND FUTURE WORK

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