Increasing nutrient awareness with the Smart Kitchen Scale

A graduation project for Creative Technology

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Abstract

This is a graduation project for Creative Technology. The project is about how interactive technology can be applied in the kitchen to increase nutrient awareness. 8 design heuristics were derived from past scientific literature. An application of interactive technology must provide just-in-time dietary feedback while being easy and convenient to use and being accessible to people with lower nutrient literacy. The Smart Kitchen Scale was developed to test and demonstrate these design heuristics. it can automatically detect food types and can, besides the weight, display nutrient information about that food. The Smart Kitchen Scale was found to only be suited for the scenario in which a meal is cooked with multiple ingredients. The Smart Kitchen Scale did not satisfy the heuristic related to accessibility and convenience well, which were found to be more important than found in the past literature. Furthermore, a Modular Integrated Smart Kitchen model is proposed that can possibly solve many issues with the Smart Kitchen Scale and other systems and allow its components to more effectively achieve their goals by allowing cooperation between them.

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Chapter 1: Introduction

According to the world health organization, 39% of the adults of 18 and over are overweight and 13% are obese [1]. The main cause is an imbalance in energy consumed and energy expended [1]. Therefore it can be said that many people do not have healthy diets. Furthermore, there are other forms of malnutrition unrelated to the energy balance. For example having deficiencies in micronutrients like fiber, minerals, or vitamins [2]. Many people, especially in January when new year's resolutions are made, are motivated to make a change in their diets with a healthier lifestyle in mind. However, the majority of these people fail [3]. There are different reasons for these failures, for example having unrealistic goals or too little self-confidence. A lack of nutritional knowledge and awareness is suggested to be a factor in the failures of these diets [4]. Many home cooks do not have awareness about their own diets or knowledge about nutrition, in general, to make educated dietary decisions for themselves and their families [5]. Being nutrient aware means knowing the nutritional content of ingredients used and what your body uses them for. This information is widely available, however, this information can be overwhelming or confusing.

Different methods are available for helping people become more nutrient aware, most of them are based on some sort of nutrient tracking. Tools like smart fridges, tracking apps, or even old fashioned tracking schemas exist to help people keep track of their nutrition [6, 7, 8]. However, most of these tools are cumbersome to use and require nutritional knowledge, that their users often do not have, to be effective for inferring the right dietary decisions [9, 10]. Improving the accessibility and convenience of these tools can possibly help motivated people become more aware of their nutrition so they can make better dietary choices. The home kitchen is a suitable context for such a system because there, a lot of the food people consume is prepared or stored. Therefore the context of the home kitchen offers the possibility for a system to be well integrated into the routines of its users and thus be convenient to use.

The main focus of this review is to explore what such a system should be like to effectively increase it’s users’ nutritional awareness. The main research question of this project is:

How can interactive technology be used to increase nutrient awareness in the kitchen?

For the system to be an improvement over the already available tools it must be convenient to use and be accessible to people without extensive nutritional knowledge. Therefore sub-questions to this project are:

How can a system increasing nutritional awareness in the kitchen be convenient to use?
And how can it be accessible to people without expert nutritional literacy?

This report is structured in chronological order, with every chapter being a distinct phase in the graduation project. First chapter 2 reviews the state of the art and tries to find design heuristics that answer the research question. Chapter 3 is about the ideation resulting in concept ideas for interactive applications. Next, chapter 4 describes a user questionnaire and how it contributed to the specification of the final prototype. Chapter 5 describes the technical aspects and construction of this prototype. The prototype was evaluated in a real-world user test that is elaborated in chapter 6. The report will conclude with the discussion and conclusion in chapters 7 and 8 respectively.

Chapter 2: state of the art

In this chapter, the current state of the art is discussed. Design requirements will be gathered from the current literature. These requirements are used later on as heuristics to ideate, design, and evaluate a hi-fi prototype. This chapter will be structured as follows. Section 2.1 is about the extent nutrient awareness improves people's diets and the distinction between nutrition literacy. Next, section 2.2 will discuss the methods and techniques used by past research to increase the subjects' nutrient awareness by using interactive technology. In section 2.3 the ways to conveniently measure dietary context are discussed followed by section 2.4 discussing how to make the feedback accessible and effective. Finally, 2.5 will conclude this chapter by listing the design heuristics found in the literature.

2.1 Enabling healthier diets

If a system succeeds in increasing its users' knowledge about nutrition or awareness thereof, it will likely help these people adopt a healthier diet, because both nutrient awareness, as well as nutrition literacy, are correlated to having healthier diets. Even though the users are free to do whatever with the feedback this system provides, it is interesting to know that systems focusing on increasing nutrient awareness actually help people adopt a healthier diet.

In a study about nutrition knowledge and obesity Bonaccio et al. [1] found that an increased knowledge of nutrition associated with a lower chance of being obese. Besides that in a literature review about the effect of the understanding about the nutrition labels on food products, Malloy-Weir and Cooper [2] found that the choices of different levels of nutrition literate people differed and that people with low nutrition literacy could benefit from intervention helping them better understand nutrition-related information. However, they also state that the research done on this topic has issues with the method of measurement and thus further research is needed.

Chen et al. [3] found that people that gained awareness about their own diets by using their Smart Kitchen had a smaller difference between intake calories and the recommended amount. Suggesting that increased awareness causes people to adopt diets with a better energy balance. However because this study did not account for the variable of nutrition literacy, it could just as well be that the subjects simply gained knowledge about nutrition and consequently started eating healthier. Although this is, as Malloy-Weir and Cooper found, also a factor, statements from the participants reveal that awareness certainly was a factor in their dietary decisions: “this kind of instant feedback is effective to remind me of what I already know…”.

Although this topic can use more research on both the effects of nutrient awareness as nutrition literacy on diets, The existing studies strongly suggest that both these variables positively influence the dietary decisions of people. However the extent to which is uncertain. This means that a user would benefit from a system that increases their awareness about their dietary choices on top of just increasing their nutrition literacy.

2.2 Increasing nutrient awareness

To increase the nutrient awareness of its users, a system must provide feedback to its users about their diets. This process can be split into two actions. First, a system has to measure the dietary context. Second, the system must provide information about this context to the user. Ideally, this feedback should be provided at the time the user makes the dietary decision, or just-in-time.

Mankoff et al. [4] measured the dietary context by analyzing grocery shopping receipts. Their system prints a grocery list for the next time with suggestions for better alternatives for its items. The user can read these suggestions at the time when they are about to make their dietary decision, in the grocery store. This can be called just-in-time dietary feedback as the feedback is provided when the user needs it, even though the dietary context was measured earlier. The Smart Kitchen by Chen et. al. [5] and the diet-aware dining table by Chang et. al. [6] can be described as providing real-time dietary feedback. Real-time dietary feedback can be seen as a subset of just-in-time dietary feedback: the feedback is provided at the moment of a dietary decision. Furthermore, these systems measure the dietary context at the same time (in real-time). The Smart Kitchen detects ingredients of a meal being prepared and shows nutritional information on an LCD, while the diet-aware dining table shows nutritional information about dishes being consumed at the dining table.

Providing dietary feedback is a fundamental requirement for a system aiming at increasing its users' nutrient awareness (*heuristic 1*). The three above mentioned systems have in common that they are implemented as part of the flow of food from the grocery store to consumption, i.e. buying groceries, food storage, food preparation, or food consumption. This is because these are the scenarios in which dietary decisions are made and thus provide opportunities for interactive systems giving real-time or just-in-time dietary feedback (*heuristic 2*).

2.3 How to measure dietary context

The first thing a nutrition feedback system must be able to do is autonomously measure dietary context in some way that can be well integrated into the routines of its users, which is best done using a combination of quantifying and classifying sensors. To be convenient, a nutrition feedback system must require as little human interfacing as possible and it should be able to function as much in the background as possible. Autonomously measuring context is the aspect of a nutritional feedback system that is most difficult to achieve. Using a single sensor in many cases does not provide the information needed to properly infer dietary intake from. The previous example of the single sensor shopping list analyzer by Mankoff et. al. demonstrates this well [4]. A single optical camera was used to measure the dietary context from one source: the shopping list. This was found to be unreliable. However, the system was quick and easy to use.

Systems that are able to be more accurate in the measurement are using multiple sensor types or acquire the dietary context from multiple sources. A trend seen in the literature is systems using different combinations of the following sensor technologies: RFID (Radio Frequency Identification), optical cameras, infrared cameras, weight sensors, and networked kitchen appliances. The most common combination of sensors is a combination of at least two, a classifying, and a quantifying sensor. One sensor measures what food is consumed, stored, or prepared while the other measures the amount of that food. This combination is essential to be able to measure dietary energy balance.

An often used sensor type for classification is RFID. The diet aware dining table by Chang et. al. [6], the smart kitchen cabinet by Amutha et. al. [7] and the smart fridge by Luo et. al. [8] showed that when food is already pre-classified (prepackaged and tagged), RFID is really accurate in determining the food type. However, the user's interaction with the system is limited to strict actions, as for example misplacing a container can cause it to be misclassified and thus the system will fail [6, 7]. In some systems, this is solved by combining RFID with other sensors (mostly cameras). Using smart algorithms the system can correct for some of these inaccuracies [3]. However, the study on their smart kitchen by Chen et. al. [5] found that using RFID classification was troublesome when using fresh products. In their experiment they used a wizard of oz method for their prototype, however, they suggested some type of computer vision for the recognition of fresh and chopped food.

Other attempts have been made to conveniently measure dietary intake from a completely different direction. By placing sensors of different kinds on a person's body, attempts have been made to track every bite people eat. Examples are: classifying food type using acoustic sensors by Päler et. al. [9] and by Bi et. al. [10] or detecting food intake by bodily motion by Dong et. al. [11] and by Amft & Tröster [12]. These methods can be accurate for determining the quantity or a global food type, however the struggle to classify the difference between closely related food types, i.e. different breads. On-body sensing is promising as it can be unobtrusive and possibly accurate in the future. However, at this moment in time, they fall short in the accuracy part compared to sensors in for example the kitchen environment.

To be convenient and unobtrusive, a dietary feedback system has to be able to autonomously measure the dietary context, to minimize the user effort (*heuristic 3*). This can be done with at least one sensor measuring quantity and one classifying the food. More different sensor types can be used to increase accuracy mainly in the classification part. Weight sensors have been shown to be a simple and effective way of measuring quantity, while the classification is still the most difficult requiring combinations of different sensors with their own advantages and disadvantages. Computer vision and bodily sensing show potential, however, these sensing types are lacking in accuracy at the moment and require further development. Lastly, the system should be convenient to use, meaning that the actions required from the user should be self-evident, this can be achieved by incorporating the system into the routines its users already have (*heuristic 4*).

2.4 How to provide accessible feedback

After measuring the dietary context, a nutrition feedback system must be able to provide feedback that is accessible to users with lower nutrition literacy by simplifying nutritional information, being transparent about suggestions, providing the possibility to compare alternatives and providing the feedback in a just-in-time manner

For a system to be able to increase it's user's nutritional awareness the system can not just suggest different foods without reasoning. The system should try to make it's users understand the good and the bad of their diet and then suggest changes upon that. Moreover, the system must make the information it is providing accessible for people without a lot of nutritional knowledge (*heuristic 5*). This can be done by simplifying the information or by teaching it's users about nutrition along the way.

The smart kitchen by Chen et. al. [3] tries to help its users to understand what the calories of a single ingredient mean for the calorie total of the meal they are cooking, but also compare the calories of the ingredient and the meal to the recommended calorie total of the day. This helps its users to estimate what amount of calories a meal should contain (*heuristic 6*). The users can compare different food choices or quantity thereof: "I'm glad to get this kind of calorie information without additional effort, because I should really be aware of using less of an (high-calorie) ingredient and not all in the whole package." said one of their participants (*heuristic 7*). A key principle in the system by Mankoff et al., where grocery shopping receipts are used to suggest substitutes, is that the system must be transparent [4]. Their system always gives a proper reason for why they are suggested substitutes: i.e it contains fewer calories or more healthy nutrients. "By showing the shopper what the system believes he has bought, and why the alternative is believed to be better, we give the shopper the power of an informed veto." [4]. A feedback system should not constrain its user. It should enable its users to effectively compare different dietary options so they can make their own informed choices (*heuristic 8*).

To make a nutritional feedback system effective in increasing nutrient awareness, the feedback should be provided in a certain way. For any quantitative values, reference values should be given and the user should be given the opportunity to compare. This allows the user to understand different dietary options and their content. When giving dietary suggestions the system should be transparent about its reasoning and allow the user to make their own choices. Finally, the nutritional information should be simplified or explained so that users with lower nutrient literacy can understand it.

2.5 Conclusion state of the art

How can interactive technology be applied in the kitchen to increase nutrient awareness? An increased nutrient awareness can improve someone's diet and as a result someone's health. Interactive systems can be deployed in different contexts to improve its users' awareness of their own diet. The flow of food from the grocery store to consumption allows for different opportunities of increasing awareness: buying food, storing food, preparing food, or consuming food. The literature reviewed in this chapter indicates the following design heuristics for a system increasing nutrient awareness. Using the MoSCoW prioritization system:

1. *The system **must** provide dietary feedback.*
2. *The feedback **should** be given in a just-in-time manner*
3. *The system **should** minimize the user's effort by autonomously measuring dietary context.*
4. *The system **should** be easily incorporated into its users' routine and the required actions of its users should be self-evident.*
5. *The information the system provides **should** be simplified and understandable to people with lower nutrition literacy or the system should teach its users about the principles used.*
6. *The system **should** provide reference to the values given. (e.g recommended calorie total when giving calorie amount)*
7. *The system **should** provide the opportunity for comparison between different dietary choices.*
8. *The system **should** be transparent about dietary recommendations and allow the user to make their own informed dietary choices.*

Increasing awareness can be done by providing just-in-time or real-time dietary feedback. Such a system should measure the dietary context autonomously to minimize user effort, by using a combination of sensors that can classify and quantify nutritional content. Computer vision and bodily sensing are becoming more accurate and versatile, suggesting these technologies can be used to measure dietary context. This should be done in a way that can be easily incorporated into its users' eating routines. Furthermore, the dietary feedback should be provided in an accessible way by simplifying the nutritional suggestions, so people with lower nutrition literacy can understand it. Finally, the system should provide the opportunity for comparison and be transparent about its suggestion to allow the user to make their own informed dietary choices.

Chapter 3: Ideation

This chapter is about the ideation phase of this project. The first section is about the ideation methods used in this project. In the two sections thereafter concept ideas that emerged from the ideation phase are discussed. This discussion involves a general description of the concepts and their functionality and their satisfaction of the design requirements from the state of the art chapter.

3.1 Ideation methods

The ideation method used in this project was a combination of design heuristics and brainstorming. Using heuristics means using design guidelines determined by previous work. In the case of the project, these guidelines were inferred in the state of the art chapter. Brainstorming is freely generating ideas. The brainstorming followed the rules by Daly et al.: “(1) postpone all judgment of ideas, (2) encourage wild ideas, (3) aim for quantity over quality, (4) build on ideas, and (5) every person and every idea has equal value.” [13] Of which the last one is irrelevant because this project was done by one person.

First, the context of the kitchen forms the basis of all ideation because of the project constraint. In most homes, the kitchen’s purpose is storing, preparing, or consuming food. Because of these different scenarios related to nutrients, the kitchen offers many possibilities for interactive technology applications aimed at increasing nutrient awareness. These scenarios are combined with the design requirements (heuristics) from the state of the art in a matrix. Every cell is a starting point for brainstorming. As to be expected, some cells of the matrix were more fruitful than others in seeding good brainstorming.

Heuristic/design requirement:	**Action:**
	Food preparation
Autonomously measure dietary context	Using computer vision to detect ingredients to a meal (IR? Microwave? Visible light)

Easily incorporated into users' daily routine	Improve a device people already use: Pan, chopping board, measuring cup, scale.
The system should be transparent. User should have freedom of choice	Make a system that does not provide recommendations but only shows the content of food. Heads up Display? A feedback loop like looking at the speedometer in a car.

Table 1: A section of the matrix used to generate scenarios to brainstorm with. The heuristics from the literature in the left and a nutrient action in the right column.

Because of the first rule for brainstorming by Daly et al. [13], many bad ideas are generated during the brainstorming process. These are useful to spark further ideation and add up towards a few ideas that on the first look, seem to be suitable for a concept for this project. To evaluate these ideas, the design heuristics from the state of the art are used as guidelines. The amount of design heuristics a concept satisfies gives an indication of how well an idea is according to the state of the art. Furthermore, the importance of the design heuristic should be taken into account (must have is more important than could have).

1. *The system **must** provide dietary feedback.*
2. *The feedback **should** be given in a just-in-time manner*
3. *The system **should** minimize the user's effort by autonomously measuring dietary context.*
4. *The system **should** be easily incorporated into its users' routine and the required actions of its users should be self-evident.*
5. *The information the system provides **should** be simplified and understandable to people with lower nutrition literacy or the system should teach its users about the principles used.*
6. *The system **should** provide reference to the values given. (e.g recommended calorie total when giving calorie amount)*
7. *The system **should** provide the opportunity for comparison between different dietary choices.*
8. *The system **should** be transparent about dietary recommendations and allow the user to make their own informed dietary choices.*

Furthermore, the concept should be original. Besides this formal evaluation of the concept ideas, the feasibility is also taken into consideration. A working Hi-fidelity prototype is a good addition if not a requirement for this graduation project, therefore it should be possible for a Creative Technology student to make a working prototype of the concept on their own. Furthermore, the concept should be something that sparks enthusiasm, to make the project more fun, but also improve the quality of the project because of it.

3.2 The Smart Kitchen Scale

The concept that emerged from the ideation and that this project will continue with is the Smart Kitchen Scale. This scale has the ability to automatically recognize and record nutritional information like calories, protein, fats, etc. This gives the scale the ability to not only show the weight of the food on the scale but also give real-time information about the nutritional content. This allows the user to compare different ingredients and possibly understand their own diet better and make healthier dietary choices.

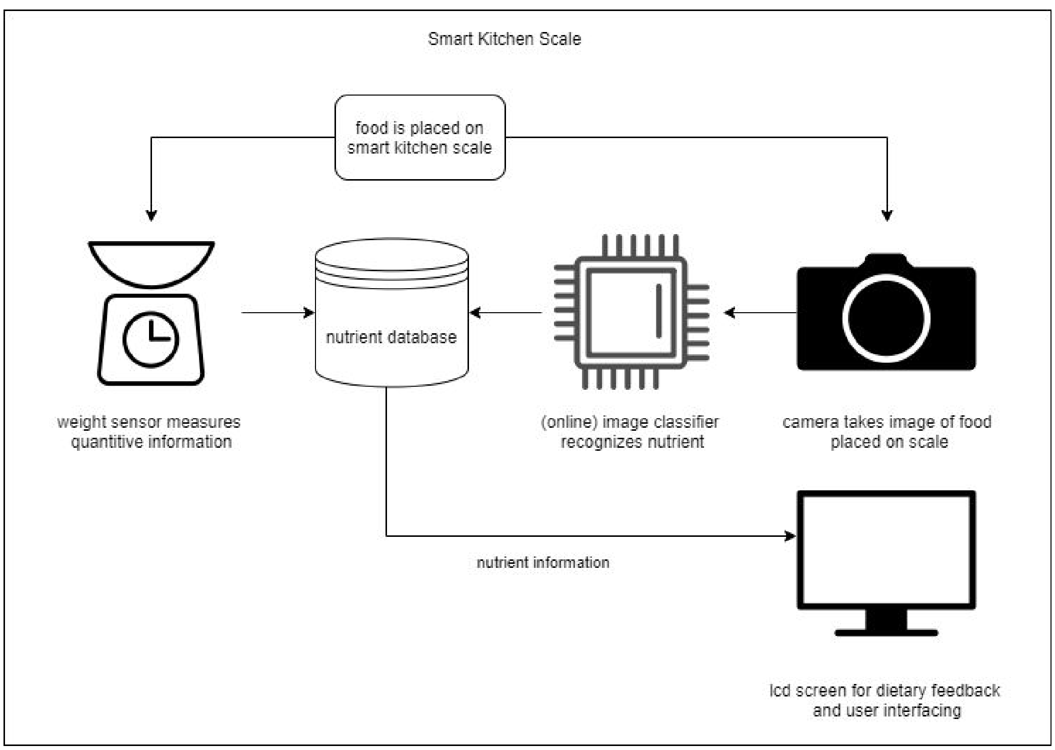

Figure 1: Graphical representation of the Smart Kitchen Scale. This graph was made using the draw.io online graph-making tool.

The Smart Kitchen Scale would function largely the same as a normal kitchen scale, which would make it be easily incorporated into peoples cooking routines. The Smart Kitchen Scale uses computer vision to recognize ingredients that are placed on it. This allows the scale to recognize fresh ingredients. A tool like the Smart Kitchen Scale could be a useful addition to the Nutrient tracking apps people already use. The Smart Kitchen Scale could also have the possibility to communicate with those nutrient tracking apps.

Design requirement	Satisfaction
1	The Smart Kitchen provides dietary feedback by showing the nutrient content of the ingredients the user uses.
2	The dietary feedback is given in real-time because the nutritional information is displayed at the moment the user weighs an ingredient when cooking. This satisfies the just-in-time requirement because the information is given at the moment of a dietary decision.
3	User effort is minimized by automating the measurement of dietary context. The user, however, does still has to measure the food, which depending on the implementation could be a lot of work.
4	The smart kitchen scale can replace the kitchen scales people already have and works largely the same. However, most people do not use kitchen scales for every ingredient and to get a complete picture of someone’s daily nutritional intake more information is needed than that of one meal.
5	The smart kitchen scale’s LCD display offers the opportunity to simplify the dietary information.
6	The Smart Kitchen Scale’s LCD display allows for reference values to be displayed in for example a bar graph.
7	The Smart Kitchen Scale allows comparison of ingredients by just

	weighing both ingredients.
8	The smart kitchen scale aims at only giving dietary feedback in the form of nutritional values. The user is free to do whatever with this information.

Table 2: Design requirements satisfaction of the smart kitchen scale concept.

3.3 Modular integrated smart kitchen

The Modular Integrated Smart Kitchen is a concept that emerged from the idea of combining the functionalities of different smart kitchen appliances. This is a concept that will not be developed into a prototype in this project, however, it is worth discussing as the Smart Kitchen Scale described above could be part of such a Modular Integrated Smart Kitchen. Using the Smart Kitchen Scale in combination with other tools, even if they have different goals, could benefit the Smart Kitchen Scale as well as the other tools.

A smart kitchen, as found in the state of the art chapter, uses different technologies often for the goal of saving time or resources. A smart kitchen is home to different systems that have separate goals. For example, a smart bin collecting waste data for better waste management, a smart fridge preventing food spillage, the smart “kitchen” by Chen et al. [3] trying to give dietary feedback, etc. All these systems use sensors to collect data in some form. This data then is used by the system itself and when that system doesn’t need it anymore, it is lost. This can be called a distributed smart kitchen because all the parts are isolated and are focused on achieving their own goal.

The idea of an integrated smart kitchen is one where all components share their resources. This can be done by storing all the collected data centrally so that other components can use that data to more effectively achieve different goals. Think of the smart fridge for example sharing spillage information with the smart bin to help the bin detect that food has been thrown away. Such information can be stored on a central data server, that can be reached by a public API. Using this API, systems within and outside the smart kitchen can be improved. It also enables bigger, more complex, and more powerful systems. For example, a health-tracking system that combines systems like kitchen appliances, training equipment, measurement equipment, and mobile/web-applications to give the user or third parties a better understanding of the health situation of the user.

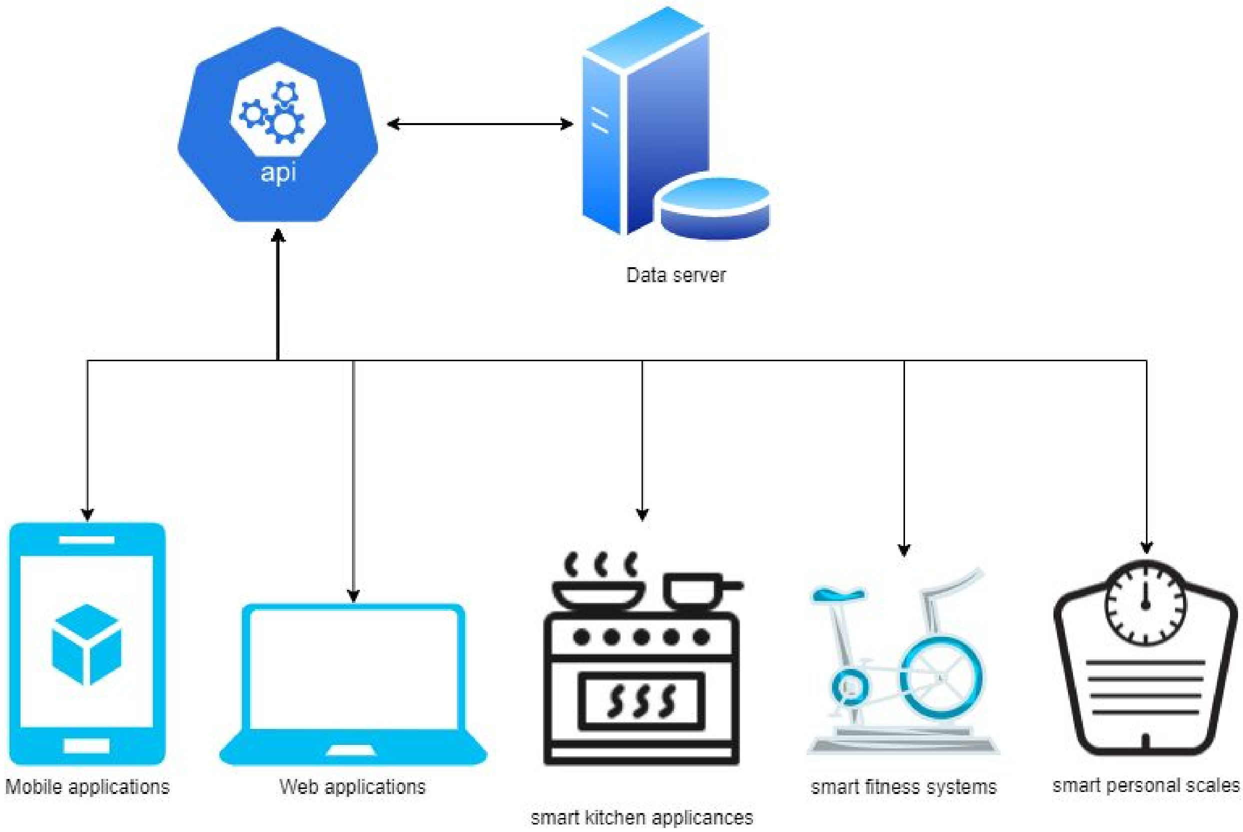

Figure 2: Graphical representation of an integrated smart kitchen / integrated e-health system. This graph was made using the draw.io online graph-making tool.

Sharing the data between the components of a smart kitchen has the potential of making all of its components more effective. However, it is important that one component does not completely depend on the data generated by a different component. This ensures that the integrated smart kitchen, just like a distributed smart kitchen, is modular. Meaning that all the components will work independently from which other components are installed in the smart kitchen. This allows the user to freely add, remove, or upgrade different systems within the smart kitchen.

Chapter 4: Specification

This chapter is about the specification of the concept and the high fidelity prototype to go with it. A small scale user questionnaire was done to get early feedback on the concept and to get a better understanding of the user needs. The results of this user questionnaire are used to infer design changes for the concept. The first two sections of this chapter are about this user questionnaire and the results thereof. The last section of this chapter is about how the concept has been changed and redefined as a result of this questionnaire or because of other reasons.

4.1 User-questionnaire: method

A small scale user questionnaire is done to evaluate the Smart Kitchen Scale concept and better understand the potential user and their eating behavior. This questionnaire was held online using google forms. The target audience were students because they are easily accessible as participants and many of the students fall under the potential user group: adults that are motivated to eat healthy. Another benefit is that all students are proficient in the English language, allowing for the questionnaire to be English. The goal of this questionnaire was not proving a point empirically, rather acquiring some initial feedback on the concept. This allows for early design changes at the moment when they are most easily implemented: at an early stage.

The questionnaire contains both open and closed questions. The questionnaire is a combination of three parts. The first is about getting an understanding of the eating behavior of the potential user. It is about nutrition awareness and knowledge about nutrition. The second part is about the participant's experience with nutrient tracking. The goal is to learn from other tracking tools and why they do or don't work for the subject. Finally, the third part explains the early concept as described in the ideation chapter. The subject is asked for their opinion on different aspects of the system. This information is used for early design changes. The complete questionnaire can be found in appendix A.

4.2 user-questionnaire: results

In total 23 valid responses were received (N = 23). This is a large enough sample size for the goal of the questionnaire. The questionnaire does not aim at proving anything empirically, however, the 23 answers to the open questions give a good indication of the user's initial opinion on the concept. Of the participants, all of them were students of the ages 18 to 29 with an almost even split between males and females. ¾ of the participants were Dutch, with other nationalities being: Italian, British, Bulgarian, Surinamese, and Indian.

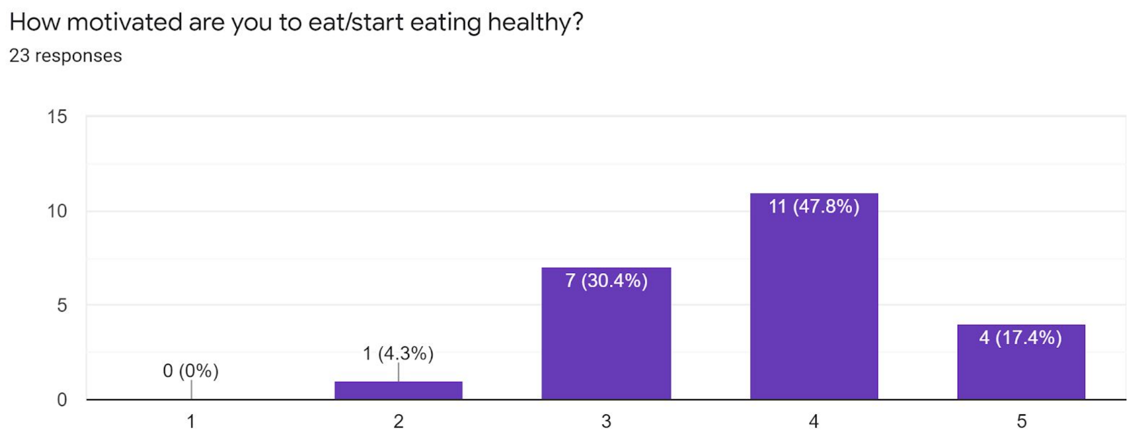

Figure 3: The responses on the question: How motivated are you to eat/start eating healthy? On a range from 1: not at all - 5: exceptionally.

The majority of the subjects say being reasonable to exceptionally motivated to eat healthy according to figure 3. This result shows that the sample mostly contains subjects that fall within the target user group. Ideally, the sample would have been expanded to also include adults in a broader age range with different occupations and levels of education. However, for the initial feedback on the concept, this sample will suffice.

Eating habits

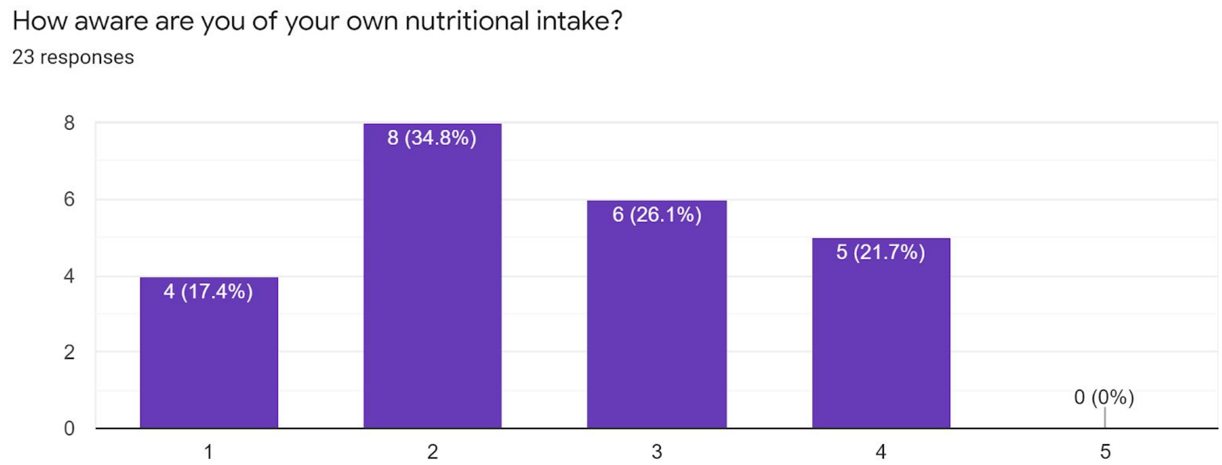

Figure 4: The responses on the question: How aware are you of your own nutritional intake? On a range from 1: completely unaware to 5: exceptionally aware. This question contains an additional explanation to the user which can be found in appendix A

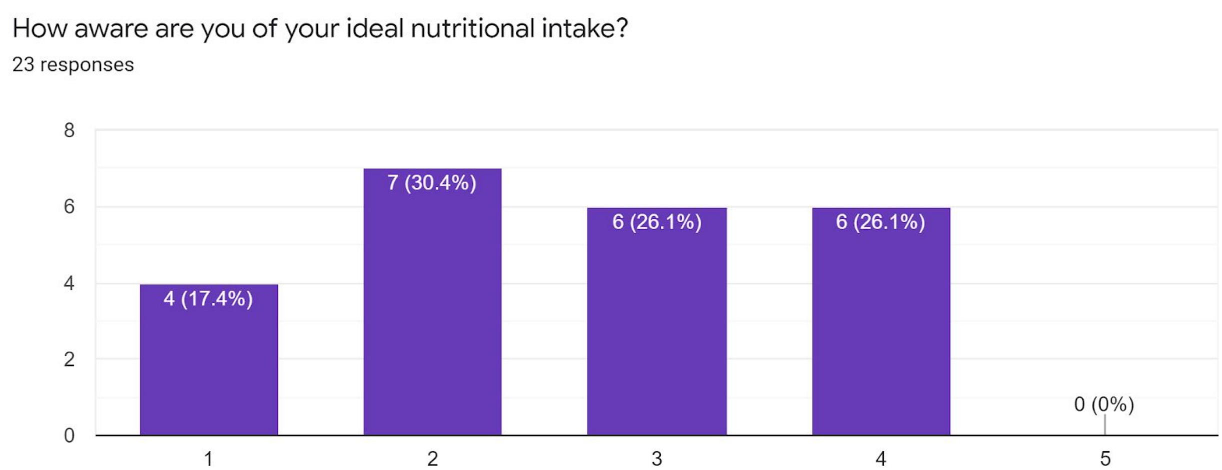

Figure 5: The responses on the question: How aware are you of your <u>ideal</u> nutritional intake? On a range from 1: completely unaware to 5: exceptionally aware. This question contains an additional explanation to the user which can be found in appendix A

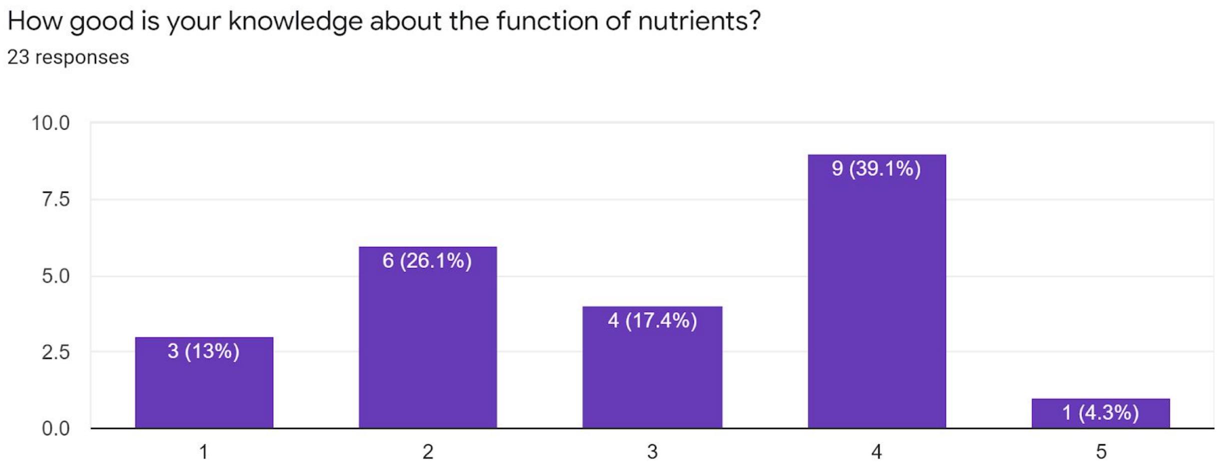

Figure 6: The responses on the question: How good is your knowledge about the function of nutrients? On a range from 1: exceptionally bad to 5: exceptionally good. This question contains an additional explanation to the user which can be found in appendix A

The 3 figures above, figures 4, 5, and 6, give a good indication of the broad user needs. Figure 4 shows that the majority of the subjects think they lack nutrient awareness. Which means that a tool that successfully increases nutrient awareness can be useful to the user because their awareness can be improved, and the literature shows that an increased nutrient awareness is correlated with a healthier diet [1], which most subjects are motivated for as can be seen in figure 3. The results also show that the user could benefit from a system that next to increasing nutrient awareness also teaches the user about nutrition. Figure 5 shows that a large part of the subjects is not aware of their ideal dietary intake, which suggests they can benefit from a system that puts their intake into context in some way. Figure 6 shows that about half of the subjects also lack the knowledge about different nutrients, which suggests that users with lower nutrient literacy are a significant part of the target audience.

Nutrient tracking

Of the 23 subjects, 9 say having experience with tracking nutrients. With the majority having weight gain/loss as the primary motivation. A trend can be seen in the experience the subjects have had with tracking nutrients. Tracking nutrients does seem to increase people’s awareness of their own dietary intake: “It was very useful because before I had no idea about the nutritional values of the stuff I was eating.” said one subject. But also many subjects feel that tracking nutrients takes too much time. Despite 8 of the 9 subjects having used mobile nutrient tracking applications. This means that there would be a use for a system that makes it easier and faster to track nutrients (as the state of the art suggested). One other important result worth discussing is the following. A few subjects said they stopped tracking nutrients because they feel they can estimate nutritional content without any tools. This suggests that tracking nutrients for a period of time can have benefits even when the subject stops. This sounds obvious but could be worth exploring in future works.

The Smart Kitchen Scale

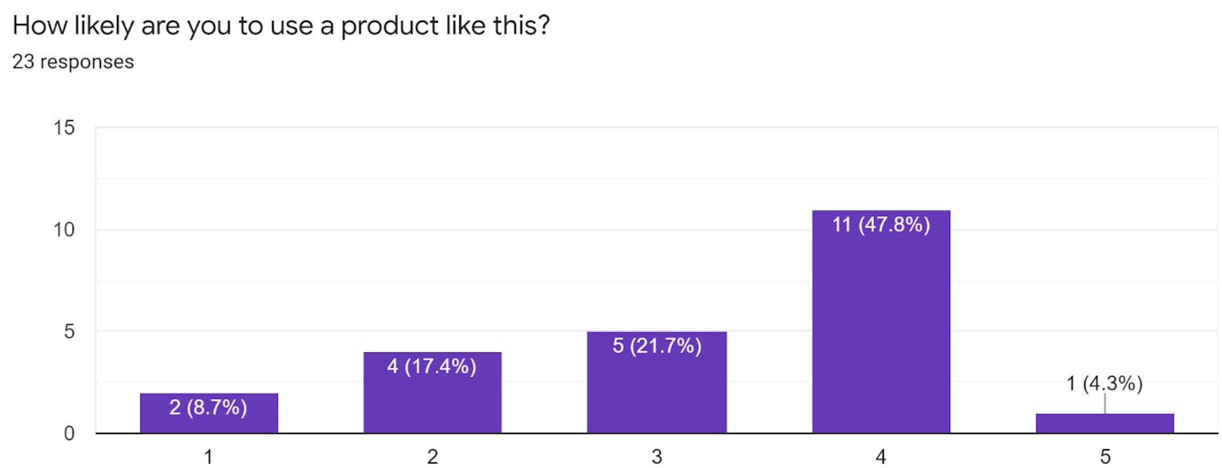

Figure 7: The responses on the question: How likely are you to use a product like this? On a range from 1: very likely to 5: not at all. The Smart Kitchen Scale is explained before this question was asked, this explanation can be found in appendix A.

The results of the last section about the concept idea are valuable. The results contain positive feedback and more importantly some well-worded critiques and concerns. The most common of which is the concern that the device will be outperformed by the mobile application in many scenarios. Some subjects think that using the device would be too much of a hassle. This is a valid concern, as the state of the art chapter showed that convenience is an important design requirement for such systems. The Smart Kitchen Scale seems to be limited as the primary tool for dietary feedback. Combining the Smart Kitchen Scale with a mobile application solves issues like not always having the scale at hand to add nutrients. A part of the subjects seems to see potential in the concept provided that some changes are made. The Smart Kitchen Scale seems to be useful in specific cases like cooking larger, more complex meals, however, it isn’t versatile enough to be the main and only tool for dietary feedback. This suggests that a link to a mobile application is critical, so the Smart Kitchen Scale can be used in situations it is useful, while not hindering the users in situations it is not.

4.3 Concept iteration and specification

The user questionnaire has been useful for getting feedback on the first concept. This section is about how the concept has been changed as a result of the questionnaire or other input. The state of the concept at this point in the project is discussed while going more in detail than the ideation chapter.

Measurement

As discussed in the state of the art chapter, a system giving dietary feedback first has to measure the dietary context. Both the food type as well as the quantity have to be measured to create an overview of the user’s dietary intake. The Smart Kitchen Scale should function more or less the same as a regular kitchen scale, which would allow it to be easily incorporated into people's daily routines. This means that all the features from a kitchen scale should be present like displaying the weight and having the option to measure tare weight/set the 0 point of the scale. The food should be classified at the same time the weight measurement is taken to immediately also show the nutritional values as well as the weight. The scale should be able to classify as many as possible food types for it to be useful in the kitchen. Because the results of the user questionnaire suggest that the Smart Kitchen Scale would be most useful when cooking meals. It should recognize fresh whole foods that often are ingredients of a larger meal. Besides this, some users suggested a barcode scanner to augment the classification by computer vision. This would be useful for prepackaged and processed food, of which the nutritional information is specific to that product only.

User interface

To be able to make the user interface more powerful so it can better fulfill the design requirements, a larger size touchscreen would possibly benefit the system. This would allow us to better put dietary feedback into context by also showing for example the recommended daily amount instead of just the values, which the state of the art chapter as well as the user questionnaire results have shown is important to increase nutrient awareness. Furthermore, this would allow to also give more information about the function of different nutrients to better inform the user about nutrients, which figure 6 suggests some users could also benefit from because they have lower nutrient literacy. A user interface using bar graphs to show nutrition information of ingredients in context of the recommended daily amount and the rest of the meal would give the user a point of reference to be more aware of the nutritional values of different food types.

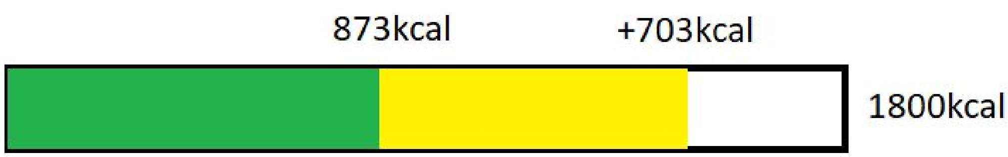

Figure 8: Visualisation of the bar graph component of the potential user interface. In green the calories of the meal so far and in yellow the total calories of the ingredient being weighed on the scale. The total bar length represents the recommended daily amount of 1800kcal for women. This value is an example and should not be taken as the truth. Furthermore, the ingredient and meal calories are arbitrary.

Mobile application

The results from the user questionnaire suggest that integration with a mobile application is important. This allows the user to only use the Smart Kitchen Scale when it is convenient like when cooking a larger meal and use the app when the user is for example not at home. This prevents the scale from being a restriction to people's daily routines while still supplementing it where it is convenient. Ideally, the system should be integrated with an application that is tested and that people already use: MyFitnessPal and Fitatu amongst them. There should be an option within the user interface of the smart kitchen scale where the meal can be saved to the fitness tracking app.

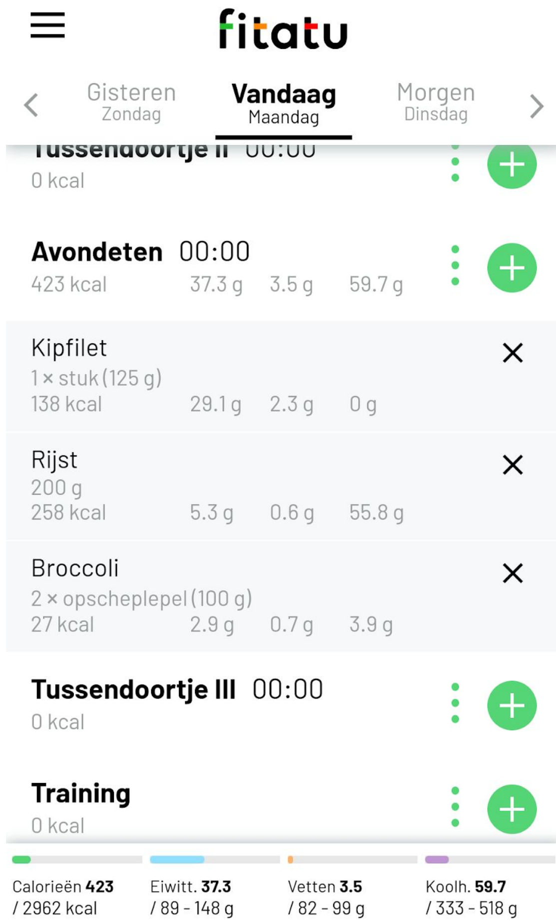

Figure 9: A screenshot from Fitatu after having added a meal. Although this meal is simple and plain, it would have been suitable for the Smart Kitchen Scale to add it to the total.

4.4 Conclusion specification

The user questionnaire was done to collect early feedback on the concept and to better understand the user needs has been useful. It was found that besides lacking awareness of their own nutritional intake, the user can also benefit from a system that gives more information about nutrients and reference for how much of them you need in a day, which the state of the art also suggested. This results in the design decision that nutritional values are represented in bar graphs that represent the recommended daily total for that nutrient. It was also found that mobile app integration is essential. Without mobile app integration, the scale would become as much of a burden as it would be convenient for people. The Smart Kitchen Scale shows potential in situations where many whole fresh ingredients are used like in cooking large meals. However, when grabbing a quick snack or while on the go a mobile application is seen as far more convenient than the Smart Kitchen Scale. The integration with such a mobile application allows the user to use whatever system is more convenient at that time, eliminating the situations where the Smart Kitchen Scale is a burden while still being able to use the Smart Kitchen Scale when it is most useful.

Chapter 5: Realisation

This chapter is about the realization of the Smart Kitchen Scale prototype. The inner workings of the hi-fidelity prototype will be discussed, along with the engineering choices that lead to the final version. The first prototype comes with its limitations, most of which will also be discussed in this chapter.

5.1 Platform: Raspberry Pi and Python

As discussed in the specification chapter, an essential part of the Smart Kitchen Scale prototype is a graphical user interface. This combined with the need for processing power to do the image classification and read spreadsheet files leads to the choice of using Raspberry Pi as the processing platform for the Smart Kitchen Scale. In particular, the Raspberry Pi 4 (4Gb) was used in this project for the simple reason that that was available. Using the Raspberry has the added benefit that there are a lot of add-on components available that are easy to use and are well documented. Furthermore, the Raspberry Pi has a large array of GPIO pins, that allows for the interfacing with many sensors including the load cell used to measure weight in this system. Using the more powerful Raspberry Pi over smaller cheaper microcontrollers does have the drawback that power consumption is higher. This is not a problem for the prototype as it can be connected to wall power.

Because of the availability of documentation and libraries and because of the good compatibility with Raspberry Pi, the programming language chosen to write the software of the Smart Kitchen Scale is Python 3. PyCharm on pc was used to individually test the components. These components then were transferred to the Pi using an SSH connection. For bug fixing the Thonny IDE for python was used on the Pi itself.

5.2 Weight sensing

As many regular kitchen scales, a strain gauge load cell was used to measure the weight. The load cell has a range of up to 5kg. For the analog to digital conversion, an HX711 module was used. This module has two analog input channels that are used for reading differential signals like the one provided by the Wheatstone bridge load cell. Conveniently there is an HX711 library available for Python on the Raspberry Pi. This adds a layer of abstraction that makes it easy to read out the load cell via de HX711 module with one line of code. Actions like taring (setting the 0 point) also require minimal programming.

5.3 Nutrient database

For the nutrition information, a database has to be used. The RIVM provides the Dutch Nutrition Database (Nederlands Voedingsstoffenbestand or NEVO) [14]. This is offered online or as a spreadsheet file. Using the Pandas library for Python 3 this spreadsheet can be read and searched. The NEVO database provides all the necessary nutrient information for more than 2000 types of food. Most whole foods are covered by NEVO, which makes it suitable as the main resource of nutrient information for the Smart Kitchen Scale. All nutrients have their own identifier, that can be used by different components of the system to reference a nutrient.

5.4 Image classification

The recognition of the nutrients on the Smart Kitchen Scale is done using computer vision. A camera module for Raspberry Pi is placed underneath the bowl on the kitchen scale so images can be taken from below the nutrients. A simple white led provides lighting so the camera can see when there is food on the scale covering the environmental light. Even Though this setup satisfies for a small number of food types to classify, the images don’t have a lot of detail as a result of the camera being lower quality and having the wrong lens. Also, the plastic underside of the bowl is reflective, causing the light from the LED to be reflected into the camera, again reducing image detail.

Figure 10: An image taken with the camera of the Smart Kitchen Scale prototype of white rice. The red ellipse marks the flash caused by the LED being reflected by the plastic of the bowl.

The picture taken by the Smart Kitchen Scale shows the issues the current camera setup has. The image is blurry as a result of the wrong lens for closeup images like this. At the moment when the scale registers a stable positive weight, it takes an image using the strategically placed camera module. This image is then used to classify the food.

Microsoft custom vision

For classifying nutrients from the picture taken from underneath the food, computer vision is used. Microsoft custom vision on Microsoft's Azure environment provides a quick to use image classification service that can be accessed with an easy to use API. This service uses machine learning to train the classifier. There are more services like it, however, Microsoft offers a free version that can be used for smaller projects like this.

Before the classifier can be used, it has to be trained for the situation it is used for. This is done by uploading a range of images that show a nutrient to be classified. These images are then given a tag, which corresponds to the unique identifier used for that nutrient by the NEVO database. After this is done the AI can be trained to successfully link all images to the correct tag. A trained classifier can classify images it has never seen before to the nutrients it knows. The images used for training should be taken in the same way as they will be classified, to optimize the performance of the classifier. “ Be sure to use images that are representative of what will be submitted to the classifier during normal use. Otherwise, your classifier could learn to make predictions based on arbitrary characteristics that your images have in common.” [15]. Therefore the images used for training are taken on the Smart Kitchen Scale’s camera.

This however points out the issue with the placement of the camera. When food is being measured that doesn’t cover the camera completely, the background is captured in the image. This could mean that the classifier learns to make predictions based on the background, which should be avoided. Because the classifier in the prototype was trained in the same location it was used to classify food, this was not a problem. However, this does have to be solved for a final product by for example changing the placement or covering the background. Randomizing the background in training could also stop the AI from using the background details as information.

Using more images per tag will increase the performance of the classifier. “The number of training images is the most important factor. We recommend using at least 50 images per label as a starting point. With fewer images, there's a higher risk of overfitting, and while your performance numbers may suggest good quality, your model may struggle with real-world data.” [15]. Therefore it is important to provide the AI with enough training images. Later on, prediction images can be used to improve the model.

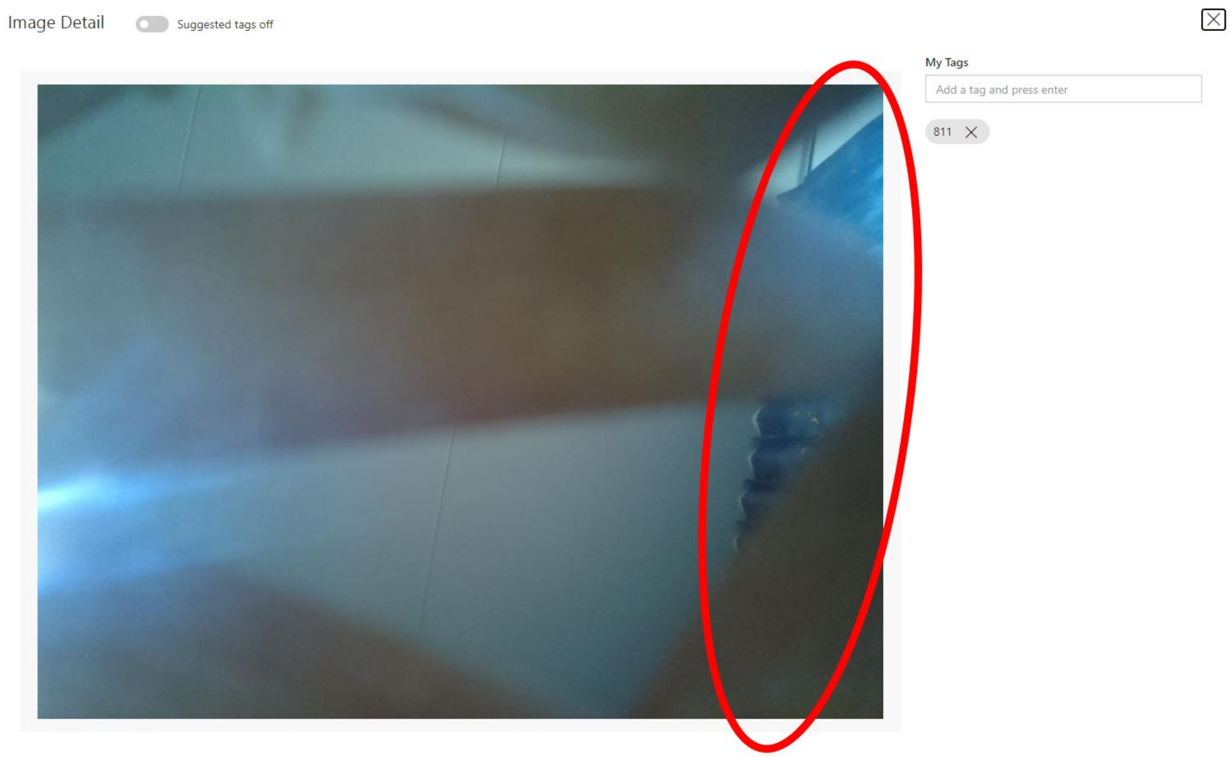

Figure 11: A training image taken for tag number 811 which is the entry ID for whole-grain pasta in the NEVO database. The red ellipse highlights the issue of the background being visible.

Once the classifier is trained it can be used for predicting new images the system has not seen before. The Smart Kitchen Scale prototype uses Microsoft's REST API to send the image to the classifier and receive the result. Because this is done using HTTP, the Smart Kitchen Scale prototype requires an internet connection.

The method of classification where only one image is taken at a certain time (when the weight is stable and positive) is a result of the classification method using an internet connection. This process has a roundtrip time of a few seconds which means that the user might have to wait for the classification result to be able to see the nutrient information. Furthermore, the system used in the prototype has the drawback that when the classifier is mistaken, this is only corrected when the scale is reset, i.e. when the weight gets below zero or the scale is tared. For a final product, the neural network could run on the device itself and instead of a still image, it could take a live feed and classify the food in real-time. This would make the system quicker, and it would also allow for the device to recover from mistakes automatically because the system is constantly classifying the food.

5.5 User interface: Touch Screen

For the main user interface, a 5-inch touchscreen is used. This is a larger display that is usually on a kitchen scale. This allows for nutrient information to be displayed in context graphically as discussed in the specification chapter. The touchscreen also makes it possible for the user to interact with the system without any extra buttons. For the Smart Kitchen Scale prototype, the Waveshare 5 inch HDMI TFT-LCD (G) screen was used because it has the right dimensions, offers a touchscreen version, and is compatible with Raspberry Pi. The touchscreen is connected to the raspberry pi using HDMI. Using the Tkinter library for Python 3, a fullscreen touch-enabled user interface was made. This user interface includes the bar-graph representation of the nutrients while also offering the normal kitchen scale functionality.

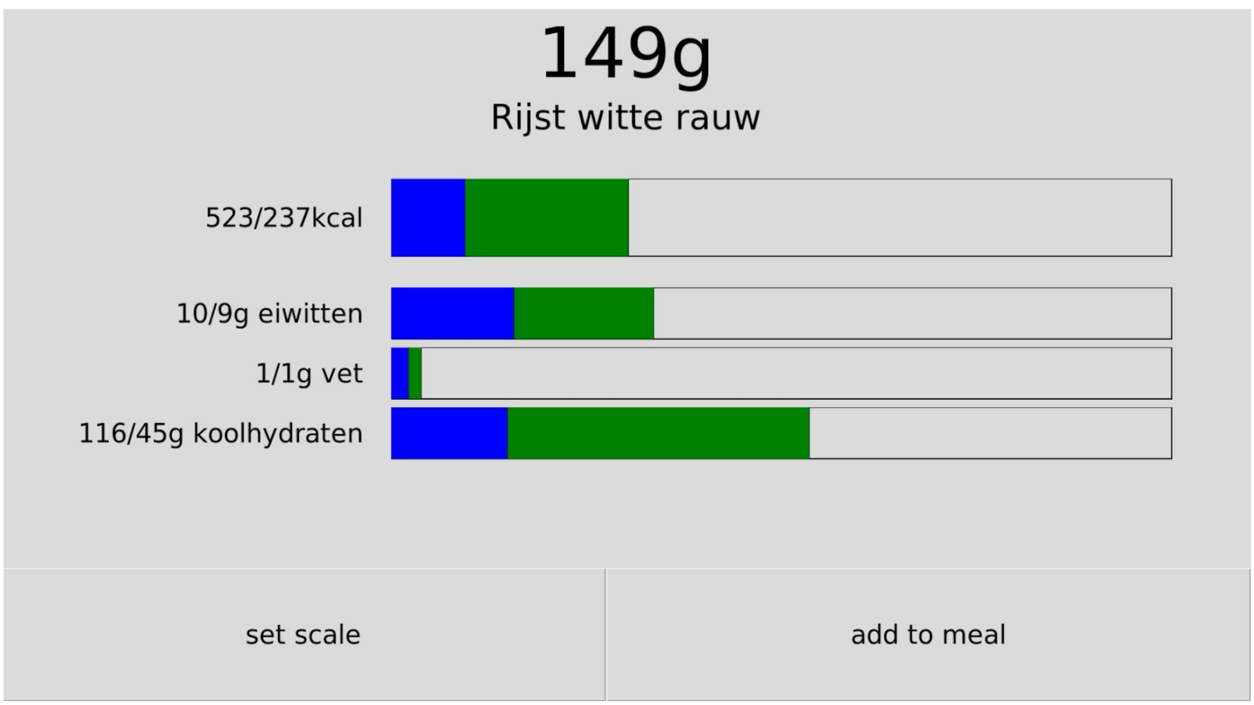

Figure 12: the graphical user interface of the Smart Kitchen Scale prototype. In blue the total nutrients of the meal so far, in green the nutrients of the ingredient (white rice) being added, and the buttons for user interaction on the bottom.

5.6 Housing

The housing for the Smart Kitchen Scale prototype is made from primarily wood and screws. If available this preferably would have been done using 3d-printing, however, because of the working-from-home situation caused by the Covid-19 pandemic made access to 3d-printers more difficult. Using food to construct the Smart Kitchen Scale limits the design to using primarily right angles and flat services. However, for the first prototype, this is not a problem, because the main function is demonstrating the Smart Kitchen Scale functionality.

Figure 13: Side view of the Smart Kitchen Scale prototype showing the structure of the housing.

The housing consists of a base plate with rubber footing that provides a stable platform for the system. On this base plate, the load cell is mounted fully supporting the supporting disc for the food bowl. This disc has a hole cut out under which the camera is installed on the base plate. The disc is made to fit the dimensions of a predetermined plastic food bowl that is see-through, so the camera can capture the food from below. The touchscreen is mounted on a wooden backplate that is mounted using steel angle mounts to the base plate with screws. Raspberry Pi is also mounted on the base plate using stand-off screws.

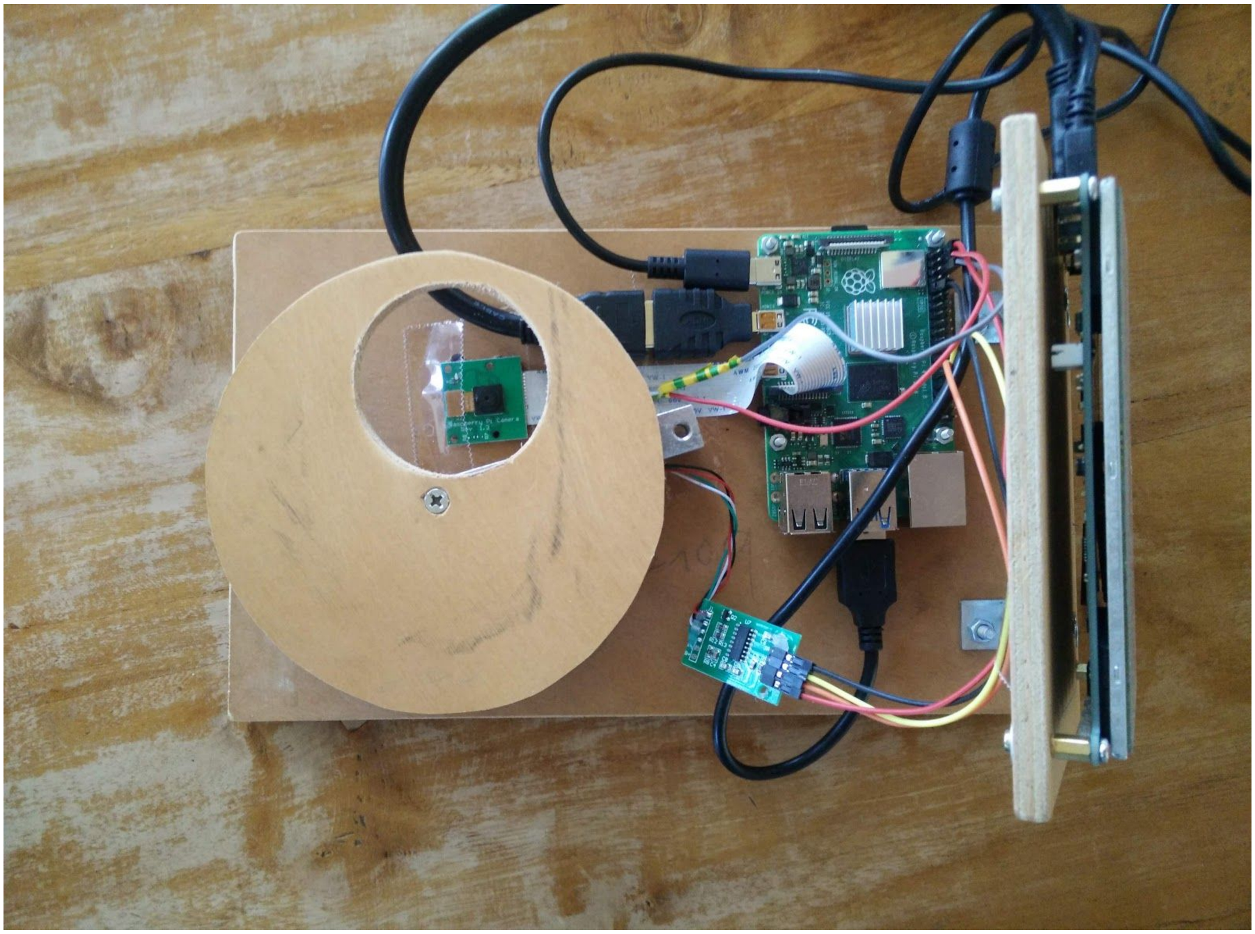

Figure 14: Top view of the Smart Kitchen Scale prototype showing the camera and Raspberry Pi placement.

The wooden construction exposes the electronics and cables of the prototype, which can be a problem for use in the kitchen. A final product version of the Smart Kitchen Scale would use a plastic construction that covers all the internals to shield them from moisture or anything that could damage the Smart Kitchen Scale. This would also be an extra layer of safety, as the exposed internals could be dangerous to the user when in contact with moisture.

Chapter 6: evaluation

To evaluate the first prototype of the Smart Kitchen Scale, a small scale user test was done. This user test has two goals. The first is to evaluate the concept of the Smart Kitchen Scale further. The second goal is to evaluate the technical aspect of the prototype. The user test involves three one-on-one sessions with a subject in which the subject is asked to cook a meal with the Smart Kitchen Scale prototype. The subject is asked to complete a task list while cooking a meal of their choice, to encourage the use of the prototype. Before and after the cooking task, an interview is held with the subject.

Because of the project constraints as a result of the Covid-19 pandemic, the sample size is small and the target audience is misrepresented. The test was conducted with the three family members of the researcher, of which only one falls partially within the target population. However with the purpose of this test not being to prove a point empirically rather evaluate the concept for iterative design, doing the test like this still gives new and valuable insight and understanding of the Smart Kitchen Scale prototype and its user.

6.1 method

The test starts with having the subject read the information brochure and signing the informed consent form. These can be found in appendix B1 and B2. Both the information brochure as the informed consent form was written in Dutch because the subjects don’t understand the English language enough to give informed consent. After consent is given, the first user interview is held. This interview is about getting an understanding of the subject and their eating habits. This interview is also used to test to what degree the user falls within the target audience. The interview was semi-structured and the questionnaire used for this interview and it can be found in appendix B3

After the first interview with the subject, they are asked to cook a meal of their choice. This meal was determined beforehand, so the ingredients could be taught to the image classifier the Smart Kitchen Scale uses. Because the subjects did not completely fall within the target audience, they might need some stimulation to actually use the prototype in their cooking process.

Therefore a task list was made for the subject to complete right before, during, and right after the cooking. This can be found in appendix B4. The researcher was also present during the cooking to be able to observe the interaction of the subject with the prototype as well as to answer possible questions the subject might have or help them with issues they have.

After the cooking has been done and the meal has been consumed, one last interview with the subject is held. This interview is about their experience using the Smart Kitchen Scale prototype and their opinion on the concept. This interview was semi-structured and the used questionnaire can be found in appendix B5. After all the tests were done, a hamburger meal was cooked by the researcher as compensation.

section	duration
introduction/informed consent	5m
First questionnaire	10-15m
cooking	-
Dining (not part of the test)	-
Evaluation questionnaire	15-20m

Table 3: Time table for the evaluation study.

6.2 Results: Smart Kitchen Scale concept

The user test revealed mixed opinions on the Smart Kitchen Scale concept. Two out of three subjects really enjoyed using the Smart Kitchen Scale prototype. They reported having fun with the automatic detection of food even though the scale sometimes made mistakes. These subjects also seemed to have an increased awareness of the nutritional values of the ingredients they were using. One subject reported: “I did not know that vegetables are so low in calories” (translated into English) reported one of the subjects while using the Smart Kitchen Scale to measure the nutrients content of zucchini. The other subject already has extensive nutrient literacy, however, she reported liking using the scale to refresh her awareness of her own diet.

One important difficulty with using the Smart Kitchen Scale was revealed during the test. Because the meal is cooked for multiple family members with differing appetites, the meal portions varied. This resulted in the nutrient information about the total meal provided by the Smart Kitchen Scale prototype was not accurate on an individual level, as dividing the total nutritional value by the number of diners would underestimate the nutritional value for some while overestimating for others. One subject mentioned a potential improvement where the scale would be used after preparation, however, for a lot of dishes, this is not possible because the ingredients are already mixed, making it a lot more difficult or even impossible to classify them and estimate the amount.

In the above paragraphs, the third subject is not discussed yet. This is because the results from the test with this subject are divergent to that of the other subjects. The third subject was overwhelmingly disapproving of the Smart Kitchen Scale prototype and concept overall. During the test, the third subject did not use the prototype at all. The interview afterward revealed that this was because the user did not understand the Smart Kitchen Scale and was not interested in the nutritional value of the ingredients. It could be argued that this subject did not fall under the target audience: healthy adults willing to adopt a healthier lifestyle, as the subject showed being motivated to eat healthy however not motivated to change their diet because they are content with it. The interview beforehand also revealed the subject having a lower nutrient literacy, which suggests the Smart Kitchen Scale in this state does not fit users with lower nutrient literacy.

6.3 Results: Smart Kitchen Scale prototype

The user test also provides the opportunity to test the technical performance of the prototype. The real-world use of the Smart Kitchen Scale prototype revealed technical limitations of the current setup.

The image classification performance was satisfactory for a small set of nutrients, however, would the complete content of the NEVO database be taught to the Smart Kitchen Scale (over 2000 entries), the system would not perform well. At the end of the user test, the Smart Kitchen Scale prototype knows 12 different ingredients. The scale was able to classify the ingredient roughly with 70% accuracy. Reclassification of the ingredient often resolves the mistake. In cases where the prototype is wrong, often the color and shape of the ingredients are very similar. Because of the poor quality of the camera and the lighting issues, a lot of the color detail is lost. Also because the camera uses the wrong lens, fine texture details of the food cannot be seen with the camera. The texture of an ingredient could be the distinction between two ingredients with a similar color.

Besides the issues with the classification method, some aspects of the user interface were found to be lacking. To get a better understanding of the nutrient composition of a meal, the subjects expected the bar graph to be divided into ingredients. The prototype shows the bar divided into a meal total and the new ingredient.

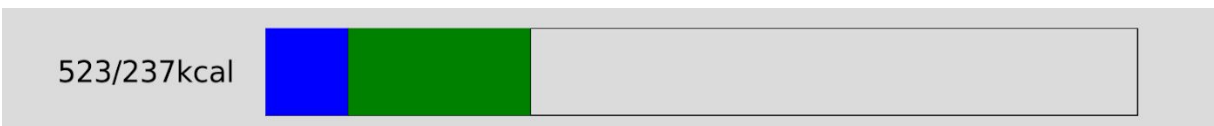

Figure 15: The bar graph used by the prototype. Blue shows the total calories so far and green shows the calories of the ingredient on the scale.

One subject did not use the add to meal function at all, instead, they opted for using pen and paper to note down the nutrients of every ingredient. This suggests a history feature would be useful, so the user can determine the effect of every ingredient on the nutrition balance after cooking. Also, a feature like having an overview of the meals within a week was suggested, to be able to compare different meals.

Chapter 7: Discussion

The Smart Kitchen Scale is a concept of interactive technology applied in the kitchen to increase nutrient awareness. It was designed to satisfy the design heuristics as found in the state of the art chapter. A hi-fi prototype of the Smart Kitchen Scale was constructed and evaluated to demonstrate and test these design heuristics. This chapter discusses the extent to which the research questions can be answered and how well the Smart Kitchen Scale demonstrates the design heuristics from this project. Furthermore, the Modular Integrated Smart Kitchen concept and how it relates to the Smart Kitchen Scale, existing literature, and future work are also discussed.

7.1 Limitations of the concept

From the user questionnaire in chapter 4, it is clear that the Smart Kitchen Scale is only suited for a very particular scenario: cooking meals with multiple ingredients. The Smart Kitchen Scale is not well suited to create a complete picture of one's nutrition. For other scenarios like having a quick snack, the user much prefers to use a mobile application instead of the Smart Kitchen Scale. However, even when tested in its best-suited scenario of cooking multi-ingredient meals. The Smart Kitchen Scale has many limitations. These limitations are mainly related to the convenience of use and to the accessibility to people with lower nutrient literacy.

In the evaluation study described in chapter 6, the first Smart Kitchen Scale prototype was tested in its most well-suited scenario. Test subjects were asked to cook a meal of their choice using the Smart Kitchen Scale to complete a set of nutrition-related tasks. The Smart Kitchen Scale was found to increase nutrient awareness in the majority of subjects. However, these test results hold no significant value, due to the sample size being too small and the subjects being highly biased. Nonetheless, the results of the evaluation study showed that the first prototype did not satisfy heuristics 3 well.

- *The system **should** minimize the user's effort by autonomously measuring dietary context.*

Having to use the Smart Kitchen Scale while at the same time cooking a meal, was found to be difficult. Besides doing usual cooking tasks, the subject still had to take extra steps in order to use the Smart Kitchen Scale because it is not fully autonomous, unlike the Smart Kitchen by Chen et. al. [3], from which this heuristic was partially derived. However the participants of the evaluation study were using the Smart Kitchen Scale for the first time, and some were new to nutrient tracking completely. Possibly using the Smart Kitchen Scale would become easier and more convenient after having some practice.

- *The system **should** be easily incorporated into its users' routine and the required actions of its users should be self-evident.*

Using a kitchen scale for every ingredient you use is something that most people do not do. This means that using a kitchen scale is not part of the regular cooking routine people have. Therefore it can be said that heuristic 4 was also not satisfied by the Smart Kitchen Scale. This was also seen in the evaluation study. Some participants had trouble determining when and how they should measure the nutrients on the scale, which suggests the user-required actions are not self-evident. It seems that heuristic 3 and 4 are more important than first thought. If the system is not easily incorporated into people's routines and requires too much user effort, people will simply not use the system or choose an alternative. Ultimately, the Smart Kitchen Scale would not be able to fulfill its goal of increasing nutrient awareness.

7.2 Limitations of the prototype

Some issues like the ones described above are fundamental to the concept of the Smart Kitchen Scale, while others are related to the prototype. Issues related to the prototype can be solved by iterative design. These issues related to the prototype could be detrimental to the user experience and could be the reason for some heuristic to not be satisfied by the first Smart Kitchen Scale prototype. Even though these issues have been identified, they have not been solved in this project. The issues range from being caused by the choice and execution of technical solutions, or also from design elements of the prototype like the user interface.

Multi-diner problem

Most families have dinner together. This means that if a user is cooking for multiple people, the nutrients the Smart Kitchen Scale displays are not corresponding to the nutrients consumed anymore. The prototype used in this project has a feature that allows the nutrients to be divided by the number of diners, however, this only works when every diner gets the same portion. Usually, this is not the case. People eat different amounts and different ratios of dishes on the table. This issue can be solved for later iterations of the Smart Kitchen Scale, by having a second round. The first round would work the same as described. The cook would measure every ingredient, however, this time subdivides the dish into sub-dishes. For example one sub-dish with potatoes, one with vegetables and one with meat for a typically Dutch meal. Then at dinner time every diner would place their plate on the Smart Kitchen Scale and select a sub-dish and thereafter put the desired amount on the plate. After doing this for every sub-dish, the Smart Kitchen Scale can calculate the number of nutrients per diner accurately.

Although technically solving the multi-diner problem, it can be argued that this solution overcomplicates the system which would be at the expense of convenience, especially heuristics 3 and 4. The system would require a bunch of extra steps for every diner that are new to the eating routines people already have. Furthermore adding this feature would require even more effort from the user, which as argued above is already too much.

Reliability of nutrient classification

During the evaluation, the Smart Kitchen Scale was used in a real-world setting. This revealed some problems with the solution for nutrient recognition. The classifier used was able to correctly recognize the ingredient in about 70% of the time while only knowing 20 ingredients. Would every ingredient in the NEVO database be taught to the classifier, this performance would be far worse, as this database contains over 2000 entries. Furthermore, the classifier was taught in the same environment as it was used in. This means that using the Smart Kitchen Scale in a different environment could worsen the performance. Ideally, the images taken for classifying the nutrient should be independent of the environment.

The classification performance of the Smart Kitchen Scale can potentially be improved a lot by changing the placement of the camera used to take the images to be classified. For the first prototype, the camera was placed below the food at close range. Because the camera did not use the correct lens, the images appear blurry reducing image detail like for example fine texture information. Furthermore, because the camera was below, an artificial light source is needed. A single LED was used for this in the prototype which produced significant glare by reflection in the bowl, which washed out a lot of the color, again reducing the image detail. Moreover, in the case that the nutrients did not completely cover the food, the background can be seen in the classification image, which negatively affects the performance.

To increase the performance of the nutrient classification the following changes can be tried. First, a better camera should be used that has a broader color range as color is an important detail distinguishing food types. Second, the camera should use a lens that allows it to capture more of the food details from close range. A wide-angle macro lens would be suitable for this. This would allow the camera to capture for example texture details to distinguish between ingredients with similar color and shape like many shopped vegetables. Third, the lighting issue should be resolved. The background light should be kept out by closing the area around the camera. A more diffused light should be used to illuminate the ingredients to avoid prominent reflections in the material of the bowl used. Fourth, the camera placement should change so that it does not capture the background when little of the ingredient is on the scale. It might be worth it to experiment with the camera above the nutrients which, although less elegant than a camera below, would also solve the lighting issue and the issue with the lens as having the camera above allows for it to be placed further away.

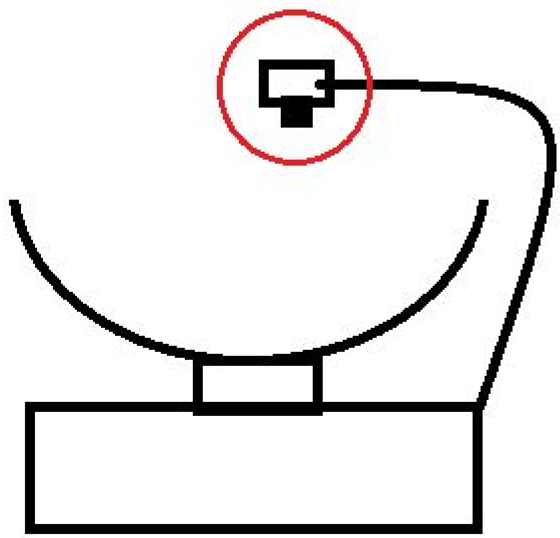

Figure 16: A representation of the Smart Kitchen Scale with the camera (in red) placed above the food bowl.

accessibility

In the evaluation study, it was found that subjects with lower nutrient literacy did not understand the Smart Kitchen Scale idea. Because of this, they were not able to use the Smart Kitchen Scale as intended and the nutrient awareness did not increase. This suggests that the Smart Kitchen Scale prototype does not satisfy the heuristics to accessibility well enough. Mainly heuristic 5:

- *The information the system provides **should** be simplified and understandable to people with lower nutrition literacy or the system should teach its users about the principles used.*

The user interface used by the Smart Kitchen scale uses the scientific terminology regarding nutritional values. To subjects with lower nutrient literacy, these values mean nothing. Even the concept of having numerical values related to their food can be a new idea to some. The Smart Kitchen Scale should do more to help these people understand these dietary concepts, before trying to make its users aware of the information related to these concepts. However, nutrient literacy varies depending on the user. Simplifying the complete system to the benefit of the users with lower nutrient literacy could be detrimental to the user experience of people with higher nutrient literacy. Customizability could possibly be the key to solve this issue and other issues like it.

7.3 Modular Integrated Smart Kitchen

The Smart Kitchen Scale's user interface has many issues, which result from it having minimal functionality. Adding different features and increasing the complexity of the software can solve a lot of the issues with the user interface. However, it can be argued that some of the issues with the user interface are highly individual, just like the accessibility to lower nutrient literacy. Adjusting the user interface for one audience group could be detrimental to the other user group. Being able to customize the user interface would be a good solution. However, using different mobile applications to go along with the Smart Kitchen Scale could be a more elegant and efficient solution. This would even allow the user interface to be largely absent from the Smart Kitchen Scale and its functionality be transferred to the mobile application. This allows the Smart Kitchen Scale to be simpler, cheaper and as described below, part of a more powerful system.

In a Modular Integrated Smart Kitchen al components work to make the whole more effective or efficient. As a component of such a Smart Kitchen, the Smart Kitchen Scale would function only as the sensor part of the feedback system. It would be part of a larger system aiming at increasing nutrient awareness. The mobile application would be the means of giving information about the dietary context measured by the Smart Kitchen Scale. This allows there to be multiple applications able to communicate with the Smart Kitchen Scale each with their own features, for example, accessibility. The applications could even have completely different goals.

Having the Smart Kitchen Scale as part of a Modular Integrated Smart Kitchen also solves some of the issues that are fundamental to the concept of the Smart Kitchen Scale on its own as it not being convenient in many scenarios. A user could for example use a nutrition tracking tool of their liking like MyFitnessPal for their smaller meals and then use the Smart Kitchen Scale for the multi-ingredient meals. The Smart Kitchen Scale would then provide MyFitnessPall with this information, therefore strengthening the complete system and making it more convenient to the user.

Besides increasing the appeal of the Smart Kitchen Scale, the Modular Integrated Smart Kitchen could combine a lot of the existing system to create a powerful whole to increase its user's nutrient awareness. The Smart Kitchen Scale would work really well with for example the Diet Aware Dining table by Chang et. al [6]. and the Smart Kitchen by Chen et. al [3]. The Smart Kitchen Scale would classify and register the nutrients of the ingredients being used. Thereafter the Smart Kitchen by Chen et. al. would be used to track in which sub-dish or pan these ingredients end up in. Finally, the weight sensors combined with the RFID classification in the Diet Aware Dining table would be used to determine the amount per sub-dish per diner and thus solving the multi-diner problem described above. This larger system solves a lot of the issues of its components and can possibly be more effective in reaching the common goal of increasing nutrient awareness.

7.4 Answering the research questions

Although the testing methods used in this project do not have any significant value, (partial) answers to the research questions can be given. The design heuristics found in the state of the art in chapter 2 provides a suggested answer for answering all three research questions. The set of all heuristics aims at answering the main research question. For an interactive technology application in the kitchen to increase nutrient awareness:

- *The system **must** provide dietary feedback.*
- *The feedback **should** be given in a just-in-time manner*
- *The system **should** minimize the user's effort by autonomously measuring dietary context.*
- *The system **should** be easily incorporated into its users' routine and the required actions of its users should be self-evident.*
- *The information the system provides **should** be simplified and understandable to people with lower nutrition literacy or the system should teach its users about the principles used.*

- *The system **should** provide reference to the values given. (e.g recommended calorie total when giving calorie amount)*
- *The system **should** provide the opportunity for comparison between different dietary choices.*
- *The system **should** be transparent about dietary recommendations and allow the user to make their own informed dietary choices.*

Convenience and accessibility seem to be a user requirement for an application of interactive technology in the kitchen aiming to increase nutrient awareness. Furthermore, the answers to the questions of how to achieve both convenience and accessibility (the sub-questions of this project) can be found as subsets of heuristics. Heuristics 2, 3, and 4 answer the question of how such an application of interactive technology can be convenient. Heuristic 5, 6, 7, and 8 can be used to answer the question of how to make such a system accessible.

Although the validity of the individual heuristics and the extent of their influence on the user experience was not tested in this project. The complete set of heuristics was evaluated by designing and testing the Smart Kitchen Scale. It was found that in scenarios where the Smart Kitchen Scale satisfies the heuristics best, the system was successful in increasing nutrient awareness to an undetermined extent. However, in the real world, the Smart Kitchen Scale would be competing with other systems like it, especially regarding the user requirement of convenience in heuristic 3 and 4.

It seems that convenience as well as accessibility is a large determinant of whether people would use such an interactive system or not, which is required for it to achieve its goal of increasing nutrient awareness. Therefore it could be argued that heuristics 3, 4, and 5 are more important than first thought and should be a “must” on the MoSCoW prioritization system instead of “should”. Contrary, it could be said these heuristics say more about the tendency of users to use the system than about its effectiveness in increasing nutrient awareness of its users if used. Therefore it could be argued that these heuristics do not belong in the list of heuristics used in this project. However, personally I would argue that being used by more people for a system is also a means towards the goal of broadly increasing nutrient awareness in the kitchen.

Chapter 8: Conclusion

To increase nutrient awareness in a kitchen setting, an interactive technology application must provide (real-time) dietary feedback to its users. The system will only be used by the user if it is convenient to them meaning that the system should minimize the user effort and be easily incorporated into peoples eating routines. To broaden the potential user population, the system should be accessible to people with different levels of nutrient literacy. Such a system should simplify nutritional information where needed and provide reference to any numerical values given. The system should allow the user to compare different dietary options and be transparent about potential dietary suggestions it makes.

Although imperfect, the Smart Kitchen Scale concept and prototype serve to demonstrate how the 8 design heuristics determined in this project and summarized in the paragraph above, can be applied. Although significant evidence is lacking, it’s users do seem to be more aware of the nutritional value of the ingredients they use. The Smart Kitchen Scale however does fall short on the satisfaction of the heuristics related to convenience and accessibility. Integration with a mobile application solves most of these issues. This demonstrates the principle of the Modular Integrated Smart Kitchen where the Smart Kitchen Scale is a component that makes its information available for other systems, like the mobile application, to be used more effectively.

The Integrated Smart Kitchen model opens the door for other systems to be developed in the future that specialize in other scenarios to strengthen and work with the Smart Kitchen Scale concept. These systems could have different goals or also have the goal of increasing nutrient awareness. The design heuristics from this project can apply to these other systems with the goal of increasing nutrient awareness. The extent to which every heuristic determines the effectiveness of a system in increasing nutrient awareness could not be determined in this project. Therefore, how a new system could improve on the satisfaction of these heuristics and the resulting difference in effectiveness in increasing nutrient awareness could be a topic for future research.

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Appendix A: Online questionnaire

This is a printout version of the online questionnaire. This version has the same questions however it is paginated which makes it more easily formatted into this report.

Nutrition awareness questionnaire

Dear reader,

With this letter, I'm informing you about the research you are about to participate in. This test is part of my graduation project for Creative Technology titled: Increasing nutrient awareness by applying interactive technology in the kitchen. The goal of this questionnaire is to get an understanding of the potential user and the user requirements and to evaluate early concepts.

Some important notes before you start:

-You must be 18 years or older to participate in this questionnaire and be able to give informed consent.
-This questionnaire is completely anonymous and no sensitive or personal data will be collected.
-Participation in this questionnaire is voluntary, you can stop whenever you want without a reason.
-Participation in this questionnaire should last no more than 10 minutes.

Finally, I want to thank you for your participation in this questionnaire. By participating you are helping me to create a better prototype and complete my graduation project successfully.

For any questions, remarks you may contact me:
Hessel Bosma
Creative Technology at the University of Twente
h.r.bosma@student.utwente.nl

Or my supervisors:
Dr. J.H.W. van den Boer
Postdoc Eating behavior and eHealth at the BSS-group of the University of Twente
j.h.w.vandenboer@utwente.nl

Dr. R.A.J. de Vries
Postdoctoral researcher on Behavior Change Technology at the BSS-group of the University of Twente
r.a.j.devries@utwente.nl

If you have any complaints about this research, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethics-comm-ewi@utwente.nl)
* Required

1. Do you agree with the conditions above and do you agree with participation? *

Mark only one oval.

- ( ) No
- ( ) yes I've read the information letter and agree with the formalities described.

Demographics

This section is about your demographics

2. What is your age? *

Mark only one oval.

- ( ) 18-29
- ( ) 30-49
- ( ) 50-64
- ( ) 65 or over

3. What is your gender? *

Mark only one oval.

- ( ) Female
- ( ) Male
- ( ) I Prefer not to say
- ( ) Other: ______________________

4. What is your nationality? *

Mark only one oval.

- ( ) Dutch
- ( ) Other: ______________________

5. Are you a student? *

Mark only one oval.

- yes
- no

Awareness of nutrition

This section is about you as a potential user of the product

6. How motivated are you to eat/start eating healthy? *

Mark only one oval.

	1	2	3	4	5	
not at all						exceptionally

7. How healthy would you say your current diet is? *

Mark only one oval.

	1	2	3	4	5	
extremely unhealthy						exceptionally healthy

8. What is the reason for your answer on the previous question? Why is your diet as healthy (or unhealthy) as it is?

9. How aware are you of your own nutritional intake? *

Do you know the answer to the following questions: How much X do I consume? With X for example being: Calories, protein, carbohydrates, saturated- /unsaturated fats, vitamins, fiber, water

Mark only one oval.

	1	2	3	4	5	
completely unaware	◯	◯	◯	◯	◯	exceptionally aware

10. How aware are you of your ideal nutritional intake? *

Do you know the answer to the following questions: How much X should I consume? With X for example being: Calories, protein, carbohydrates, saturated- /unsaturated fats, vitamins, fiber, water

Mark only one oval.

	1	2	3	4	5	
completely unaware	◯	◯	◯	◯	◯	exceptionally aware

11. How good is your knowledge about the function of nutrients? *

Do you know the answer to the following questions: What does your body do with X? And what are the consequences of an excess/deficiency of X intake? With X being for example Calories, protein, carbohydrates, saturated- /unsaturated fats, vitamins, fiber, water

Mark only one oval.

	1	2	3	4	5	
Exceptionally bad	◯	◯	◯	◯	◯	Exceptionally good

12. Do you have experience with tracking food intake in any way? *

Mark only one oval.

◯ Yes *Skip to question 13*

◯ No *Skip to question 18*

nutrition tracking

this section is about tracking nutrients

13. For what reason are/were you tracking your food intake?

14. What food intake tracking tools have you used? *

Check all that apply.

- [ ] food diaries (pen and paper schemas)
- [ ] nutrient tracking app e.g. myfitnesspal

Other: [ ]

15. How useful are/where the food tracking tools to you? and why?

16. How useful is/was nutrient tracking to you? Does/did it help you achieve your goals? Why or Why not?

17. If you stopped tracking food intake, why?

Concept evaluation

This section is about your opinion about different concept ideas of the use of interactive technology in the kitchen to increase nutrition awareness. Please be honest in your answers. Do not hesitate to be critical, you're only doing me a favor with that!

The smart kitchen scale concept

Next to measuring the weight of your ingredients, the smart kitchen scale is able to recognize the nutritional content of the food you place on it by using computer vision. The smart kitchen scale has a touchscreen on which nutritional information like energy-, protein-, carbohydrate-, fat-, vitamin- and the fiber content of the nutrients placed on the scale is shown. These values are automatically updated to accurately describe the nutrient content of the type and amount of food present on the scale. The scale also shows information like recommended daily intake for different types of food. The scale can be linked to a nutrition tracking app (myfitnesspal if possible) which allows the user to use the smart kitchen scale to keep track of their nutritional intake.

18. Do you understand the concept? *

Mark only one oval.

- Yes
- No
- Maybe

19. What is it that you don't understand about the concept?

If you answered "No" or "Maybe" on the previous question.

20. How likely are you to use a product like this? *

Mark only one oval.

	1	2	3	4	5	
not at all	◯	◯	◯	◯	◯	certainly

21. Why would you (not) use a product like this? *

22. What is your favorite aspect of the concept? *

23. How can this concept be improved? *

24. What is your opinion on mobile app integration?

The concept includes a touchscreen on the kitchen scale itself. On this screen nutritional information about the product placed on the scale is displayed. One of the features of the concept is integration with a mobile app. This allows all the nutritional information to be transferred to a mobile application, giving the user the opportunity to adjust and complete nutrition tracking information

Appendix B1: User test information brochure

Beste lezer,

Bedankt voor de interesse in dit onderzoek. Dit onderzoek is onderdeel van mijn afstudeerproject voor Creative Technology op de Universiteit Twente met de titel: Increasing nutrient awareness by applying interactive technology in the kitchen. Het doel van dit onderzoek is het evalueren van een prototype. Dit prototype is een Slimme keukenweegschaal die automatisch voedingswaren kan herkennen en hierbij de voedingswaarden op zoekt.

Het onderzoek begint met een vraaggesprek. Dit gesprek gaat over u als potentieel toekomstige gebruiker en uw eetgewoonten en voedingskennis. Een papieren vragenlijst zal worden gebruikt als leidraad voor dit gesprek, echter het gesprek kan van deze vragenlijst afwijken. Dit vraaggesprek zal ongeveer 15 minuten duren. Na het vraaggesprek wordt u gevraagd om een maaltijd na keuze te bereiden (dit is vooraf al besproken). U krijgt een opdrachtformulier met vragen die zowel voor, na en tijdens het koken moet worden ingevuld. Dit is om u aan te moedigen om de slimme keukenschaal te gebruiken. U mag na eigen inzicht ervoor kiezen deze vragen niet of later in te vullen, mocht het kookprocess dit niet toelaten. U mag zelf bepalen hoeveel tijd u nodig heeft voor het koken, en dit hoeft niet vooraf bekend te zijn. Tijdens het process mag u vragenstellen aan de onderzoeker en de onderzoeker zal indien nodig aanwijzingen geven over het gebruik van de weegschaal. Na het koken is er een onbepaalde tijd voor het opeten van de maaltijd. Na de maaltijd volgt een vraaggesprek vergelijkbaar met de eerste. Deze zal gaan over de slimme keukenschaal en de evaluatie hiervan. Een vragenlijst zal weer gebruikt worden als leidraad, maar hier kan van afgeweken worden.

Voordat u uw deelname toegezegd, zijn de volgende praktische aspecten belangrijk:

1. Deelname aan dit onderzoek is vrijwillig en u kunt stoppen wanneer u wilt zonder opgave van reden.
2. U bent verantwoordelijk voor uw eigen handelingen wat betreft het kookproces. Dit betekent ook dat u tijdens het kookproces, vrij bent na eigen inzicht van de instructies van de onderzoeker af te wijken.
3. Er worden geen fotos of videos opnamen gemaakt van u tijdens dit onderzoek.
4. Alle data die tijdens het onderzoek verzameld wordt zal anoniem blijven, zodat u niet als individueel te identificeren valt aan de hand van deze data.
5. Persoonlijke data zal veilig worden opgeslagen en kan alleen worden ingezien door de onderzoeker of zijn begeleiders.
6. Mocht u nu of tijdens het onderzoek vragen hebben, dan kunt u deze ten alle tijden stellen aan de onderzoeker.

Tot slot wil ik u bedanken voor uw interesse in dit onderzoek. Met uw deelname helpt u mij mijn concept te verbeteren en mijn afstudeerproject succesvol af te ronden.

Voor vragen of opmerkingen, neem contact op met:
Hessel Bosma
Creative Technology student at University of Twente
h.r.bosma@student.utwente.nl

Heeft u klachten over dit onderzoek, neem dan contact op met:
The Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethics-comm-ewi@utwente.nl)

Appendix B2: Evaluation study informed consent

Formulier van informed consent

Hierbij verklaar ik dat:

- Ik ben dusdanig geïnformeerd dat het mij duidelijk is waar het onderzoek over gaat, hoe het onderzoek uitgevoerd gaat worden. (Zie informatiebrochure)
- Al mijn vragen over het onderzoek zijn op dit moment voldoende beantwoord.
- Ik geef goedkeuring uit eigen overweging om mee te doen aan dit onderzoek.
- Ik weet dat ik altijd en zonder reden mag stoppen met dit onderzoek.
- Ik weet that als de resultaten van het onderzoek gebruikt worden gepubliceerd op wat voor manier dan ook, deze geheel anoniem blijven.
- Ik ben mij ervan bewust dat mijn persoonlijke informatie niet zonder mijn toestemming wordt gedeeld met derden.
- Ik weet dat wanneer ik meer vragen heb over het onderzoek, nu of later, ik terecht kan bij: Hessel Bosma (Tel: +31 (6)83123174 Email: h.r.bosma@student.utwente.nl)
- Ik weet dat ik als ik klachten heb over dit onderzoek, ik terecht kan bij: the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethics-comm-ewi@utwente.nl).

getekend door beide partijen

Deelnemer:

Naam: Handtekening:

Voor de onderzoeker:

Ik heb het onderzoek uitgelegd. Ik verklaar mijn best te doen om alle vragen zo duidelijk mogelijk te beantwoorden nu, tijdens en na het onderzoek.

Naam: Handtekening:

Appendix B3: Pre-cooking questionnaire

1. Wat is uw leeftijd?

   ____

2. Wat is uw geslacht?

   Mark only one oval.

   - ( ) man
   - ( ) Vrouw
   - ( ) Zeg ik liever niet
   - ( ) Other: ______________________

3. Wat is uw nationaliteit

   Mark only one oval.

   - ( ) Nederlands
   - ( ) Other: ______________________

Voedingsbewustzijn en voedingskennis

Dit onderdeel gaat over uw kennis over- en bewustzijn van- uw voeding

4. Hoe gemotiveerd bent u om gezond te eten?

   Mark only one oval.

	1	2	3	4	5	
helemaal niet	( )	( )	( )	( )	( )	heel erg

5. Hoe gezond is volgens u, uw huidige dieet?

Mark only one oval.

	1	2	3	4	5	
heel ongezond	◯	◯	◯	◯	◯	heel gezond

6. Wat is de reden van uw antwoord op de vorige vraag? Waarom is uw dieet zo (on)gezond?

7. Hoe bewust bent u van uw eigen voedingsinname?

In hoeverre weet u het antwoord op de vraag: wat is mijn dagelijkse X-inname? met X zijnde bijvoorbeeld: calorieën, eiwitten, vetten, koolhydraten, vitaminen, mineralen etc.

Mark only one oval.

	1	2	3	4	5	
volledig onbewust	◯	◯	◯	◯	◯	heel erg bewust

8. Hoe bewust bent u van uw ideale voedingsinname?

In hoeverre weet u het antwoord op de vraag: wat zou mijn dagelijkse X-inname moeten zijn? Met X zijnde bijvoorbeeld: calorieën, eiwitten, vetten, koolhydraten, vitaminen, mineralen etc.

Mark only one oval.

	1	2	3	4	5	
volledig onbewust	◯	◯	◯	◯	◯	heel erg bewust

9. Hoe goed is uw voedingskennis?

In hoeverre weet u het antwoord op de vraag: Wat doet mijn lichaam met X? En wat houd een tekort/overschot van X in voor mijn gezondheid? Met X zijnde bijvoorbeeld: calorieën, eiwitten, vetten, koolhydraten, vitaminen, mineralen etc.

Mark only one oval.

	1	2	3	4	5	
heel slecht	◯	◯	◯	◯	◯	heel goed

Voedingwswaarden tellen

Dit onderdeel gaat over uw ervaring met het tellen en bijhouden van voedingswaarden

10. Heeft u ervaring met het bijhouden van voedingswaarden?

Mark only one oval.

◯ Ja (ga door naar de volgende vraag)

◯ Nee (dit is het einde van dit onderdeel)

11. Welke hulpmiddelen heeft u hiervoor gebruikt?

Check all that apply.

☐ Papieren schemas

☐ (Mobiele) applicaties zoals MyFitnessPal

Other: ☐ ____________________

12. Hoe behulpzaam zijn deze hulpmiddelen voor u geweest? En waarom (niet)?

____

____

____

____

____

13. Hoe veel baad heeft u (gehad) van het bijhouden van voedingswaarden? Heeft u uw voedingsdoelen bereikt? Waarom wel of niet?

14. In het geval dat u gestopt bent met het bijhouden van voedingswaarden, waarom?

Appendix B4: evaluation study task list

Smart Kitchen Scale opdrachten:

Voor het kooken

In totaal, hoeveel calorieën schat u dat er in de maaltijd zitten:

________ KCal

Ter referentie: A.D.H man = 2500 KCal, vrouw = 2000 KCal

Tijdens het koken

Bepaal met behulp van de weegschaal, wat de energie inhoud van de maaltijd is:

________ KCal

Welk ingrediënt zorgt voor het grootste aandeel in energie van de maaltijd:

____

Welk ingrediënt bevat het meeste vet in totaal?

____

Na het koken

Vergelijk de antwoorden op de vragen voor en tijdens het koken, wat valt u op en waarom?

____

____

____

____

Appendix B5: Post-cooking questionnaire

Vragenlijst na het koken

Deze vragenlijst gaat over de slimme keukenschaal

1. Wat voor gerecht heeft u gekookt?

2. Welke ingrediënten heeft u gebruikt

3. Wat ging er goed en wat ging er fout tijdens het koken?

4. bij welke ingrediënten werkt de slimme keukenschaal goed en bij welke niet? Waarom?

5. Hoe heeft u de slimme keukenschaal gebruikt om de opdrachten te beantwoorden?

6. Waarom zou u dit product wel of niet willen gebruiken?

7. In welke situaties zou u de slimme keukenschaal gebruiken en in welke niet? waarom?

8. Op wat voor manier zou de slimme keukenschaal verbeterd kunnen worden volgens u?