Apto

for Bureau Moeilijke Dingen

FINAL BACHELOR PROJECT REPORT

EXPLORING THE POSSIBILITIES OF MEANINGFUL INTERACTION WITH ADAPTIVE INTERFACES IN A WORLD OF CONNECTED PRODUCTS.

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Joep Elderman

I got to know you through the DIGSIM squad, being one of the coaches during my research project. I immediately liked your practical view on design. You are always enthusiastic, but also realistic and never condescending. This gave me as a student the motivation and confidence to try new things. During my third year, you were my coach as well. Together with Joep Frens, you provided me with multiple perspectives on design, therefore shaping me to the designer I have become today. You too supported me beyond the practice of design. You are never too busy to help, which I really appreciate. I look forward to a future with more collaboration.

Contents

Summary

Systems design is an upcoming design challenge for interaction. Most of these systems de-materialize as a result of flexibility and efficiency. In an attempt to re-materialize parts of the interaction within this domain, Apto is designed. Apto is a coffee machine with an adaptive interface resulting from a design process focused on exploring adaptive and meaningful interaction. This project is defined in collaboration with Bureau Moeilijke Dingen and executed within the DIGSIM squad. DIGSIM is focused on Rich interaction and systems design. In three iterations, three different adaptive mechanisms are explored and designed, each with a different balance between adaptivity and meaningfulness. Furthermore, additional challenges, resulting from the multi-product and multi-user environment in systems design, are discussed. The design of Apto illustrates some of the potential of adaptive interfaces with meaningful interaction in the design for the Internet of Things (IoT).

Prologue

The focus and skill-set of industrial designers is shifting from aesthetics to interaction, and now to systems design (Frens & Overbeeke, 2009). This forms not only a challenge, but also an opportunity for industrial designers. Especially within the field of everyday life, which is closely related to smart homes and IoT, challenges and opportunities to design for systems arise.

The consequences of the increasing amount and complexity of systems relate to my vision. The dynamic and unpredictable environment newly designed products arise in, results in universal designs focused on optimal flexibility and efficiency. Although these elements are important, they are not the only considerations for good design. A lot of the interaction experience is left untouched by these "de-materialized" interactions (van Campenhout, 2016). Additionally, the multi-functionality and genericity creates interactions that don't "mean" anything anymore, but instead are designed to fit as many features as possible. Consequently, it becomes more difficult to use them. Therefore, I argue for a focus on simplicity: focus on the core functionality of a product and make that perceivable.

The squad Designing for Growing Systems in the Home is most closely related to this vision. It focuses not only on design for systems, but also on implementing more meaningful interactions with those systems, specifically by means of Rich interaction (Frens, 2006). This framework is aimed at implementing meaningful interaction by respecting human skills beyond cognition (i.e. perceptual-motor and emotional skills) and creating unity of form, interaction and function (Frens, 2017).

In order to guide my development, I have set four goals for this semester: designing an algorithm, creating an aesthetic and functional digital prototype, shortening time spend on thinking and increasing time spend on creating, and build arguments from literature and user research rather than intuition (see appendix A).

Introduction

The project assignment and goal of Apto is defined in collaboration with Bureau Moeilijke Dingen. Bureau Moeilijke Dingen is a design studio which designs products and services. Their areas of expertise include, amongst others, artificial intelligence (e.g. AI-kit), adaptive interfaces (for multiple clients) and interaction design. Therefore, an interesting design project would be to combine these, and explore the possibilities of physical interaction with an adaptive interface controlled by artificial intelligence.

Collaborative framing between the involved parties (Bureau Moeilijke Dingen and me) has resulted in the following design challenge:

how can we create an interface, that adapts itself to match user needs in a meaningful manner in the multi-user and multi-product context of a connected (smart) home?

This challenge relates to both Bureau Moeilijke Dingen, as well as the squad Designing for Growing Systems in the Home (DIGSIM).

The focus of this design process is not the product itself nor the specifics of the algorithm, but rather the way the interface transforms from its default to the personalized state, (see figure 1), and how to interact with such a dynamic interface in a meaningful way. Therefore, a coffee machine is chosen to be used as the "carrier" for the project, to eliminate product design from the process, and shift the focus towards the interface.

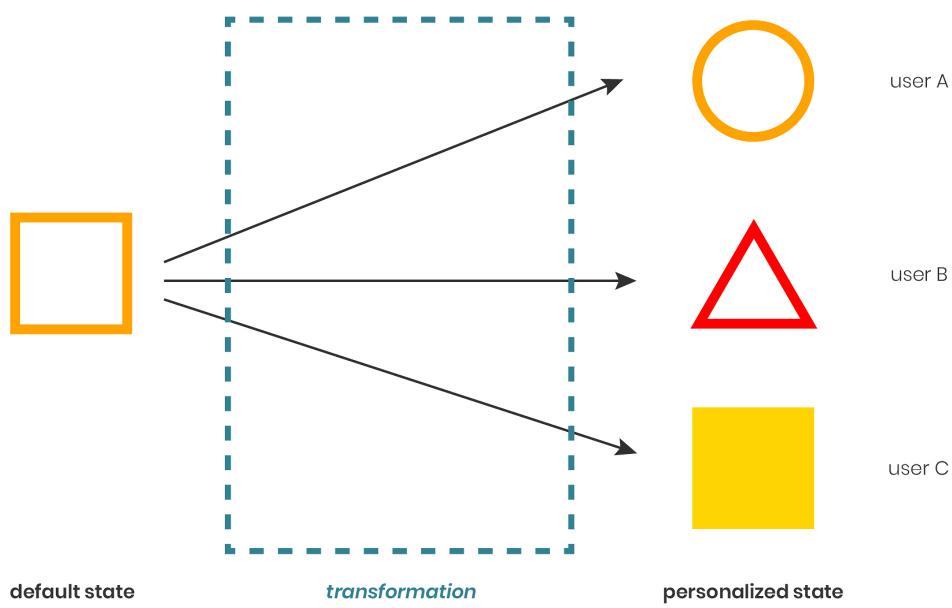


figure 1: *abstract representation of project focus*

Problem space

For this project, I explored and designed an adaptive interface for an interactive everyday device in a multi-user context (i.e. the DIGSIM house). In this context, there exist different needs and demands, and therefore the interface should respond appropriately to these factors to sustain a personalized and meaningful interaction. As explained above, instead of designing a product, this project started from the notion of an adaptive interface. The resulting product is only used as a "carrier" for the interface. Nevertheless, they need to be seen as one holistic design, not two separate entities, because the interface is designed for a coffee machine, not as a general-purpose interface.

The above-mentioned design challenge can be divided into a couple of sub-topics that will be addressed in the iterations. A brief overview of the sub-topics will clarify the problem space of this project.

Firstly, the interface itself needs to be defined in terms of functionality and context of use of a coffee machine. This determines the scope of the design project.

Next is adaptivity. This is relevant because user needs vary, and because meaningful interaction is not "rigid" and doesn't need to be a "one size fits all" interaction. The adaptive behavior can be defined in a variety of ways, which are depending on, and influenced by the flexibility and functionality of the interface.

Thirdly is addressing the user needs, which are not limited to individual users, but stretch to include scenarios with implemented intentions, preferences and priorities (Funk, Chen, Yang, Chen, 2018), of which individuals are a part.

The fourth sub-topic is making the interface meaningful. But what does this mean? Whether something is meaningful depends on the individual and is related to our intuition and perception. Intuition, according to Oxford University Press (OUP) (n.d.), is: "The ability to understand something instinctively, without the need for conscious reasoning", or: "easy to understand or operate without explicit instruction" (Collins English dictionary, n.d.).

Perception is better explained by the notion of affordances. First coined by Gibson and further defined for application on everyday objects, Norman (2013) defines affordances as action possibilities, or more specifically the relation between an actor (user) and an object. He describes perceived affordances as the action possibilities an actor extracts from the physical world. I define meaningful interaction as the combination of perceivable action possibilities and knowing what those will do without explicit instruction, i.e. intuition.

This is especially valuable in a connected and growing system, as those tend to become increasingly complex as their functionality grows and interfaces merely expand over a limited set of interaction loci. Consequently, interaction, action and function lose couplings to each other, making the couplings meaningless (Frens, 2006). To make matters worse, interaction with such systems often employs "invisible" action possibilities like gestures and speech-based controls (Frens & Overbeeke, 2009) or touch screens which lack information from the physical world (Dourish, 1999). Van Campenhout (2016) calls this phenomenon de-materialization. The result is that despite the wide functionality, only limited parts are actually used, and often go paired with frustration (Norman, 2013).

Lastly is the dynamic multi-user multi-product environment of the product. The coffee machine is part of a connected (smart) home. This means devices are part of a system that communicate with each other. Constant changes take place regarding the user needs and behaviour, but also regarding the growth of the system, making the future state unpredictable and often complex, as interaction happens beyond a singular product, but also on a system level. This is where adaptability is especially valuable, because the adaptive interface is able to support such a dynamic environment.

Approach

The project consists out of four major phases: the discover and define phase, and three iterations. This section briefly describes what has been done in each phase.

To design a meaningful interface, the product it controls has to be understood first. Therefore, in the first phase, a variety of coffee machines is analysed, as well as research to adaptive interfaces is conducted. From these studies, a set of essential features is defined. Additionally, as set of low-fi prototypes is made to explore how different adaptive mechanisms could work. The result is the starting point for designing an adaptive interface for a coffee machine.

The first iteration is focused on exploring the concept of a meaningful adaptive interface by sketching and foam modelling. Meaningful interaction is implemented by addressing a wider set of human skills (Wensveen, Djajadiningrat & Overbeeke, 2004) then done in current interfaces of connected systems (Frens, 2017). Concretely, this means implementing frameworks like Rich interaction (Frens, 2006), the Frogger Framework (Wensveen, et al., 2004), embodied interaction (Dourish, 1999) and the Third Stand (van Campenhout, 2016). Combining these appropriately should result in meaningful couplings between action and function that go beyond cognition.

The iteration is finalized with a complete coffee machine deploying an adaptive interface. This interface is used to test meaningful couplings. Due to the Corona crisis, only digital prototypes are appropriate for user testing. Additionally, a user study is done to find what use patterns to expect in practice.

The second iteration is built on the results of the validation of iteration one. A variety of 3D models is designed, each with iterative improvements regarding the combination of meaningfulness and flexibility. The interfaces' meaningfulness is assessed based on compliance with the Rich interaction and frogger framework. The flexibility is assessed based on the extent of (potential) functionality it holds.

The third iteration is the result of a pivot in adaptive mechanism. Based on the exploration and analysis of the second iteration, limitations were found in the interaction with the current adaptive mechanism. Therefore, the third iteration explores a new mechanism, and opens up a new design direction.

Related work

This section briefly discusses related research and products related to adaptive interfaces and learning algorithms. The goal is to get a better idea about the scope of this project, to find inspiration and to identify common pitfalls in these areas.

Google home

The Google home is an example of a de-materialized interaction style employed in a (connected) smart home (Google, n.d.). It employs "adaptive interaction" based on machine learning since learns what you want it to do based on speech commands. These commands can become more abstract the better the Google Home is trained. This interaction, however, misses any kind of information-for-use and therefore remains limited to the creativity and (cognitive) knowledge of the user.

Foot-LITE adaptive interface

An application specifically employing an adaptive interface is lowering the cognitive load while driving (Birrell, Young, Stanton & Jennings, 2017). This is similar to the goal of this project, though in a different context. Foot-LITE, the adaptive interface discussed by Birrell, et al. (2017), changes the auditory and visual information presented on a (digital) display based on a workload algorithm (see figure 2).

Three important elements can be extracted from this research: (1) the interface adapts itself based on an algorithm that identifies a scenario (workload), (2) the interface is completely digital, presented on a display and (3) the information shown on the display is divided into levels (Birrell, et al., 2017).

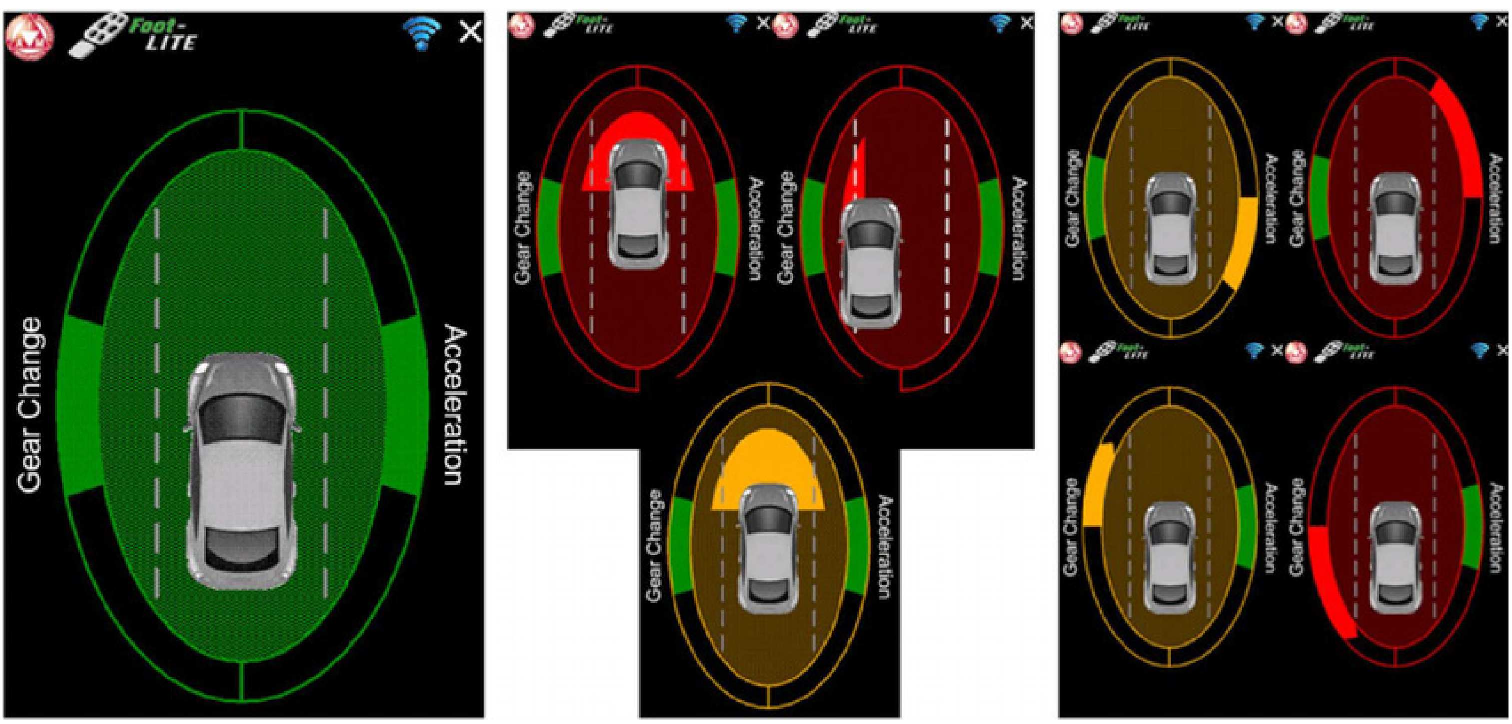


figure 2: *Example screenshots from the Foot-LITE 1 smart driving advisor. Only one "oval" is ever presented on the IVIS at any one time, but all aspects depicted can change in real time and in combination. (Left) Default green display. (Center) Top left to bottom—Headway warning, lane deviation warning, headway caution. (Right) Top left to bottom right—Braking caution, acceleration warning, change up caution, change down warning.*

Adaptive lab interface for students

Another application of adaptive interfaces is found in education. The adaptive interface is used as an addition to remote (online) laboratories (Zapata Rivera & Larrondo Petrie, 2018). Students with different expertise can use the same adaptive interface to perform online lab experiments. The complexity of the interface is matched with the mastery of the student and the complexity of the experiment (Zapata Rivera & Larrondo Petrie, 2018).

It is interesting to note that for this application too, a digital platform is used to advance the adaptivity of the interface. Also, similar to the levels of the Foot-LITE interface (Birrell, et al., 2017), one of the proposed concepts uses a predetermined set of views (Zapata Rivera & Larrondo Petrie, 2018).

Adaptive user interfaces

Browne, Totterdell & Norman (1990) did research about the general concept of adaptive interfaces. In their book, they mention some examples of adaptive interfaces. Remarkably, all of these examples are software based and do not include tangible interaction of any sort.

Nest learning behaviour

More focusing on adaptive behaviour instead of an interface, Yang & Newman (2013) analysed the Nest thermostat (figure 3) and reveal some relevant considerations when designing for learning algorithms. The Nest thermostat is unable to distinguish between routine tasks and temporary (exceptional) adjustments. The impact of this issue is amplified by the lack of user control. The user cannot tell the system, but it also can't identify such differences itself. Additional consequences of lacking control are a too sensitive or too arrogant system. It changes its behaviour too soon or not at all. Lastly, the system learns from a too limited set of sources; only time.

Yang & Newman (2013) suggest a couple of solutions to problems related to distinguishing routine from exceptional adjustments for a more general context: ask for feedback on the system's output, acquire a more detailed input and, a more passive method, exception flagging to exclude adjustments from training.

***figure 3**: Nest thermostat*

Discover and Define

In order to offer a meaningful interface for the device, a set of coffee machines is analysed to identify the most essential features and parameters (see figure 4 and appendix B). Each coffee machine is analysed on the kind of action possibilities (e.g. touching a screen or pushing a small rod) and what those actions control. Also, the "directness" of controls is assessed (figure 5). This is further explained in the parameters section.

Another part of this phase included making a set of low-fi paper prototypes (figure 6) and sketches to get a feeling of how different adaptive mechanisms could work. Striking about these prototypes is that the adaptive mechanism here is only focussing on shape changing or directing focus. I considered this as a limitation to adaptivity, so I explored these mechanisms further and as a result created a spectrum of different mechanisms. They range from full user control (i.e. no adaptation) to complete automation (i.e. implicit adaptation without explicit interaction).

Progression of the adaptivity

Similar to the levels of Foot-LITE (Birrell, et al., 2017) and the predetermined set of views of the adaptive lab interface (Zapata Rivera & Larrondo Petrie, 2018), the low-fi prototypes revealed that a continuous progression could be unwanted. Instead, discrete steps in adaptivity seemed more appropriate. To make this more concrete, a set of modes is defined (see appendix C for a detailed description):

- Full user control without adaptation,
- Give suggestions about values that match use patterns,
- Rearrange mapping of functions to controls,
- Automatically changed values of controls based on identified scenario,
- Change the spatial location of controls,
- Offer pre-sets without controls,
- Automation without user control.

Parameters

In this report, two different kind of parameters are distinguished. Technical and control parameters. The technical parameters are defined as the lowest level of control, closest to what is actually being controlled. They are determined by a product's hardware (Frens, 2006). Control parameters are defined as the functionality a user has control over (Frens, 2006). These may be technical parameters but could also transform into more context related combined parameters.

Technical parameters

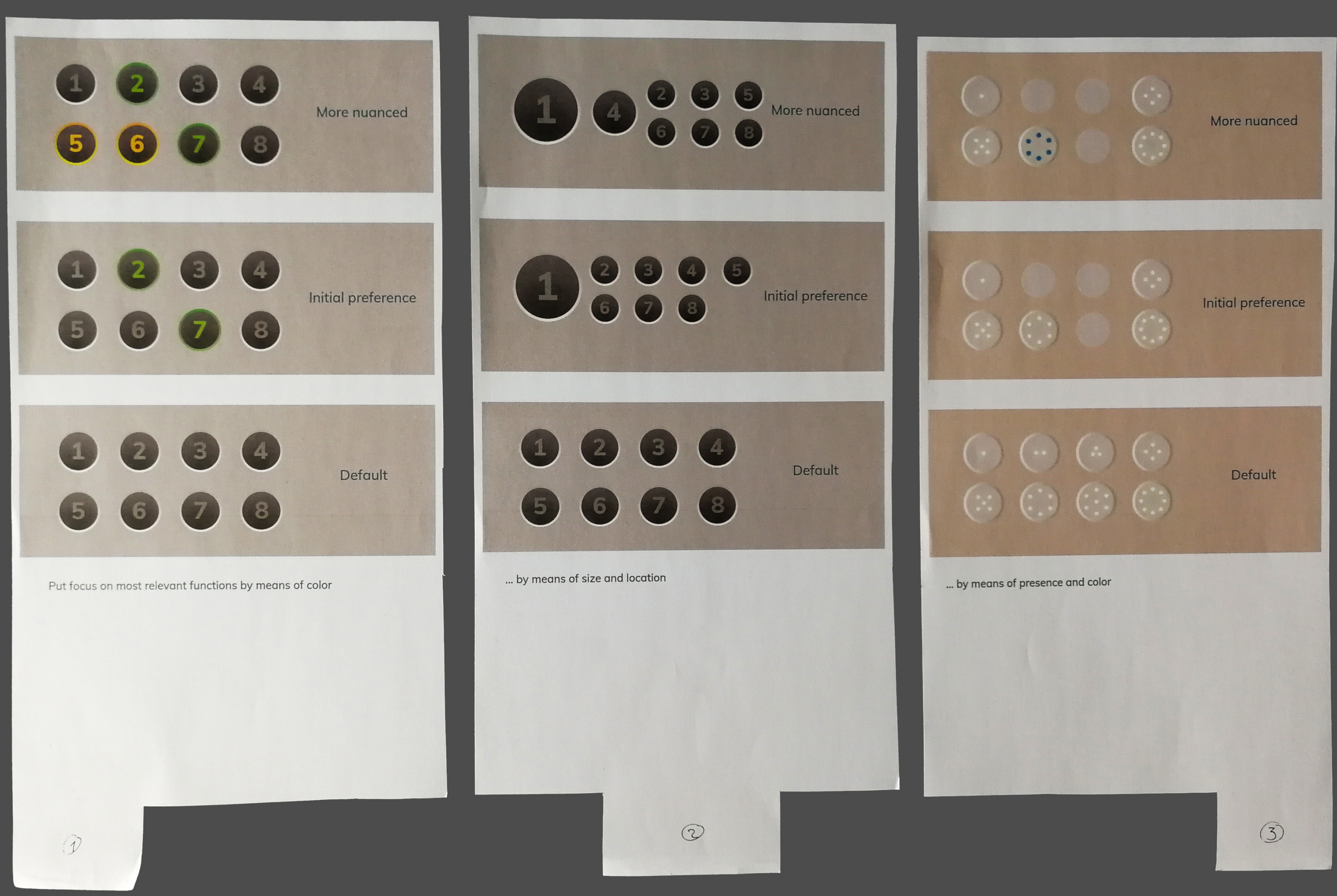
The coffee machine analysis yielded as set of the most essential technical parameters for a coffee machine. To limit the number of possible variables, a selection of those parameters used for making coffee is made. They are listed below. These parameters cover the most common coffee recipes.

1. Amount of coffee beans
2. Amount of water
3. Amount of milk
4. Amount of frothed milk
5. Amount of sugar
6. Amount of cocoa
7. Grind of beans
8. Temperature of water

figure 4: *The Dolce Gusto coffee machine (left) uses cups and physical action possibilities. The Rancilio coffee machine (centre) offers physical action possibilities too and offers more options than the Dolce Gusto machine. The Segafredo coffee machine (right) offers a similar quantity of control as the Rancilio, but most control happens through a touch screen.*

figure 5: *Coffee machines categorized based on direct and indirect action possibilities*

***figure 6**: paper prototype of three different adaptive mechanisms using flexible: color, size, location and presence.*



Iteration 1

The first iteration is kicked off by designing a coffee machine with elements of Rich interaction (Frens, 2006). The idea of coupling the function of pouring to a downward motion above the mug was established rather quickly. Soon, this idea was expanded by including the configuration of the coffee in the downward motion by literally pushing down the ingredients above the mug (figure 7).

At first, the controls were presented next to the ingredients as well, but this made the “pour handle” feel cluttered and left little room to build in adaptivity or expressivity in the controls. Distinguishing between coffee quantity and grind amongst others yielded problems regarding expressivity. Therefore, the “pour handle” was stripped from the ingredients-feedback and controls. Controls to change the configuration were relocated to be spatially closely coupled to the ingredients they affected to make the action coupled to their function (Wensveen, et al., 2004) (figure 8 and 9).

The problem with this approach is the lack of flexibility. Controls could not disappear when unused resulting in ambiguity and the only way to adapt the interface was in terms of the values of each control. What’s more, there was a lack of information sources for the interface to adapt. Using external data sources would only result in implicit interaction and thus automation, which is not the goal of this project. Internal input data is limited to the values of controls, resulting in little adaptation possibilities.

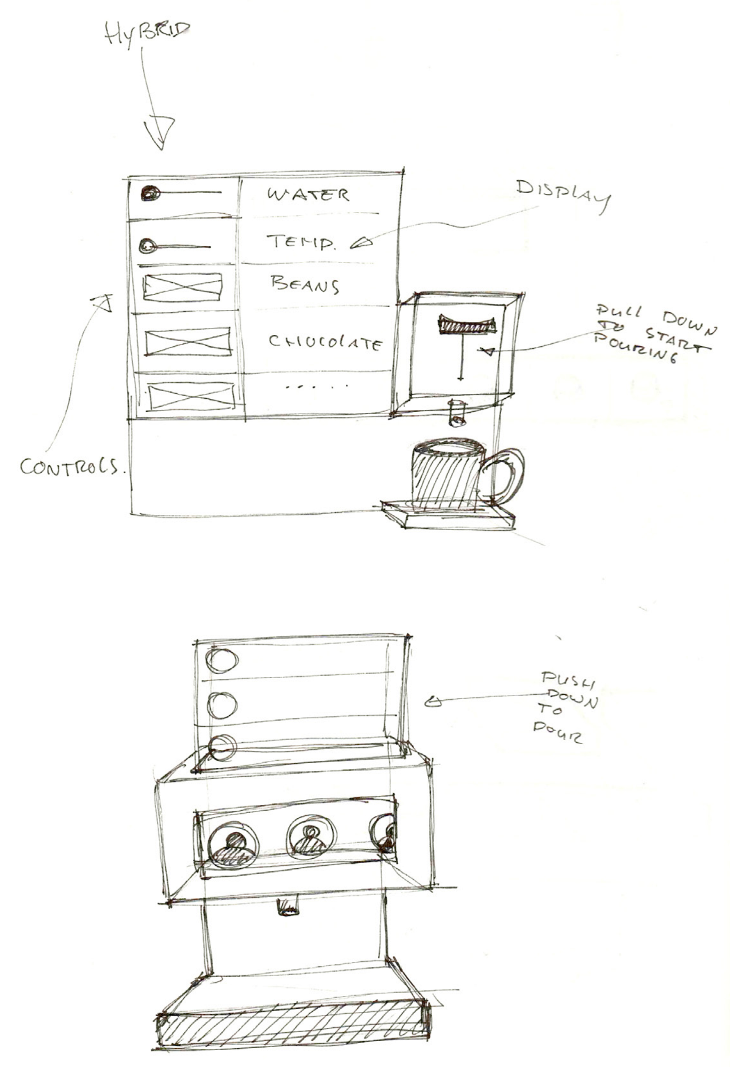


***figure 7**: Initial ideation sketches of “push down to pour” concept.*

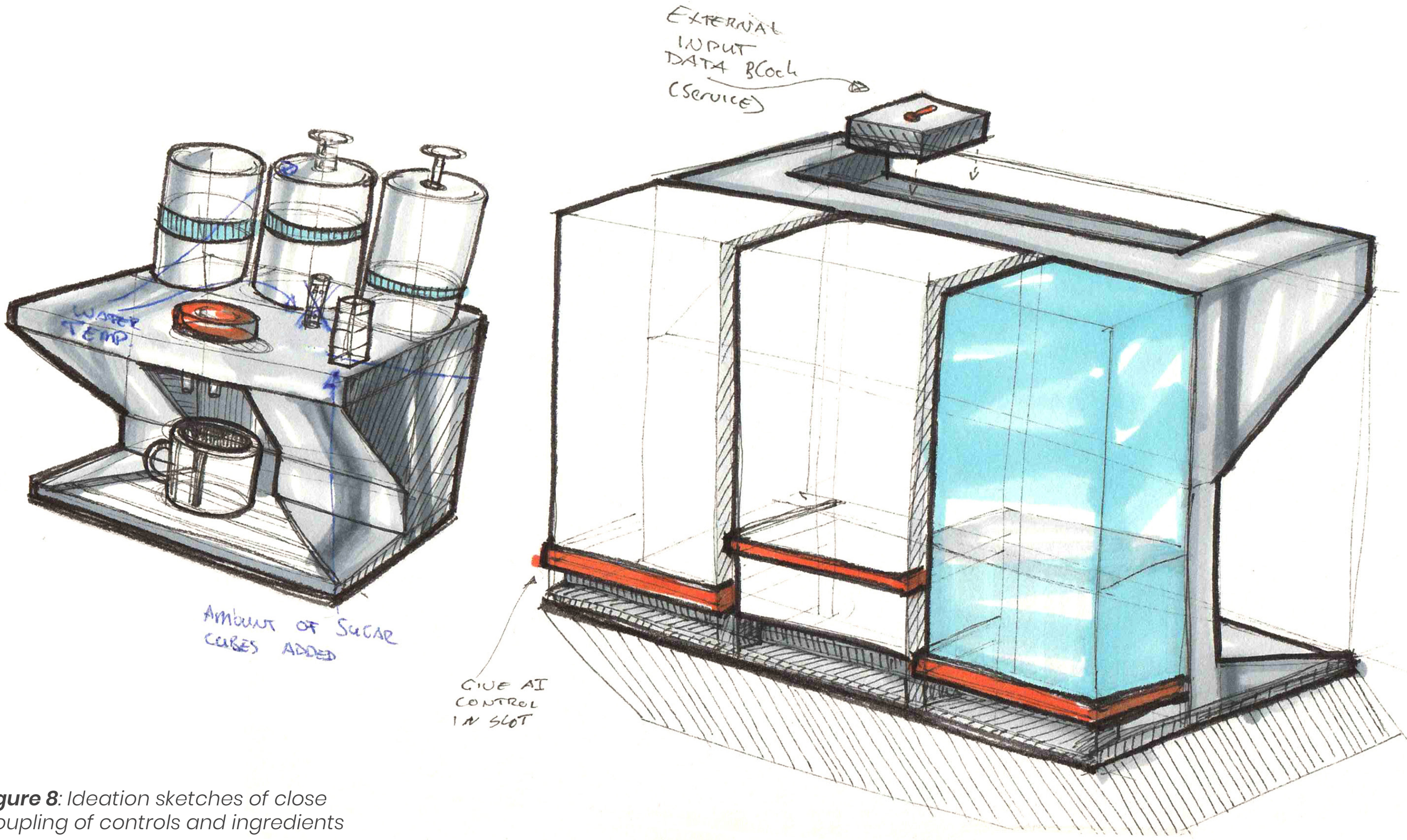


***figure 8**: Ideation sketches of close coupling of controls and ingredients*

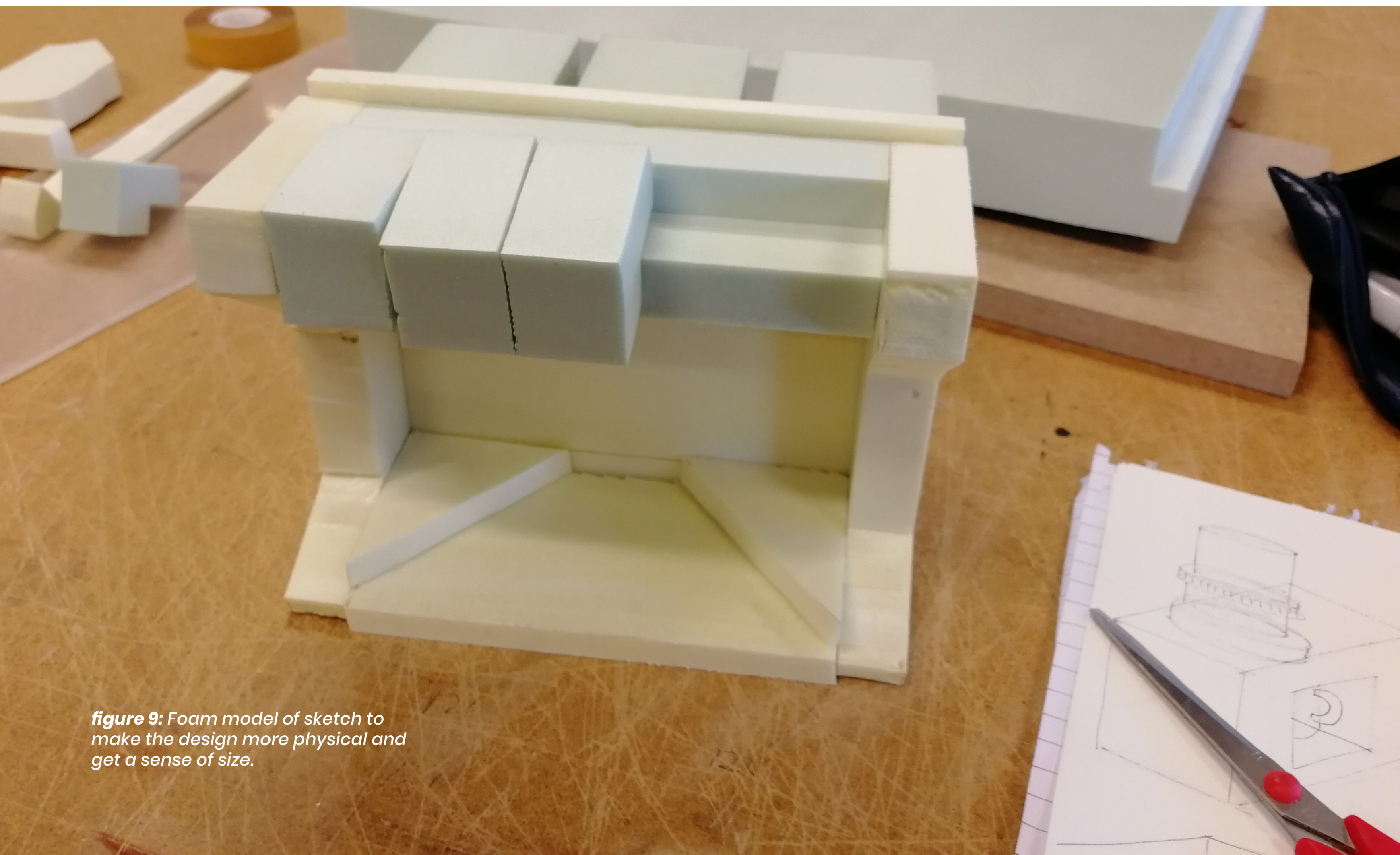


***figure 9:** Foam model of sketch to make the design more physical and get a sense of size.*

Design

After lots of explorations regarding control mapping, interaction and flexibility (figure 10 and figure 11), I settled for the first holistic design of Apto (figure 12). For the video see: *https://youtu.be/5owlb_c-P_M.*

It consists out of four containers each with a separate quantity control (the small dials). Before a dial can be rotated, it must be "activated" by pushing it down. As a result, it rises from the surface. By rotating a dial, the connected "gutters" show a flow animation to communicate to the user that they are controlling the "flow" of content, i.e. the quantity.

The container for coffee and milk both have an additional control on top to control a more specific parameter related to the content of the container. For coffee that is the grind and for milk it is the amount of frothed milk.

Thirdly is the pour handle, which can be rotated to browse between pre-sets displayed on the screen and pushed down to pour the selected present. The ring underneath changes the temperature of the drink.

Flexibility vs Rich interaction

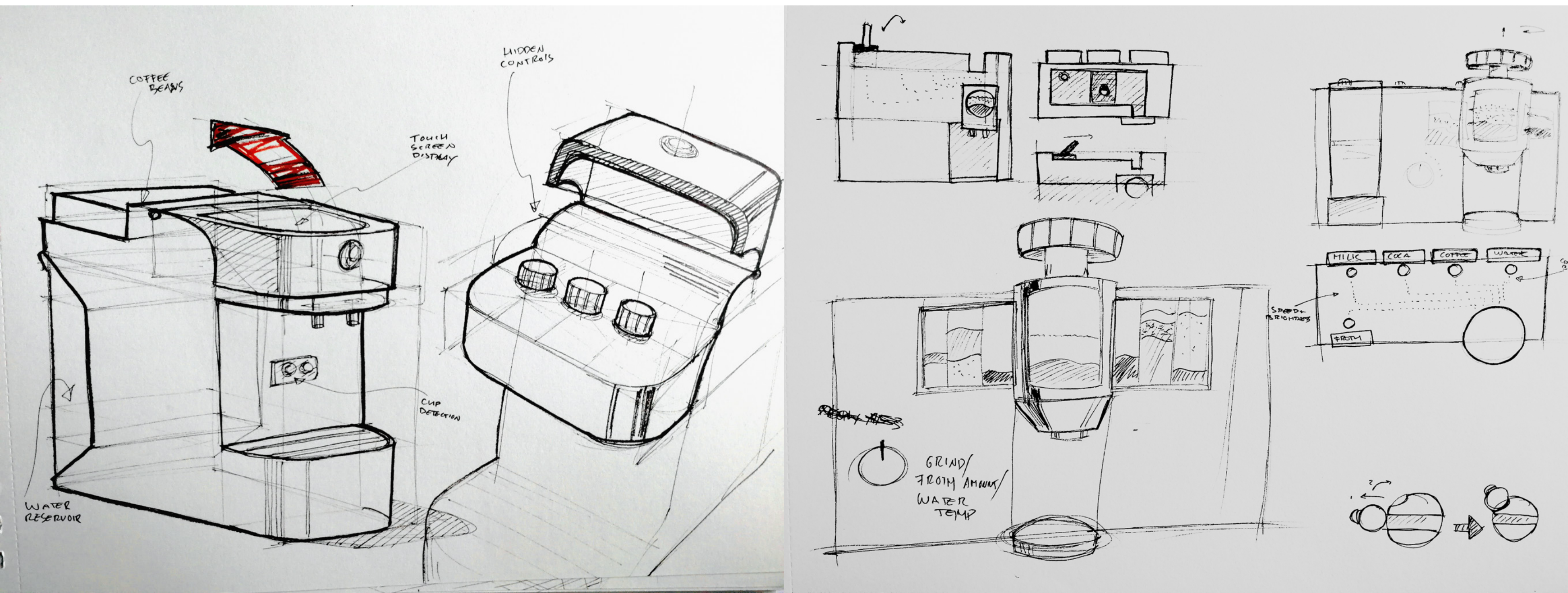
Some actions are obviously better coupled to a function (e.g. the pour handle), while some are much more abstract (e.g. the temperature ring). The dials are left in between, as they provide a closer spatial mapping to the affected element and show more feedback. However, in this design, the flexibility outweighs rich interaction, even though all the action possibilities are tangible. They mostly lack expressiveness.

Adaptivity

The machine offers pre-sets of coffee. By tracking the changes made to the pre-sets (by using the controls), pre-sets adapt over time, as well as the behaviour of the controls. Dials get a little "tick" when they reach a reoccurring value of a parameter in the list of pre-sets. Before a parameter can be changed, a dial must be activated in order to distinguish between user or machine control. By activating controls, you "take over" control from the machine and only then that value is used by the machine. Otherwise, it will see that as a variable input. What this ultimately results in is a filter. By activating and changing the parameters, you limit the amount pre-sets that suffice. When no more pre-sets are left for multiple times, a new pre-set is added.

This iteration of Apto is used for validation. The goals, methods and results are described next.

***figure 10**: Some ideation sketches of control mapping, (Rich) interaction and potential to be flexible*



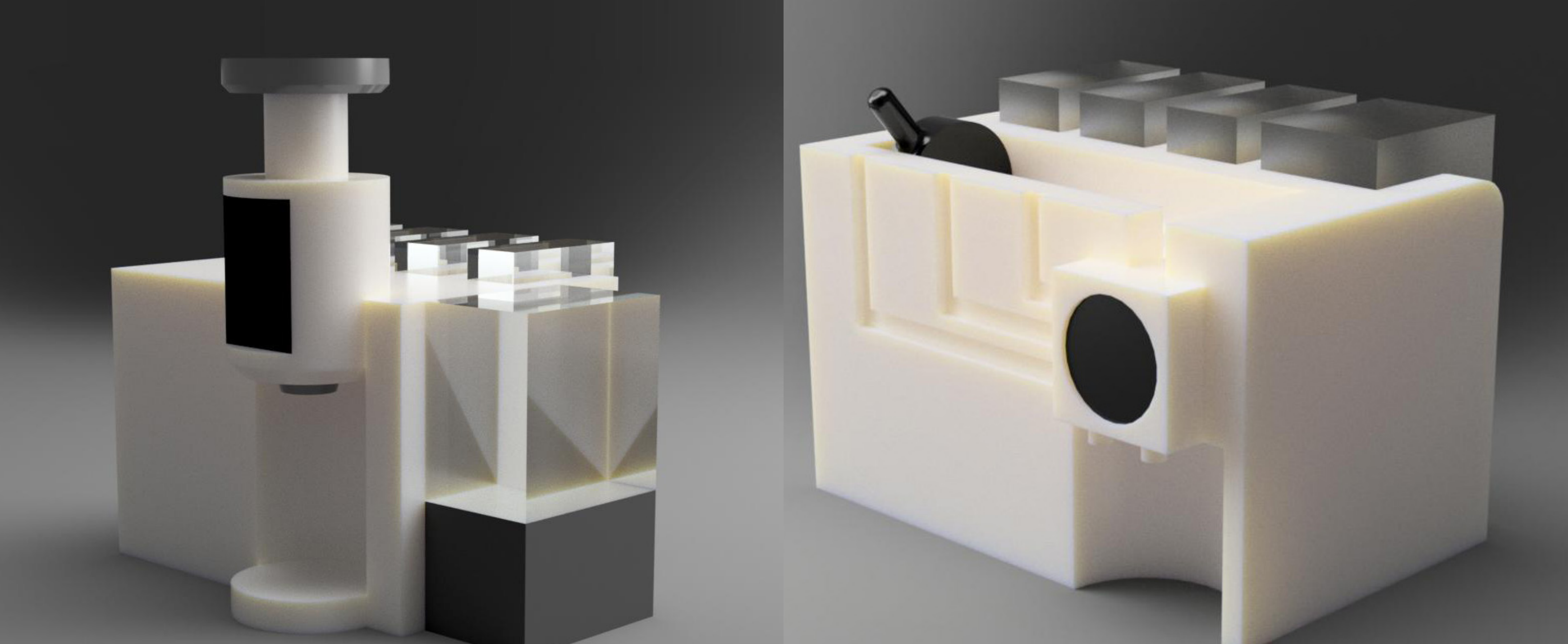


figure 11: *3D models of two interaction styles. Left: coupling a physical push handle with a digital display. Select using rotation and push down to "push" selected ingredients through the display into the mug. Right: combining vertical and horizontal motion into one physical control to both select (horizontal motion) and change (vertical motion) values. At the end, pull down to "push" ingredients through the display into the mug.*

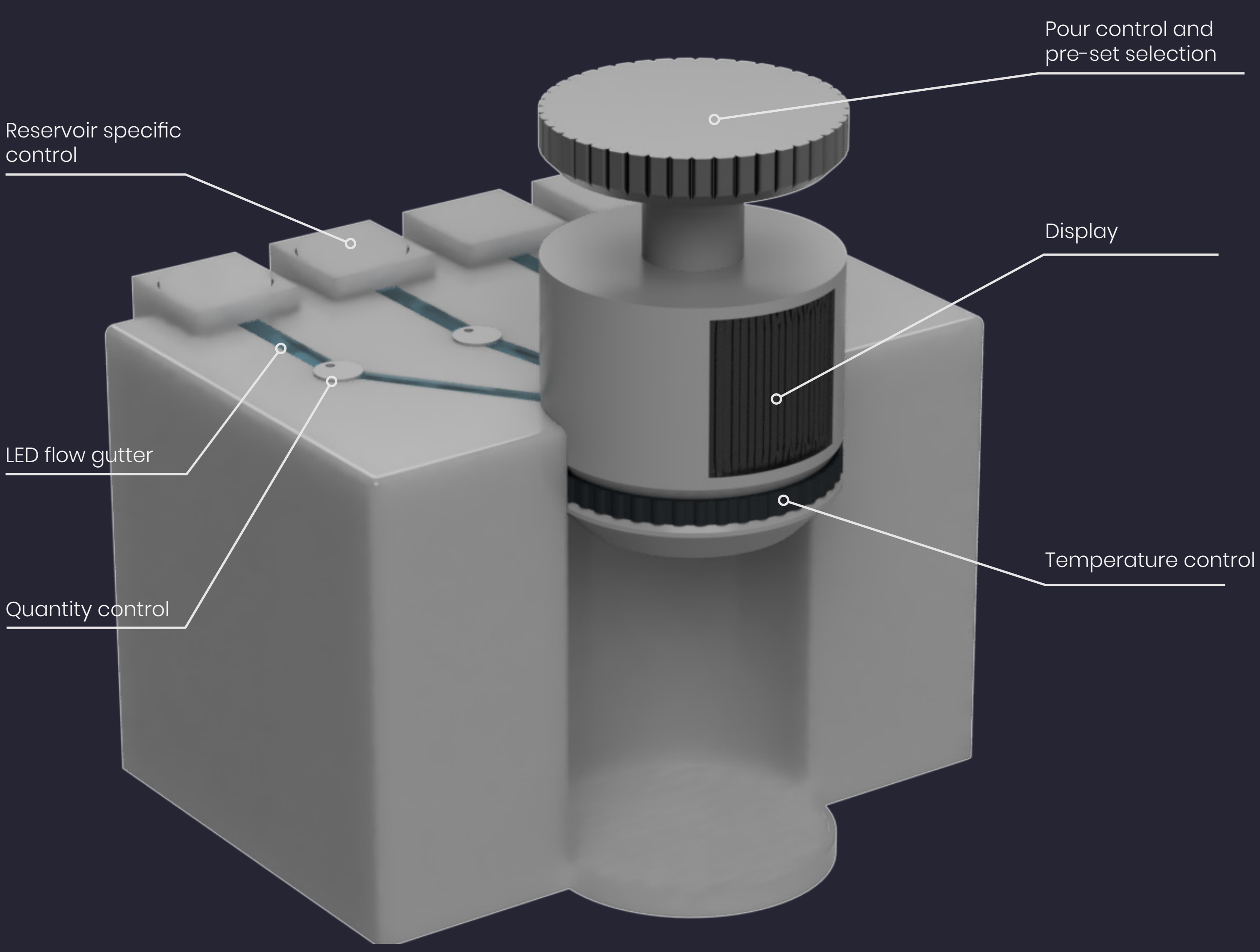


figure 12: *3D model of iteration one.*

Validation

The validation exists out of two tests. Before the tests were conducted, they were approved by means of an Ethical Review Form (appendix D). Due to circumstances, both tests are designed to be taken online, using Microsoft Forms. For distribution, the User Data-ing platform was used. Initial assumptions about the user behavior and meaningfulness of interaction are validated with these two tests. The results drive a second iteration of refinements.

Use patterns of coffee consumption

The first test is about the user behavior and their use patterns when using a coffee machine. The assumed behavior, and therefore added value of the adaptive coffee machine, is a changing or varying need in desire and preferences for coffee. To study people's coffee consumption patterns, a qualitative questionnaire is set up.

Method

The questionnaire includes questions about the needs, habits and preferences of users (see appendix E). The results yield insights about the patterns of use regarding drinking coffee. These are then used to design a more valuable way of adapting the interface.

Meaningfulness of couplings

Meaningful interaction is implemented by coupling action and functions. Action-possibilities embody their function (meaning) by implementing Rich and embodied interaction (Frens, 2006; Dourish, 2001). Intuitive elements rely less on the conscious, reflective level of cognition, like remembering what to do, and more on the subconscious, visceral and behavioral level (Norman, 2013).

These intuitive elements scale better when they grow or adapt, as they are not reliant on knowing or remembering, but rather perceiving. The test described below is meant to test how well the couplings (between action-possibility and function) are perceived and understood by people with no experience using the device.

Method

A multiple-choice test is designed with brief animations and pictures of action possibilities (see appendix F). The test has two versions:

- Match a function with the correct (numbered) action possibility.
- Match an action possibility with the correct (numbered) function.

The reason for the two versions is two-fold. Firstly, it functions as a guess correction, since participants might get hints to what functions and action possibilities are possible. Secondly, the meaningfulness of the couplings is tested both ways, i.e. to increase strength, turning a dial may be meaningful, but turning a dial is not equally meaningfully coupled to increasing strength. It could also be increasing temperature or changing pre-set for example.

The action possibilities are displayed using brief animations to also include some of the visual feedback, as that is also part of the interaction as a whole.

Results

The results from the validation are summarized into 10 take-away messages that will direct the next iterations. For the more elaborate documentation of data, results and conclusions, see appendix E and F. Raw results can be made available upon request.

1. Direct focus to most common configurations, include less-common configurations out of direct view.
2. Centralize controls for most common configurations (coffee strength, amount of milk, amount of sugar, size of drink).
3. Offer more complex configurations as pre-sets, initially downloaded from the internet. The pre-sets adapt over time, or instantly when forced, according to modifications.
4. To adapt a pre-set, display the configuration of the pre-set together with controls to change the config. Keep these settings hidden initially to comply with simplicity (hide) (Maeda, 2006).
5. The most important controls are for selection and quantity of ingredients. Temperature and grind controls are hardly ever used, so can be left out in favor of simplicity (reduce) (Maeda, 2006).
6. Better express the function of controls (if you say it is strength, make it strength, not quantity of coffee)
7. Match function with conceptual model of the user (if the user will think strength, confirm/say it is strength)
8. Distinguish between common, specific and new controls
9. Spatially map the action closer to the feedforward and feedback.
10. Allow for exploration of the interface in the next prototype and accompany this with an abundance of feedforward and feedback.

The validation concludes the first iteration. The results are further applied in the second iteration.

Iteration 2

Based on the results of the user tests from iteration one, a second iteration is commenced. This iteration focuses on balancing meaningful interaction with flexibility while complying with the test results. This section highlights the most relevant points only, for more detailed descriptions and analysis of the designs, see appendix G.

Use patterns indicated three commonly used parameters: coffee strength, amount of milk and amount of sugar. Therefore, these three parameters are mapped to the main control panel of the machine. Other parameters are located on a hidden panel (see figure 13). The biggest issue with this interface is the lack of adaptivity. Due to their spatial mapping to the containers, coupling the controls to other functions would result in ambiguity. They can't change meaning, shape or location either. The array of hidden sliders solves flexibility, but at the cost of meaningfulness.

The sliders and limited control panel are replaced with modular control panels, which can be customized by the user (figure 14). This approach is in line with the modular and service approach from Frens (2017). It makes the interface more flexible and only relevant functions for the user are mapped. The big problem with this design is with respect to adaptivity, since the user adapts the interface manually instead of the machine. The power of connectivity and machine learning is lost in this design.

Instead of the modular control panel, an array of nine generic dials is designed next (figure 15). This interface sacrifices couplings between controls and functions in favour of adaptability. Action and function are coupled by means of spatial mapping indicated on the display. The expressivity of the dials is left alone for now, and focus is directed towards selecting the input mode (control or pre-set), which for the current design decouples action and function in the control mode, and therefore affects the meaningfulness.

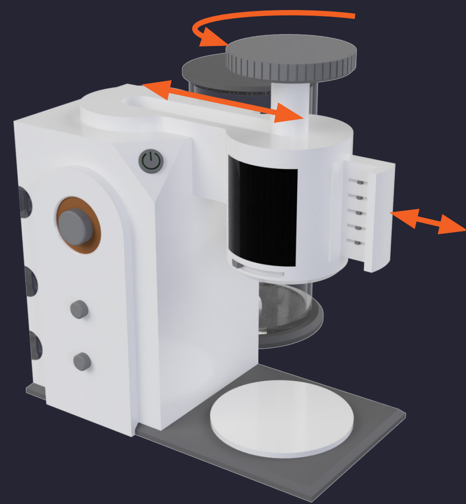


***figure 13**: Common controls are highlighted on the left. Other controls are hidden in the control panel on the right.*

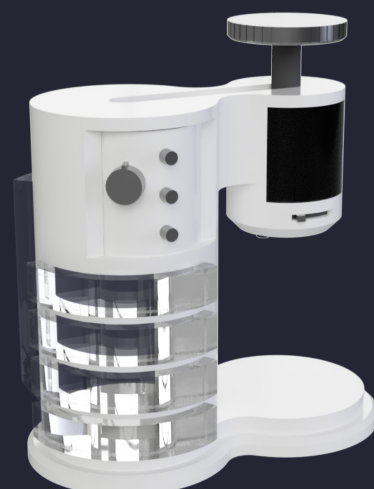


***figure 14:** control panel adhering to a modular service approach.*

***figure 15:** Control panel with nine generic dials that retract when not coupled to a function.*

At this moment, I started feeling overwhelmed by the number of considerations I had to take in mind while designing, so in an attempt to make the behaviour of the interface more concrete and experience-able, I programmed a digital interactive prototype of this design using Processing 3 and front view renders of a CAD model (figure 16). Besides experiencing the adaptive mechanism and the required flexibility and its effect on the meaningfulness, this prototype is used to explore and demonstrate emerging phenomena as a result of being part of a connected system.

figure 16: *Digital prototype made in Processing 3.*

To distinguish between routine and temporary changes more meaningfully, the location and direction of action and function are coupled according to the frogger framework (Wensveen, et al., 2004) (see figure 17). This design yields two major problems: turning away the control panel in pre-set mode decouples the controls from the display. Also, the difference of pouring a drink from pre-set mode (overwriting pre-set settings) and from control mode (temporary modification) is not clear.

Figure 18 shows a solution for these two issues. The controls are activated by folding out the control panel, which is then spatially coupled to the display. By pushing the control panel into the display, you overwrite the pre-set settings, similar to saving a photo with the "Labelless" Rich interaction camera of Frens (2006).

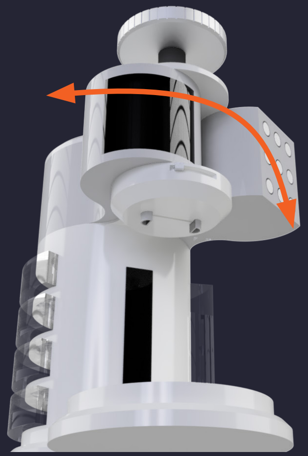


figure 17: *Design where display and control panel can both be coupled to the pour handle.*

figure 18: *The control panel in this design is activated by locating is next to the display.*

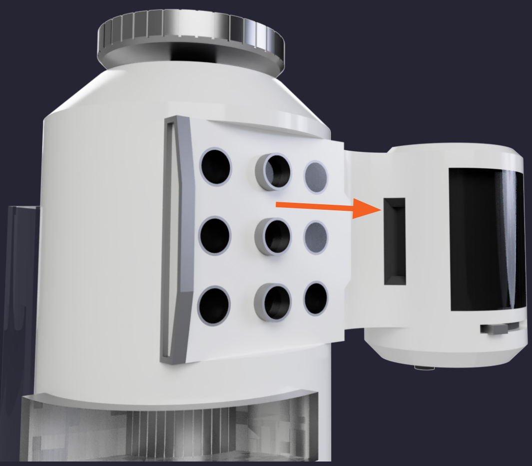


figure 19: *Sliding control panel with tiny displays in the dials. The physically higher control module constraints the pour control from being pushed down*

Two issues remain in this design. Firstly, since the selection handle can no longer be linked to the control panel, there is in this design no meaningful way to change the specificity of the controls that are offered. Also, the flexibility of the controls is still at the expense of their expressivity. Their meaning completely relies on cognitive skills of linking the physical controls with functions on the display.

To solve these issues, a step back is taken to a prior design. The ambiguity between overwriting and temporary modifying a pre-set is solved by adding the physical constraint in control mode to constrain pushing the handle down in that mode. Overwriting is done by pushing the control panel into the display showing the pre-set (figure 19).

To tackle the expressivity issue of the dials, nine tiny displays are implemented in each dial. Their function is represented by an icon. This preserves the flexibility and increases the coupling between action and function.

Again, two issues surface with this solution. The display user interface is hard to scale. When more parameters need to be mapped, the resulting configuration becomes increasingly reliant on cognition in order to show all the information (figure 20).

Secondly, I felt like adaptivity is limited by the design of the control panel. Controls with a predicted high likelihood of being used are mapped based on the scenario of use and reoccurring configurations are transformed into pre-sets. Since this project focuses on exploring and designing an adaptive interface, I wanted to take the adaptivity a step further. This is elaborated on in the next section.

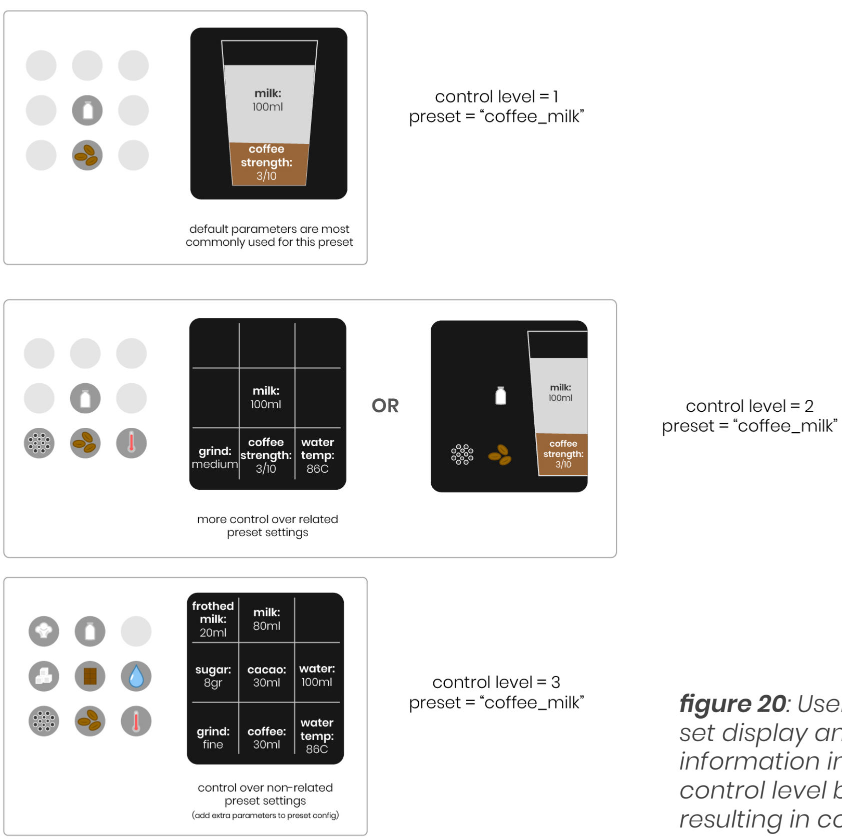


***figure 20**: User interface for the pre-set display and dial displays. The information in the second and third control level becomes too dens, resulting in cognitive strain.*

Final iteration

Offering only a varying set of predetermined (technical) parameters feels like limiting the power of the adaptive interface. New, emerging controls, as a result of use patterns could be mapped as well. However, the relationship between the new emergent control parameters and the predetermined technical parameters cannot be expressed on the current 3x3 dial array. Therefore, a new approach to mapping adaptive functionality is taken.

Approach

I started exploring this new concept by using low-fi paper prototypes (figure 21). The paper prototypes made it possible to experience the progression of the interface, i.e. what happened as a result of user behaviour. Experiencing the interface in a couple of scenarios helped to find problems and test solutions very easily. I took this experiencing approach, because the second iteration was only based on a rather static analysis, which lacked exploration of the dynamics of the interface.

After exploration with the paper prototype, I made a 3D model using CAD software (figure 22 and 23). This model, I then used to create a video prototype for demonstration using animation and graphical design software. The video can be accessed by this link: *https://youtu.be/2FnFuftKVxg.*

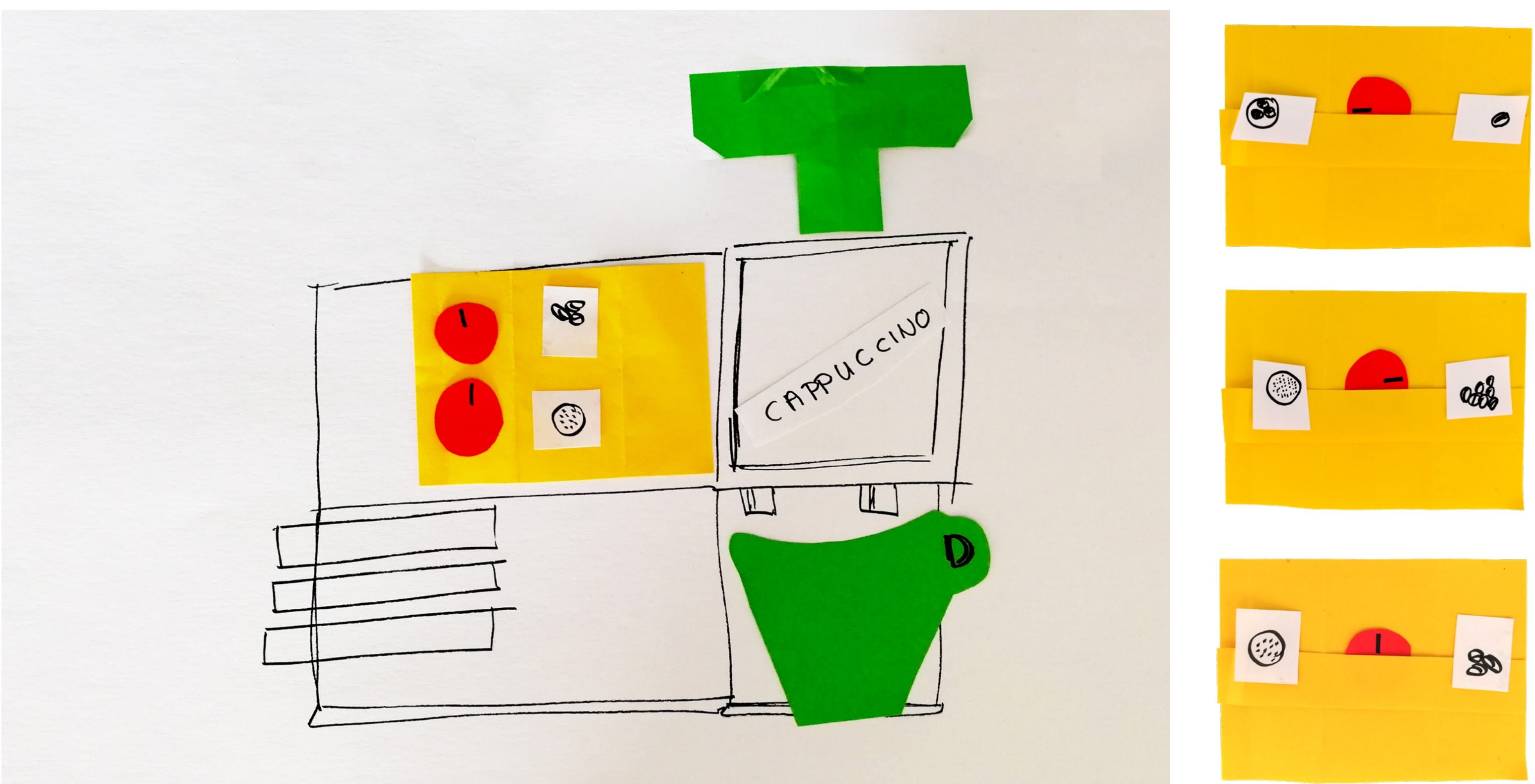


figure 21*: Paper prototype used to explore other adaptive mechanisms more quickly. The pictures on the right show additional augmented feedback when a dial is mapped to multiple, opposite, technical parameters (coffee grind / amount of coffee).*

***figure 22**: Final iteration CAD model.*

Control panel
- modify parameters indicated by icons
- parameter mapping adapts to match scenario
- dials without mapped parameters retract
- isolate a parameter by pressing the icon
- haptics indicate a preset with similar configuration exists

Panel handle
- manually overwrite a preset by pushing

Reservoirs
- keep track of content visually and by sensors
- XL water reservoir on the back side

Selection handle
- rotate to select a preset
- push down to pour
- pull up (and hold) to manually remove a preset

Display
- shows resulting configuration

Portion quantity
- get a single or a double portion at once

Height sensor
- get a portion perfectly matching your cup size

***figure 23**: Final iteration CAD model with feature description.*

Concept

The new design employs a row of dials, each initially linked to a separate technical parameter as listed in the technical parameters section. These are the most general controls in the way that they are applicable to every user. Their mapping is indicated with an icon next to the dial (see figure 24).

New control parameters emerge when a relation between multiple technical parameters is found for a certain scenario, e.g. in the morning, cappuccino is often modified with extra milk and extra sugar. These are then mapped to the same dial, indicated by multiple icons next to a dial (figure 24). Unused dials will retract to indicate they cannot be used: they no longer afford rotating. Each technical parameter can still be accessed by pressing it before turning a dial. This isolates the technical parameter temporarily.

If such emerged control parameters are often used in the same way for a certain scenario, a new pre-set will emerge for that same scenario. For the above example, this would mean that a new cappuccino pre-set is created with more milk and more sugar. However, if a pre-set is adapted in multiple ways without consistency, only the used parameters will be re-mapped in a control parameter, but their configuration (value) will not be saved in a pre-set.

***figure 24**: Close up of function mapping to dials. The icons indicate which technical parameters are mapped to a dial and what the relationship is: both are affected equally (top dial), proportional (second dial) or only one technical parameter is effected (third dial).*

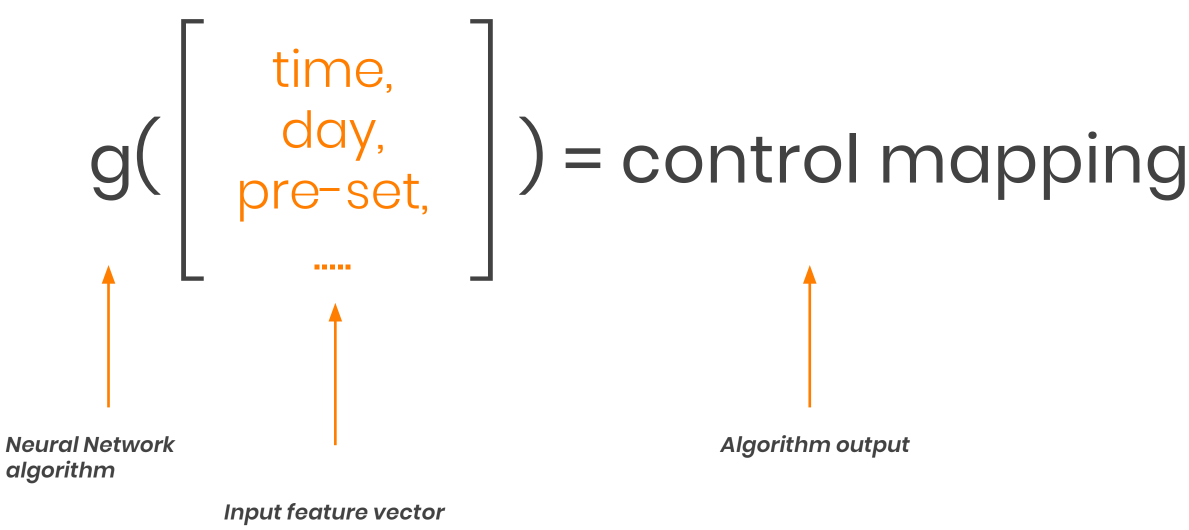
Algorithm

For the adaptive interface to work, a machine learning algorithm will be used. The specification of this algorithm is out of the scope of this project (see assignment framing by Bureau Moeilijke Dingen in the introduction). In this section I will briefly discuss the algorithm without going into technical details.

The reason a machine learning algorithm is used rather than a fixed set of rules has to do with the dynamic and uncertain environment of a connected system (Frens, 2017; Funk, et al., 2018). Also, user intentions and preferences in a specific scenario may change over time (Funk, et al., 2018). By allowing the machine to learn from various inputs, and keep updating its decision-making model, the interface will be more robust, flexible and sustainable.

In fact, there are two algorithms. One to determine the mapping of technical parameters (see formula below) and one for the configuration of pre-sets. It uses input data to determine a scenario and links the mapping of parameters (the algorithm output) to that scenario. A scenario is determined based on time, day and selected pre-set. However, since the machine is part of a connected system, additional external data sources (weather, agenda, etc.) can be used for more fine-grained scenarios.

Note that a scenario here is defined as the combination of similar input data. What "similar" means is determined by the algorithm, based on how different combinations of input data affect the use patterns. A neural network algorithm seems most reasonable to use, because it determines the "weight" of relations between input data (and hidden layers). This makes it possible to learn varying definitions of "similar" scenarios.



Rich and meaningful interaction

Part of the design challenge is making (the interaction with) the interface meaningful. In order to make the interaction meaningful, Rich interaction (Frens, 2006) and the frogger framework (Wensveen, et al., 2004) are implemented. Both argue for addressing human skills beyond cognition and tangible interaction which favors intuitive interaction and meaningful couplings. Wensveen, et al. (2004) go even further by defining six practical characteristics for coupling action and information.

I don't think interaction either is or is not meaningful. Instead I see a continuum of "meaningfulness" in interaction. For example, the icons added to the buttons, i.e. augmented feedforward (Wensveen, et al., 2004), make the buttons more meaningful. However, the buttons do not express their function, they only indicate what they relate to, but not how. In terms of Rich interaction, the coupling between form and function misses (Frens, 2006).

A more meaningful interaction can be found in the selection handle used to select a pre-set and pour the beverage. The shape and size afford rotating and pushing, which is amplified by the display underneath and space to place a mug . I coupled the physical action possibility (the handle) with the digital display. Wensveen, et al.'s (2004) coupling characteristics of time, location and direction apply here. What's more, the action possibility of pushing only appears when the water is heated. This is in line with the Mode Relevant Action Possibilities (MRAPs) of Frens' Rich interaction framework (2006), with the "mode" being the water temperature.

MRAPs are also visible in the dials, which retract when not mapped to any parameter. The mode relates to the mode of the dial itself. This makes the interface simpler, because the number of options is reduced (Maeda, 2006), which makes decision making less complex according to Hick's law (Soegaard, 2020). This favors the user experience.

The quantity slider to select either a single or a double portion (figure 25) is an example of Frens' (2006) Mode of Use Reflected in Physical State (MURPS). Selecting a single portion will unify the nozzles into a singular nozzle, indicating a single portion. Besides the semantics, it now is physically impossible to pour the coffee into two mugs, i.e. a semantic and physical constraint (Norman, 2013).

Sliding the control panel over to the display is meaningful on a metaphorical level. The settings are pushed into the pre-set and therefore overwrite the pre-set. This action possibility is made perceivable by means of the protrusion, which affords pushing, and is amplified by the augmented feedback that says "overwrite".

***figure 25**: Quantity selection. Left: one portion. Right: double portion.*

Emergent phenomena

By combining data and functionality of the system, a variety of new functionality could emerge (Frens, Funk, Hout & Le Blanc, 2018). Some potential emerging functionality is described below. The exact components (the connected devices and their functionality) of a system grow and change in ways that cannot be predicted. Therefore, the described functionality is only a part of potential emerging phenomena. For exploration and demonstration purposes, the latter two examples are implemented in the digital prototype discussed in Iteration two by using the OOCSI library (Funk, 2013).

Identifying new scenarios

The adaptation of the interface as a result of adding external input sources adds to emergent phenomena. By connecting the machine with new devices or sensors, unexpected but emergent scenarios can be identified.

For example, a standalone coffee machine would not be able to know when a user's alarm is set, making it almost impossible to distinguish two similar scenarios in terms of the available data. By connecting with a smart alarm clock, the machine "knows" more which could make the two scenarios very different. Although this is not necessarily a completely new function, it is functionality which is only possible by combining the two devices.

Improving sleep quality

A second phenomena that emerges from combining a smart alarm clock with an adaptive coffee machine is providing a warning when a user wants to get a cup of too strong coffee too shortly before going to bed. Caffeine does not match quality sleep well (Paddock, 2013). Therefore, by combining bedtime data and amount of caffeine, a smaller or less strong coffee can be suggested by the machine.

Balancing energy consumption

A coffee machine needs to heat up water and build up pressure. These are two power intensive events. According to a report by Energy Star (2011), the average power consumption of a coffee machine is around 900 Watts. By combining this data with power consumption and scheduled times from other power-hungry devices like a washing machine, a more balanced power division can be achieved, and more power can be drained when more power is produced by for example solar panels (for example Equi by Zandbergen (2020)). Additional control over those devices can be achieved by including a separate controller and visual feedback all around the house (e.g. Lumo by Verheijden (2020)). By showing visual feedback to the user, before a modification is pursued by, the user has the opportunity to stop or allow the modification.

Smart shopping lists

Coffee is for some people a daily beverage (see appendix E). This means the ingredients need to be bought on time. Keeping track of the reservoir's content and combining this with use times, the time at which the ingredients will run empty can be estimated. Sharing this information with a connected shopping list (e.g. BORD by Hu & Verpaalen (2020)), the items can be added automatically to a shopping list in time. Additionally, such a shopping list could track when groceries will be done, and in response, Apto could start rationing the amount of ingredient usage. This could be done in multiple ways. For example, Apto could show an indication next to the reservoirs that they will soon run out of stock, or perhaps suggest alternative pre-sets that use less of those ingredients. Even haptics could be included to indicate which ingredients will soon run out.

Future development

A design is never really finished, so in an attempt to make the final design more complete, in this section I highlight some points of improvement and future steps.

A downside of the current concept of adaptive mapping is that all the technical parameters always have to be accessible and therefore visible. In addition, the parameters need to be understood. A user can easily experiment with the parameters and see the result on the display. In this concept, flexibility is favored over meaningful or Rich interaction.

The buttons and dials on the control panel are not always all occupied with functionality. Instead of retracting, they could also be completely hidden complying with the "hide" concept from the "reduce" law of Maeda (2006). Controls with a very low likelihood of being used could be hidden as well to reduce the number of visible elements and clutter on the control panel.
A second issue which is not yet optimized is the ambiguity of the positive and negative direction of the dial rotation. It is unclear which direction increases or decreases the coupled parameter. To cope with this, an LED trace is shown to indicate that the longer end on the side of the icon is the highest value (see figure 26). Additionally, the icon is adapted accordingly to confirm the effect of the action (rotation).

Another point of improvement is related to the machine learning algorithm. The accuracy can be improved by letting the user give feedback to the machine directly (Yang & Newman, 2013), instead of only indirectly by modifying elements on the interface. For example, A user could dislike the interface as a whole, because he doesn't understand it. The interface could then adapt to a simpler interface or offer different controls.

Due to the Corona crisis, I had limited access to tools and materials for physical experimentation. Therefore, a highly relevant aspect for future development is to make this design physical. As a result of implementing meaningful interaction, lots of mechanical constructions are present, which have not been elaborately designed. I did this to prevent limitations on the concept from a technical perspective in favor of the interaction and concept of adaptivity. This is a rather radical innovation after all, since physical adaptive interfaces are scarce.

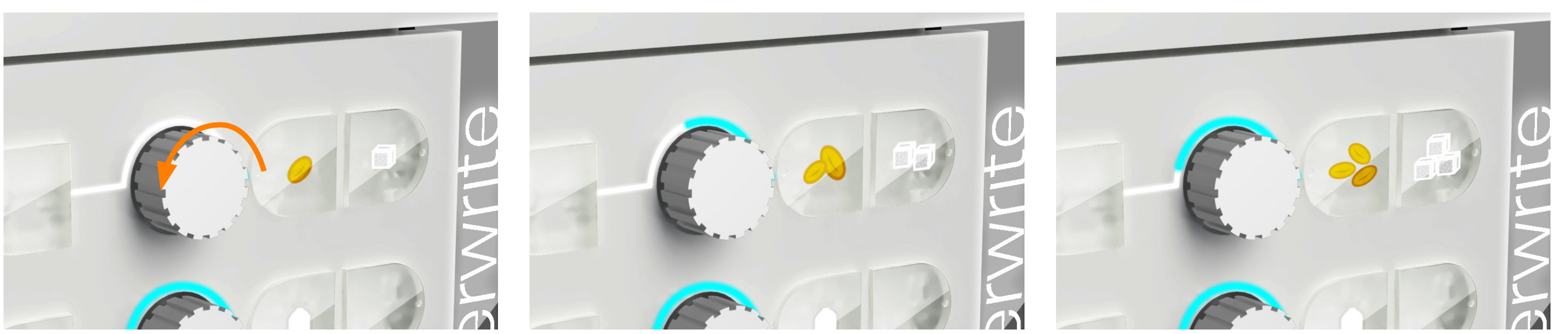


figure 26: *The progression of augmented feedback from the LED ring and icons shows the value of each parameter.*

Discussion

Exploratory approach

The approach and process of this project are opposite to those of prior projects where the focus was on the resulting product and the interface was a means for designing a great product. In this case, I started from the interface and designed the product to match that interface more or less. This opened me up to new perspectives and approaches to designing products, though I feel like this works best for an exploratory application only and does not necessarily yield a great product design, since the product is matched with the interface instead of the other way around.

Emergent controls

The design of Apto has revealed different approaches to adaptive interfaces implementing physical elements. I think the final concept is the most interesting, because it not only adapts pre-determined parameters but also creates new ones by combining parameters. Although still in its infancy, the emerging control parameters show high potential for the future of adaptive interfaces, especially in a growing systems context. The emerging control parameters could be matched with emergent functionality for example.

Problem space reflected in iterations

One of the problems with flexible and dynamic interfaces found in IoT devices, as explain at the beginning of this report, is the lack of physical elements and reliance on cognition. What is striking, is that this phenomenon is also present in this project. The first iteration adapts the least, but is most physical, whereas the third iteration employs the most digital elements and is also the most adaptive.

States of adaptivity

Looking back on the initial proposal of this project, the goal was to explore and design the “journey” from the default, starting state towards the highly personalized state. Ultimately, the journey and the personalized state became separate modules on the interface. The journey being the parameter mapping on the control panel, reflecting use patterns which are not generalizable into one configuration, and the display showing the pre-sets, which are the result of reoccurring similar or predicted configurations. This is an interesting result for designing adaptive interfaces focused on personalization. It allows the user to access the pre-set itself but also directly offers the opportunity to modify the pre-set, in case the personalization is flawed.

Limitations

Part of this project is the implementation of Rich interaction (Frens, 2006). Rich interaction is a tangible approach to interaction. However, due to the Corona crisis and the resulting quarantine, tangible interaction could not be implemented optimally. Even though the concept of the machine employs physical action possibilities, the way they are communicated is digitally. The prototypes used for testing and exploring, e.g. the video and interactive Processing sketch, are also digital. Lots of modalities are left untouched by interacting through digital manners only.

Another consequence of the quarantine is lower quality of user testing. As described above, tangible elements simply could not be evaluated and long term -and real use in a household could not be explored.

A limitation of each of the three iterations is the rigid set of technical parameters. The interface is limited to adapting based on those parameters. Therefore, for such an interface to be most flexible, many technical parameters need to be included. However, the effect is, for each interface, an extremely complex default state. An interesting point to further explore would be to start with combinations of technical parameters, which could be rearranged. The challenge is determining what those combinations should be to be meaningful, and how a changing combination is communicated to the user.

Conclusion

The main challenge of this project was to design an adaptive interface employing meaningful interaction in the context of IoT systems. This challenge is created in collaboration with Bureau Moeilijke Dingen. What makes this project relevant to them is the combination of machine learning, adaptivity and physical interaction elements, which are topics related to a variety of their projects. I doubt whether they will ever make a coffee machine, though there are some lessons to be learned from this project, which can be really valuable for application within projects related to either of these topics.

A predictable result is that the adaptiveness of the interface is affected by the balance between physical and digital elements. By implementing frameworks like Rich interaction (Frens, 2006) and the frogger framework (Wensveen, et al., 2004), physical elements are more meaningful and related to more of our human skills (Frens, 2006; Wensveen, et al., 2004). This not only creates a more intuitive and usable interaction, but also allows for a more aesthetic interaction (Frens, 2006).
Regarding the domain of connected systems and the solutions towards designing for growth, adaptive interfaces show potential as well. Frens (2017) proposes four approaches to design for embodied and Rich interaction in growing IoT systems: a hybrid, modular, shape changing and service approach. The adaptive interface could also fit within these approaches. It relates to both the shape changing and hybrid approach.

This project highlights some of the potential of physical adaptive interfaces beyond shape changing interfaces, by balancing digital and physical elements. Depending on the application, I think each of the three interfaces shows high potential. The first iteration works as an intelligent filter, while also offering quick selection possibilities (the pre-sets). The second iteration is more applicable for a situation where relevancy of controls differs over scenarios and there is limited space. Thanks to the specificity levels, many functions can be mapped, without needing a separate control for each of them. The final iteration shows most potential for situations that are very dynamic and where optimal mapping is unpredictable, as it allows for mapping relationships between controls.

Personal reflection

Approach

For this project I challenged myself with the requirement of designing an interface that's both meaningful and flexible, two properties that don't blend well. In terms of the concept, this project started from a much more defined topic than I did in prior projects. Usually, I spend the first few days or weeks on exploring a much broader topic.

The concrete design challenge had as benefit a more specific design space. Therefore, I didn't need to explore the broader topic first. However, because I only started exploring this topic after the challenge was defined, I found it more difficult to find a valuable application of this interface for a coffee machine. In practise, I think it is better to use an adaptive interface as a means to an end and not an end in itself, unless the end is exploration of the possibilities like this project.

Furthermore, I struggled with defining what "adaptive" meant for my design. After a while of iterating on varying definitions, I realized that especially this was a major part of the challenge. Finding a way an interface employing physical action possibilities was still able to adapt. In this project, I explored three different adaptive mechanisms: changing behaviour of controls, offering personalized pre-sets and changing function mapping of controls.

Looking back on my approach, I could have planned it better. This would have prevented me from losing track of my goal. I did focus on three main topics divided over three iterations, but instead of figuring these out "on the go", it would have been better to plan this beforehand. By first defining sub-topics regarding the adaptive mechanism and exploring them by implementing Rich interaction on smaller parts of the machine. This brings me by the scale of my iterations.

Scale of iterations

The scale of my iterations was quite elaborate. Though I did build these up out of smaller increments as illustrated in iteration two. The problem I ran into by trying to create the whole machine at once, was that there were too many uncertainties. Focusing on more specific parts of the machine would've decreased the number of variables and made it easier to explore and test MVPs (PDP goal 3). Instead, I spend weeks on designing the machine as a whole, losing time by getting stuck because some parts didn't work well together. The reason I did this was because I had a hard time identifying where to compromise on. Setting more concrete goals and making a planning to achieve them would have eliminated most of these difficulties.

After finishing the first iteration, I had a "base" design. It didn't do well on all aspects but included everything I needed to keep in mind. From there I started iteratively improving smaller parts of the design (iteration two). I let literature and user tests be my guideline (PDP goal 4). By doing so, I made much quicker decisions and learned much faster (PDP goal 3).

An ideation approach I only scarcely applied in my process was low-fi (experience) prototyping. The effort of making a prototype with other techniques (CAD, programming, video) seemed too high to use without certainty, resulting in lots of over-thinking, or as with sketching, the prototype cannot be experienced and lacks details about the interaction making it too shallow to make a decision based on such prototypes. The couple of experience prototypes I made using office supplies and interaction relabelling (Djajadiningrat, Gaver & Frens, 2000) (see figure 27), and paper only cost me a few minutes but allowed me to identify strengths and weaknesses of the concept I was exploring. I find it (almost) impossible to capture such a flow completely in my mind.

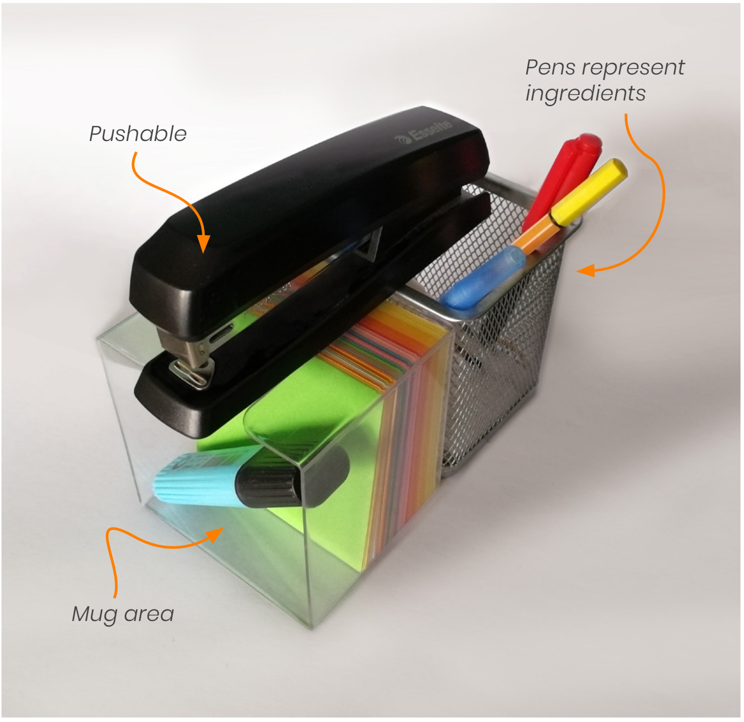


figure 27: *Prototype made with office supplies for exploring interesting interactions and the use flow.*

Prototyping

During this semester I learned new prototyping techniques due to limited access to materials and tools. I became more acquainted with digital prototyping, including video prototypes (especially animations), CAD modeling and 2D prototyping using Processing/Java. This makes it possible to design online user tests for distant and/or high-quantity testing amongst others (PDP goal 2 & 3). I also turned to the low-fi prototyping techniques of paper prototyping and experience prototyping by means of interaction relabeling (Djajadiningrat, et al., 2000), which will replace or accompany sketching in future, especially exploratory, design activities.

PDP goals

As implicitly described in my process and explicitly highlighted in the paragraphs above, I did achieve most goals defined in my PDP in this project. The first goal however (design and implement an algorithm) was not achieved in my FBP. I have two reasons for this. Firstly, focusing on the implementation of the algorithm was out of the scope of the assignment from Bureau Moeilijke Dingen. That's why I only briefly described how it works. Secondly, I followed a course on this topic where I did in fact design and implement multiple learning algorithms (a binary -and multi-class support vector classifier, K-nearest neighbors classifier and a kernel support vector classifier to be precise). Additionally, I realized that the algorithm required to make this interface work is more complex that I anticipated, as it probably involves neural networks, which were only briefly touched upon in the course I took.

Individual vs teamwork

Before the quarantine, I spend many hours a week working on campus. Working, discussing and critiquing ideas with other people helps me seeing a broader perspective and solution domain. What's more, prior projects were all team-based (including a large part of my internship).

The lack of discussion made it difficult for me to see the bigger picture. I didn't zoom out of my own process enough, which in a team is less likely to happen. As a result, I kept focusing on specifics that could've been irrelevant had I taken a high perspective and critical view sooner.

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Figure 4 (centre): Rancilio Classe 5 USB. By Rancilio Group (2019). Retrievd from https://www.ranciliogroup.com/rancilio/classe-5/classe-5-usb/

Figure 4 (right): Segafredo Dr. Coffee F11. By Segafredo (2018). Retrieved from https://www.segafredo.com.au/product/dr-coffee-f11/

Appendix

Appendix A - PDP

Personal Development Plan

B3.2

REVISED VERSION

Rick van Schie
1234438

22/04/2020

professional identity

I am a user-centred designer.

I don't design for me alone, that's why I try to understand and empathize with the people I am designing for. I really value the insights and experiences I get from user studies and use them as inspiration in my process. A product shouldn't be designed in a vacuum. They need to address user needs and behaviour, as users are inherently present in interaction.

I am a visual thinker.

I think, explore and express myself visually by means of sketches and models. They too are a source of inspiration and at the same time, force me to think about some of the details already. This clarifies the scope of the design space for me. I like to explore a wide variety of ideas before settling on one.

I strive for structure and clarity.

It helps me to create overview in complexity and it gives me a sense of control. I often visualize and order my process and ideas to strengthen my understanding of it. As a result of my structural attitude, I find unclarity and ambiguity to be extremely frustrating.

I prefer simplicity and focus.

I do not like redundant or excessively specific functionality. I'd rather have a product that does one thing extremely well, instead of multiple things poorly. The latter discards all meaningful elements in favour of (multi-) functionality resulting in an overly complex product, which I don't need (nor want). I don't want a speaker that can make phone calls, and I don't want a lamp that can charge my phone. Hence my interest towards intuitive and simple (interactive) products.

I am curious and self-directed.

Improving knowledge and skills are often my main driving forces. I have the ambition to do the best I possibly can, meaning I want to learn and apply a great variety of knowledge and skills into my designs. I want to be able to call myself a "full-stack designer" one day and I think having a varying set of knowledge and skills in one brain really helps in seeing the bigger picture.

I value honesty.

I take instructions seriously and I don't like to be misinformed. This goes for both social interaction as well as product interaction. Products that aren't clear or pretend to be more than they are frustrate me. I value products that reliably do what they promise you to do.

professional vision

problem statement

Modern interactive products completely overwhelm us with features. As a consequence, the core purpose and all meaningful links to that function vanish; Changing the volume of the TV has become a cognitively heavy task of finding the correct remote and button instead of changing the volume, i.e. the interaction is not linked to the function [1].

This switch in attention is not necessary nor desired. The remote is stuffed with redundant features that are hardly ever used, making it unnecessary complex and have a poor usability and usefulness. At the same time, it causes a lot of frustration and therefore a bad user experience. I feel there is a need for more intuitive interaction in everyday interactive products.

Design allows for the enhancement of the core purpose of a product by creating balance between usability (matching cognitive, perceptual-motor and emotional abilities of the user [2]), usefulness (ability of the device to solve the problem at hand) and desirability (demands and needs of the user/society). It's the role of the designer to find this balance and to solve problems most users don't perceive anymore due to habituation [3].

There needs to be more focus on the design of (sub-)functions that support the core purpose of a product in a meaningful way and not merely extent functionality without a useful or desired purpose. This is in line with van Campenhout's call for single-purpose devices [4]. A product is a tool that should help the user accomplish a task and it should help to do that task extremely well. Not try to solve other unrelated tasks or making it more difficult to use that product to solve the task.

approach

I try to achieve this using two approaches. First, implementing simplicity [5], that is, stripping all that is unnecessary and directing focus to the most essential interaction elements of that state. This is achieved by feedforward and feedback [2] which answers questions like: what can I do? How can I do that? And what happened?

Too many products with a simple core functionality are deteriorated because of “featuritis” [6]. There is no attention for the experience or meaning of the interaction, for efficiency and multi-functionality have a higher priority [1 & 4]. This means the interaction is no longer in favour of the core purpose, but rather efficiency and multi-functionality. Consequently, the interaction is decoupled from its function, making the controls more ambiguous and the interaction less intuitive. Their feedback and feedforward rely on no human capabilities other than cognition [2]; there is nothing left to perceive, only to know [7]. This unnecessarily increases complexity and frustration. It is those products that need more simple designs. The cognitive load needs to be limited to the unconscious visceral -and behaviour level, as defined by Norman [6]. These to levels of cognition are reliant on their context of use, which is inherently meaningful [7]. Hence, my second approach.

Secondly is creating a more meaningful coupling between interaction and function, allowing the user to perceive, rather than know, action possibilities [7] and their possible results [1]. This can be achieved by implementing aspects of Rich interaction [1], embodied interaction [7] and the Third Stand [4], by exploiting physical elements for their ability to address all human skills [1 & 2], while balancing this with the flexibility of digital elements [1 & 4] and the meaning extracted from the context of use [7]. A close coupling creates a meaningful relation [4] and makes it possible to seamlessly integrate controls into daily life to create a better user experience, not merely based on efficiency, effectivity and multi-functionality.

goals

Design and implement an (learning) algorithm to explore and communicate the effect of input data on the interface after the mapping has been designed and before the deployment period.

Create an aesthetically ~~high-quality~~ and 80% functional digital (online) prototype, ~~including looks and feeling,~~ to demonstrate at the demo day and use for user testing, using new digital realization ~~by using a combination of new and known materials and manufacturing~~ techniques that fit the context of use and improve overall quality of the product.

Make more rapid decisions to prevent getting stuck during the design process as a result of lacking information, by shortening time spend on thinking and increasing time spend on making and testing Minimum Viable Products, as opposed to former projects.

Actively learn and apply literature to include more scientific reasoning as opposed to my own intuition, feedback or user research to form a more complete and grounded set of arguments during the complete design process.

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Appendix B - Coffee machine analysis

This document includes an analysis and description of different coffee machines. The coffee machines are analysed based on their general purpose, offered controls and interaction.

There is a large variety of the amount of control a user has over the configuration of their coffee with each machine. The Dolce Gusto (Krups, n.d.), Senseo (Philips, n.d.) and Nespresso (Nespresso, n.d.) coffee makers, for example, offer different flavours in terms of cups, pads or capsules, while the Segafredo coffee machine (Segafredo Zanetti Australia Pty Ltd., 2019) offers pre-sets instead. The pre-sets can even be modified. Going a step further, you will find the De'longhi (De'Longhi, n.d.) and Rancilio (Rancilio Group, 2020) machines, which offer more direct and tangible control over (technical) parameters. The downside is the increasing complexity of using such machines and no pre-sets for getting a quick or easy coffee. However, one might argue that these machines, especially the Rancilio, are more focused on the holistic experience of making the coffee, rather than just drinking it.

Gina (Percival, 2019): A smart coffee brewer, which automatically brews the user's favourite coffee using tips and recipes it gets through a mobile app. All control is indirect and based on external inputs like recipes and app settings.

- Control over:
    - App recipes and settings

KRUPS Dolce Gusto Genio (Krups, n.d.): Uses cups with (part of) coffee of hot chocolate. For some options, like cappuccino, separate cups are needed for coffee and milk. Focus in this design is on efficiency and ease of use while offering a variety of, but limited flavours.

- Control over:
    - Amount of added water, only weakening the coffee
    - Selection of (limited) cups.
    - Option (not control) for hot or cold drinks.

Filter coffee: using a (paper) filter to separate dissolved coffee from the residue. Focus is on ease of use and larger uniform batches.

- Control over:
    - Amount (strength) of the coffee
    - Brand of coffee. (separate from the device)
    - Grind is limited to what filter is used.

Segafredo Dr. coffee F11 (Segafredo Zanetti Australia Pty Ltd., 2019)**:** Coffee machine including a set of pre-sets with the possibility to adapt those pre-sets to a limited amount. Control via a touchscreen GUI.

- Control over:
    - Option of (limited) pre-set
    - Strength
    - Amount of sugar
    - Amount of milk (in coffee only)

Aeropress Go (AeroPress, Inc., 2020): Small coffee machine without using steam. Uses lower temperature and shorter filtering times to improve flavour. You manually press the coffee through the filter. Focus is on efficiency and ease of use.

- Control over:
  - Amount of coffee (strength), (separate from the device)
  - Amount of water, (separate from the device)
  - Speed of filtering,
  - Temperature, (separate from the device)
  - Brand of coffee and (separate from the device)
  - Grind of the coffee. (separate from the device)

De'longhi Magnifica (De'Longi, n.d.): Freshly grinded coffee beans machine with more manual control. Skills are more important. Focus more on experience and user control.

- Control over:
  - Kind of coffee (beans). (separate from the device)
  - Strength of coffee.
  - Manually froth the milk for making a cappuccino or latte macchiato.
  - Temperature
  - Amount of coffee (not directly control over water).

Philips Senseo (Philips, n.d.)**:** Makes coffee using pads. Pads are placed in a pad holder for one or two pads.

- Control over:
  - Binary amount of coffee (1 or 2 cups)
  - Selection of (limited) pads
  - Binary selection of strength (single or double press makes large mild or small strong coffee)

Nespresso MAGIMIX M195 CitiZ&Milk (Nespresso, n.d.): Uses Nespresso capsules to make coffee. There is a separate milk frother included to create cappuccino or latte macchiato. This works automatically, and just needs to be poured into the coffee. Focus on ease of use and semi-control.

- Control over:
  - Selection of (limited) capsules
  - Binary control over amount of water added, indirectly strength (lungo & espresso)
  - Option (no manual control) for frothed milk
  - Amount of added frothed milk

Rancilio Classe 5 USB 1 Gr (Rancilio Group, 2020.)**:** Complete user control, is based on skill and focuses on the experience of setting coffee, instead of drinking the coffee alone.

- Control over:
  - Amount of coffee
  - Grind of coffee
  - Amount of water
  - Frothing of milk (manually)
  - Amount of milk

From the coffee machine analysis, two axes can be identified to categorize these machines on. One is the interaction style, from indirect to direct and the second is the amount of control (see figure A1). It seems like more control over direct (technical) parameters results in more complex machine like the Rancilio, while indirect control over (control) parameters results in less complex machines like the Segafredo machine, which offers one-action (press a pre-set) interaction possibilities. Also, the Segafredo machine can easily update the pre-sets a result of the touchscreen display, while adding features is hardly possible for the more physical Rancilio machine.

Figure A1: Coffee machine mapping on control axes

Appendix C - Modes of progression

Detailed description of modes of progression

The interface changes based on discrete steps; *modes of progression*. Within each mode of progression there can be little changes, but the mode itself is not adapted until a certain confidence threshold is met. The identified modes of progression are described below.

Full user control - default:

This is the default state, where the system learns from all the inputs. The user has control over each separate technical parameter. He is expected to know or try out combinations of these. The system has no influence on the interface yet.

Suggesting – behaviour change:

By means of haptic and/or visual feedback, hints are given to the users, indicating their expected configurations. A vibration indicates the setting's most probable value, and LEDs indicate what controls are most commonly selected. This allows for some nuance, when, for example, more values have a high probability, more ranges can be indicated by a vibration or LED.

Rearrange – change mapping:

The interface has changed in arrangement. Inconsistently used controls are larger and positioned in a way they allow for modification. These control inputs are still needed to grow the confidence of the algorithm. Controls that haven't changed often, or a lot, are located in the background, though still accessible.

Automatic suggestion – pre-set with controls:

As a result of setting the parameters to your liking, the machine automatically fills in the parameters, but still allows modification. If no changes are necessary, the user can immediately dispense his preferred beverage.

Re-organize – change layout:

Once the algorithm has a high enough confidence, the interface can reorganize its elements. Some elements are removed, some are grouped under one use parameter and some change from continuous to discrete controls.

Pre-set – pre-set without controls:

The interface changes even further than just re-organizing. It shows pre-sets that can be modified. The controls, however, are no longer present by default.

The last mode would be automation, however, it's excluded, since then the interaction would completely disappear. Control would be no longer in the hands of the user which is not what this design is aiming for. Automation comes with a lot of issues regarding growing and adapting contexts (Yang & Newman, 2013). New or changing needs won't be recognized correctly (Yang & Newman, 2013). Besides, it would feel like all the other modes are part of the machine's learning curve towards automation. This is not the goal.

Appendix D - ERB formal approval with enclosure

Ethical Review Form

(Version 27.06.2019)

This Ethical Review Form should be completed for every research study that involves human participants or personally identifiable data and should be submitted before potential participants are approached to take part in the research study.

Part 1: General Study Information

1	Project title	Final Bachelor Project - Rick van Schie
2	Researcher	R. van Schie
3	Email researcher	r.w.v.schie@student.tue.nl
4	Supervisor(s)	dr. ir. J.W. Frens
5	Faculty/department	Industrial Design
6	Research location	Eindhoven (online)
7	Research period (start/end date)	15/04/2020 – 22/04/2020
8	Funding agency	-
9	[If Applicable] Study is part of an educational course with code:	DFP003
10	[If Applicable] Proposal already approved by external Ethical Review Board: Add name, date of approval, and contact details of the ERB	-
11	Short description of the research question	Validation of assumptions regarding meaningful interaction and use patterns in coffee consumption
12	Description of the research method	Survey Design and usability test.
13	Description of the research population, exclusion criteria	Participants are selected and approached through and online platform: User data-ing.
14	Description of the measurements and/or stimuli/treatments	Participants will answer questions about their way of consuming coffee. With the data, use patterns will be identified. Additionally, participants will match a function with a control (action) on a proposed coffee machine. Strong and weak action-function pairs are identified.
15	Number of participants	30 +
16	Explain why the research is socially important. What benefits and harm to society may result from the study?	The validation of the assumptions provides real data to base assumptions on, which make the design of the coffee machine in terms of functionality, behavior and its interaction a better fit for the users. There are no harms to society as a result of this study.
17	Provide a brief statement of the risks you expect for the participants or others involved in the research or educational activity and explain. Take into consideration any personal data you may gather and privacy issues.	There will be no physical contact. The personal data that is collected will be regarding one's understanding and habits, preferences and needs regarding coffee consumption. The personal data is in not linked to any real individual, at most a (not real) profile will be extracted from the data in order to find a reoccurring profile or use pattern.

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Ethical Review Form

Part 2: Checklist for Minimal Risk

		Yes	No
1	Does the study involve participants who are particularly vulnerable or unable to give informed consent? (e.g. children, people with learning difficulties, patients, people receiving counselling, people living in care or nursing homes, people recruited through self-help groups)		x
2	Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children or own students)?		x
3	Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g. covert observation of people in non-public places)		x
4	Will the study involve actively deceiving the participants? (e.g. will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study)		x
5	Will the study involve discussion or collection of personal data? (e.g. name, address, phone number, email address, IP address, BSN number, location data) or will the study collect and store videos, pictures, or other identifiable data of human subjects?[1]. Please check the FAQ's on the intranet. If yes: please follow the procedure. Make sure you perform a Data Protection Impact Assessment (DPIA) and make a Data Management Plan if necessary and let the data steward check it.		x
6	Will participants be asked to discuss or report sexual experiences, religion, alcohol or drug use, or suicidal thoughts, or other topics that are highly personal or intimate?		x
7	Will participating in the research be burdensome? (e.g. requiring participants to wear a device 24/7 for several weeks, to fill in questionnaires for hours, to travel long distances to a research location, to be interviewed multiple times)?		x
8	May the research procedure cause harm or discomfort to the participant in any way? (e.g. causing pain or more than mild discomfort, stress, anxiety or by administering drinks, foods, drugs)		x
9	Will blood or other (bio)samples be obtained from participants (e.g. also external imaging of the body)?		x
10	Will financial inducement (other than reasonable expenses and compensation for time) be offered to participants?		x
11	Will the experiment involve the use of physical devices that are not 'CE' certified?		x

Important:
If you answered all questions with ''no'', you can skip parts 3 - 4 and go directly to part 5. Check which documents you need to enclose and continue with signature and submission.

Ethical Review Form

If you answered one or more questions with “yes”, please continue with parts 3 – 5.		
Part 3: Study Procedures and Sample Size Justification		
1	Elaborate on all boxes answered with “yes” in part 2. Describe how you safeguard any potential risk for the research participant.	
2	Describe and justify the number of participants you need for this research or educational activity. Also justify the number of observations you need, taking into account the risks and benefits	

Part 4: Data and Privacy Statement		
1	Explain whether your data are completely anonymous, or if they will be de-identified (pseudonymized or anonymized) and explain how	
2	Who will have access to the data?	
3	Will you store personal information that will allow participants to be identified from their data? See VSNU draft.	☑ No ☐ Yes, and I declare I will follow the general data protection regulation (GDPR).
4	Will you share de-identified data (e.g., upon publication in a public repository)?	☑ No ☐ Yes, and I will inform participants about how their data will be shared, and ask consent to share their data. I will, to the best of my knowledge and ability, make sure the data do not contain information that can identify participants.

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Ethical Review Form

Part 5: Closures and Signatures		
1	Enclosures (tick if applicable): ☐ Informed consent form; ☐ Informed consent form for other agencies when the research is conducted at a location (such as a school); ☒ Text used for ads (to find participants); ☐ Text used for debriefings; ☐ Approval other research ethics committee; ☐ Any other information which might be relevant for decision making by ERB; ☐ Data Protection Impact Assessment checked by the privacy officer ☐ Data Management Plan checked by a data steward	
2	Signature(s) Signature(s) of researcher(s) [signature] Date: 13/04/2020 Signature research supervisor (if applicable) [signature] Date: 14/4/2020	

Text used for ads (to find participants)

This document contains the description used on the User Data-ing platform used to reach participants.

Name of the study: Adaptive interaction in coffee consumption

Target audience: Anyone who drinks coffee

Topic: Interaction with coffee machines

Short description: This research is part of an FBP project about adaptive interfaces. This study validates assumptions about use patterns in coffee consumption (habits, preferences and needs) and tests the clarity of the controls used to alter the settings of the coffee machine.

Type of study: Survey and usability test (using online video prototype)

Language: Dutch & English

Time required: 10 minutes

Expiration date: 22/04/2020

Cover image:

Consent checkbox content in questionnaire:

By checking the checkbox below, you agree and consent to using your answers to the questions in this study for the purpose of this study. This concerns identifying use patterns in coffee consumption, testing the clarity of controls and function as arguments for further improvements on the design. No identifiable data will be recorded.

[] I agree to participate in the study, and I consent to having my data used and stored for the purposes described in this study.

Appendix E - Use pattern validation

Use patterns of users in coffee consumption

This document contains the set of (semi-open) questions used for the questionnaire to validate assumptions about the use patterns in coffee consumption.

The general assumption is that a single user has varying preferences for a set of scenarios which may change over time. This gives additional value to an adaptive interface, as changing needs are supported.

Additional information about more profound patterns can be extracted too. This means besides the *what*, also *why* changes in use patterns occur. This data can be used to improve the adaptive behaviour of the interface, so it better matches the needs and preferences of the users. This is achieved by building a (set of) profile(s) that match the given answers to get a better description of a character based on a real person, i.e. a persona.

Questions

The following 8 questions are meant to gain insight into patterns regarding drinking coffee. These include preferences and habits, and how these may change over time. Multiple answers may be given, since more than one place, time or preference, for example, may apply.

1. How often do you drink coffee?
2. When during the day do you drink coffee?
3. Why do you drink coffee?
4. How do you get/make coffee? (e.g. select a pre-set from a machine, order it, get it from a shared coffee can, etc...)
5. How do you prefer your coffee(s)?
6. How do your preferences vary over time?
7. Where do you drink coffee?
8. Why do you drink coffee there?

Results

The number of respondents was 15. This means the results cannot easily be generalized. Nevertheless, the results are results from the real world rather than assumed behaviour deviated from the (made up) characters of the DIGSIM house. The results from the test do not permanently exclude ideas, they just help to guide the next iteration.

<u>Question 1</u> can be divided into three categories of average coffee consumption: drinks coffee occasionally (< 1 cup per day) (4/15), drinks coffee regularly (1/2 cups per day) (9/15) and drinks coffee often (> 2 cups per day) (2/15).

<u>Question 2</u> clarifies that almost all (13/15) respondents often drink their coffee in the morning. Also, the afternoon and evening are regularly specifically mentioned answers (6/15). This implies coffee is consumed based on a discrete period of the day, like morning, during a break or after work. It is part of a routine and therefore patterns should be very well identifiable.

<u>Question 3</u> is answered with only two separate reasons to drink coffee. Though a bit unspecific, people like the taste (11/15) or the drink it to get an energy/concentration boost (10/15).

Question 4 doesn't show a clear connection between the reason to drink coffee and the way coffee is made. The (rejected) hypothesis here would be to get a boost, people get the quickest coffee there is, and for the taste, people take more effort.

What does become clear is that most people use a machine that allows to use pre-sets (10/15). The remaining responses are either mixing it yourself (like a cafetière or cappuccino powder, e.g.) or completely brewing or configuring the machine from scratch.

Question 5 gives two pieces of information. The most frequent coffee preferences amongst the sample of participants, and how many preferences an individual could have.

The most common preference is black (9/15). The rest of the preferences vary between with milk, sugar, milk and sugar. Some responses show less "simple" configurations like foamy, with hazelnut, with caramel, cappuccino or even iced coffee (7/15).

What's more, most respondents gave one preference (11/15). Two answered with two preferences (2/15), and the remaining two gave 4+ answers (2/15).

Question 6 identifies how preferences change. This question relates to a problem often seen with learning, where after the learning period, a device does not well support later changes in preferences or users (Yang & Newman, 2013; Funk, et al., 2018).

Three types of answers are given to this question: preferences don't change (5/14), they change periodically during the day (morning, afternoon, evening) or week (working days or weekend) (4/14), or they have changed over the period of their lifetime (6/14). The remaining respondent did not understand the question.

Question 7 is used to determine the context in which coffee is consumed. As this product is designed to be used in a smart home, it is relevant to known how much coffee is actually consumed in the home.

Every single participant indicated to drink coffee at home (15/15). Next to that, work/school are often mentioned (11/15). These two results are not unexpected, as they comprise the two locations people spend most of their days. A third location worth mentioning is cafés and restaurants (4/15).

Question 8 lastly indicates the rationale behind the location of consumption. What stands out is the number of people that drink coffee at home because they want to get a boost in the morning and coffee usually goes in combination with the rest of breakfast (6/15). That means, most of the coffee is consumed at home as part of a morning routine. Others indicate they drink it on the work floor to boost concentration (6/15).

Conclusion

Most people in this study indicate to drink coffee because they like the taste or they need a boost (or both). They get their coffee from a machine using pre-sets or by mixing simple configurations, and drink it mostly at home as part of their breakfast or at work to start with that boost. That being said, drinking coffee fits most people's morning routine, and sometimes plays a more present role in people's daily lives.

The number of preferences is limited, and most respondents indicate to drink their coffee black, or add simple ingredients like sugar and milk. This suggests that with simple configurations, most people will be satisfied. To include the preference of all potential users, a whole set of more complex methods, ingredients and configurations is required.

Often used methods are choosing a pre-set, or, for simple configurations, a method of simply mixing ingredients like a cafetière or instant coffee. This implies that, for more complex configurations a pre-set can be offered, and for simple configurations like coffee, milk and sugar, individual controls will suffice. To adapt pre-sets, an additional panel can be offered which displays the configuration of the pre-set together with controls to change the config. In other words, the complex configurations do not need to be prominently present, but can be hidden, though not removed, as there is still a need for those configs.

By default, the configurations can be downloaded from the internet, and these can be changed to match the modifications over time or instantly by forcing a change. This option is essential when offering adapting pre-sets, since these pre-sets are not often used. It would take too long to actually adapt well.

The categorized changes in preferences each have different design implications for the interface. The first (no change) doesn't require adaption after the learning period. The second category (periodic changes over the day or week) is, just like the fist, "learnable" as changes occur pattern-wise, although it will take longer to identify more complex the patterns.

Lastly is the third category (changes over the period of their lifetime), which cannot be predicted and thus controls are needed to be able to adjust the behaviour of the interface. These controls can also be used for exceptions and forcing on one of the first two categories. This happens for example when a new user is introduced or when a new preference is born.

Appendix F - Meaningful coupling validation

Meaningfulness of couplings

This document contains the setup results of the multiple-choice test to assess the meaningful quality of the couplings between action and function. The couplings are designed to be meaningful by employing Rich and embodied interaction (Frens, 2006; Dourish, 2001). The test has two versions:

1. Match a function with the correct (numbered) action-possibility.
2. Match an action-possibility with the correct (numbered) function.

The results will clarify which interactions are clearly understood and which need to be adapted to better suit the intuitive character of this design. A follow up test can then help determine how to best modify the flawed interactions.

The to-be-tested interactions are listed below. Each action-possibility (control) will be uniquely numbered in a picture of the design and is accompanied by a brief animation to show some of the visual feedback.

Interactions

- Turning on the machine
- Changing pre-set
- Pouring the beverage
- Activating a dial
- Changing coffee grind
- Changing coffee strength
- Changing temperature
- Froth milk

Version 1 – function to action

This section tests the clarity of controls on the adaptive interface is tested. There are two sub-sections in which a function has to be matched with a control (or more generally speaking, an action-possibility), and in which a control has to be matched with a function. For the following questions, you may select the same answer more than once.

Select the letter (the action) that:
**select more than one answer if you think more may apply*

- Turns on the machine
- Changes the pre-set
- Pours the coffee
- Activates a dial
- Changes the grind of the coffee
- Changes strength of coffee
- Changes the temperature
- Froths the milk

Version 2 – action to function

Select the function that is achieved by the (animated) action:
**you may select the same answer more than once*

- Turning on the machine
- Changing the pre-set
- Pouring the coffee
- Activating a dial
- Changing the grind of the coffee
- Changing the strength of the coffee
- Changing the temperature
- Frothing the milk

Results

For both versions, there are 15 responses. This means for the results to be significant, a very strong trend has to be visible. What's more, the results are used to gain insight into the quality and function as a guide for the next iteration.

Version 1 – match function to action

- Turning on the machine is either expected to happen by placing a cup (7/15) or pressing the pre-set control (6/15).

- Changing pre-set is expected to happen by either turning the temperature ring (6/15) or the pre-set control (8/15).

- Pouring the coffee is far from clear based on the annotated picture. Even though most respondents expect the correct control (5/15), a lot of alternatives were chosen as well. The second most expected action is the temperature ring (4/15). Together this adds up to 9/15 respondents who think pouring the coffee happens around the display, which is in fact correct. The third most chosen action is placing the cup (3/15). The remaining answers were spread over the remaining actions.

- Activating a dial has received varying expectations. It is clear it is not related to placing a cup (0/15). The correct action has been chosen by most people (4/15), though as this number is quite small, it suggests this action is not clearly communicated. This can be due to the fact this action is unexpected on a coffee machine. For some reason, 12/15 people think twisting a dial or ring activates the dial. Perhaps the question wasn't clear, or twisting is a more reasonable action.

- Changing the grind of the coffee has a varying expectation too. Changing the grind has been chosen by 4/15 respondents, changing temperature also 4/15, but most people thought changing the coffee strength (7/15). It is correctly linked to coffee, but the specific part of its functionality is missing expressivity.

- Changing coffee strength has been assigned correctly by 8/15 respondents. Another 5/15 people thought it would be by activating the coffee dial. The dial is in fact correct, but the action not. Then 3/15 respondents assigned it to changing the pre-set.

- Temperature is correctly assigned by 7/15 participants. The other reoccurring answer is the pre-set control (4/15). These are very closely mapped and look almost identical. However, from discussion with some of the participants it became clear that this option was only clear due to the limited number of options. Temperature just did not fit anywhere else.

- Frothing the milk is correctly assigned by 9/15 respondents. The quantity control of the milk is next with 5 guesses in total. Though for this function the same argument as for temperature can be made. It just doesn't fit anywhere else.

Version 2 – matching action to function

- Most respondents thought the shown action activated a dial (6/15), which is correct. 4/15 respondents thought the machine was turned on this way. Another 5/15 respondents answered with a function that dial could have. This suggest the question was misunderstood by these people.

- 10/15 respondents matched the action of changing coffee strength correctly. 2/15 respondents thought it changed the pre-set, which in a way, it does. The question was not well formulated here.

- The next action is turning the pre-set control. 5/10 respondents thought this was changing the pre-set. 6/10 thought it changed the grind of the coffee. Again, this is not wrong, as changing a pre-set does affect the grind of the coffee. This also goes for the 2/15 respondents who matched it with changing the coffee strength or frothing of the milk. All the answers given are based on changing the ingredients.

- 15/15 participants guessed pushing down on the pre-set control pours the coffee. This was to be expected, as the actual coffee flow is seen.

- The action of placing a cup is also successfully matched with turning on the machine (10/15). 2/15 participants thought this activated a dial, which it does. This was another ambiguous question.

- Twisting the dial on the coffee reservoir was correctly matched by 9/15 participants. 5/15 matched it with changing the coffee strength, which is not odd, as there is no further distinction possible that expresses grind or strength. A probable cause of this incorrect assignment is the ambiguity of strength and amount of coffee.

- By twisting the same dial on the milk reservoir, this misconception is not made weirdly enough. 14/15 reactions match it with frothing the milk. No one thinks it changes the amount of milk.

- Rotating the lower ring on the machine is correctly matched with temperature control (6/15), followed by the grind of the coffee (4/15). The latter is not weird, as grind, strength and amount of coffee are functions that can be mapped, while there are only two action possibilities for the coffee. That leaves the unassigned ring for on of the three. In fact, there is a misconception in conceptual model regarding the three functions, as there are only two: amount of coffee (called strength) and grind. A second cause could be the idea that the grind is a central feature of a coffee machine, which needs a central place on the interface. In fact, coffee strength is assigned to this ring too (1/15). 2/15 respondents match the ring with changing pre-set. This was to be expected too, as long as per-sets are conceptually linked to the display. The display is namely in between the pre-set control and the temperature ring.

Conclusion

For these tests it should be noted that the limitations on the results and therefore this conclusion is threefold. Firstly, the test was only conducted with 15 participants, which is not much. Next is the compromises that had to be taken due to online testing. The resulting prototype does not convey the same amount of expressiveness as a real functioning prototype would. Third, due to the way the tests are set-up, all possible actions and functions were already given. This could be a hint for a participant when in reality they could also have guesses a function or action that doesn't exist.

The pre-set control is expected to change the coffee strength, which is not weird. It is a main action-possibility, and when making coffee, the strength could be expected to play a central role (which it doesn't do here). The same seems true for the coffee grind, which is expected at a central location too.

Maybe the most often used controls should in fact have a more central mapping, as this is apparently where they are expected. For specific controls is searched beyond the common controls based on these results.

Questions that showed animated feedback were answered more convincingly, though not always correctly. This suggests the digital prototype is inherently less clear as it misses some feedforward and feedback modalities. Besides, it cannot be explored in this setup. For future testing, a more elaborate prototype is required that allows for exploration and more feedback possibilities.

The question about pouring the coffee does confirms this by illustrating the importance of feedback. Matching the function of pouring the coffee with the correct action (version 1) was not clear at all, while matching the action with a function (version 2) was clear for all 15 participants.

There was a misunderstanding regarding the conceptual model of people. This conceptual model needs to be expressed more clearly in the action possibilities in order to lift uncertainties, i.e. changing the amount of coffee and the strength of coffee are different things, though in the current interface, the strength of the coffee is technically changed, while the amount of coffee is visually changed on the display. This mismatch in combination with a lack of expressivity of the controls, makes the interface very ambiguous and difficult to use.

Another point that raised problems was the lack of distinction between common, specific and new controls. The conceptual model of users is not well acquainted with those specific controls and not familiar at all with the new (adaptive) controls.

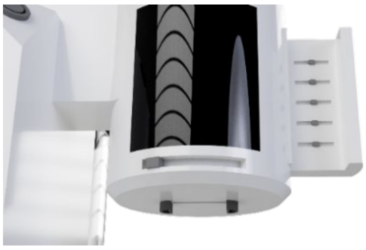
One way to better express the function of an action possibility is to map the action closer to the feedforward and feedback. The display was mismatched multiple times with the temperature ring below it, instead of the pre-set control above it.

Appendix G - Detailed documentation iteration 2

This document describes the process of the second iteration is more detail.

Iteration 2.1 – common physical controls

Another part of the user test was meant to get an idea about the use patterns of people who drink coffee. A couple of reoccurring configurations were highlighted, using a rather limited set of just three parameters: coffee strength, amount of milk and amount of sugar. This is reflected in the second iteration.

Action possibilities

The three controls are spatially mapped to the containers which they affect. From top to bottom: coffee (beans), sugar, milk. Behind the machine is a large water tank, so multiple portions can be acquired without the necessity to refill compartments.

The selection handle on top can be pushed, rotated and slid across. By doing so, you switch from pre-set mode to control mode. The controls will turn on and allow to tweak the most commonly used parameters. In pre-set mode, the small array of sliders allows to more precisely modify a pre-set.

Flexibility vs Rich interaction

The limited set of common controls allow for direct mapping to the containers they are linked to. This improves their expressivity. However, the controls themselves do not express any function explicitly. The coffee strength dial (top) becomes darker when rotated, implying stronger coffee. The other two dials express even less. Their meaning is based on the experience the user has with dials and increasing quantities, i.e. cognition.

The limited set of controls is also not very flexible. Despite their generic form and interaction, they cannot be linked to other functions in a logical way and can't change shape or location either. The solution for this is shown in the array of sliders next to the display. These are spatially mapped to the content on the display, but they themselves do not express anything.

This iteration can be improved by adding more expressiveness to the controls and/or making the interface more flexible and open to change.

Iteration 2.2 – modular control panel

Action possibilities

The following design employs a set of modular control panels which can be customized by the user and ordered via a service approach. The array of sliders to more specifically modify a pre-set is removed and incorporated in the choice of controls for the control panel.

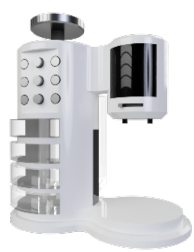
Flexibility vs Rich interaction

Since the user is free to choose whatever controls they prefer, they link meaning to those controls and therefore make them more intuitive to use, though this is limited to their own understanding of expressivity. To make this interface suitable for a whole family, multiple control panels can be added to the interface. They can be browsed by turning the selection handle on top of the control panels.

Adaptivity

The big problem with this design is with respect to adaptivity, since the user adapts the interface manually instead of the machine. The power of connectivity and machine learning is lost in this design.

Iteration 2.3 – generic control panel



Action possibilities

The next design makes use of a generic set of controls in order to give the adaptive interface some room to work with. No final couplings have been established between action possibilities and functions. This is what defines the adaptive behaviour in this design; the mapping of functions.

The selection handle on top is used to select an input mode (pre-set or control) and selection of a specific item of that mode. For pre-set mode this means browsing through pre-sets and for control mode this means selecting the “level”, i.e. specificity of the offered controls. A control that is mapped to a function then rises from the array, allowing for interaction since it can be grasped. The mapped function is spatially mapped on the display, i.e. the top-middle dial's function is shown at the top-middle on the display.

Flexibility vs Rich interaction

The generic array of dials allows for flexible behaviour but in return the expressiveness and meaningfulness of the dials fade away. More cognitive load is put on the user, since they have to link each function with a dial by comparing the display with the array of dials. Additionally, the selection handle can be pushed down to pour a drink in control mode as well, which does not make sense, as this action is no longer spatially aligned with the pouring nozzles and is therefore decoupled from that function. This therefore creates an ambiguous situation which is to be prevented.

Another problem with this design is that there is no sensible way to distinguish between a temporary modification, which is used for training the machine, and a permanent modification, i.e. overwrite the current selected pre-set. This distinction often lacks in such machine learning powered interfaces like the Nest for example, and ultimately results abandonment of the intelligent behaviour (Yang & Newman, 2013). Therefore, it is considered essential to support separation of temporary and permanent changes.

Adaptivity

In addition to the modifications of pre-sets, this interface adapts the offered controls to the way pre-sets are usually modified, i.e. it adapts the parameter hierarchy. The most commonly changed parameters are mapped to the control panel and are linked to their function via the display. When a modification occurs that is similar to an already existing pre-set, this will be communicated to the user by adding a haptic "bump" in the rotation. This prevents a user form modifying a pre-set to his likings, when there is already a pre-set with a similar configuration present.

Iteration 2.4 – separated temporal and permanent changes

Action possibilities

In an attempt to keep the coupling of the selection handle and pouring a drink logical, the selection handle is fixed and the display -and control panel themselves can be moved. This way, the action of pouring a drink (pushing down) is directionally and spatially aligned with the function of pouring a drink, which is depicted by functional feedback of fluid coming out of the nozzles (Wensveen, et al., 2004). By moving an input mode in between the selection handle and the nozzles, you select that mode.

Flexibility vs Rich interaction

According to Wensveen, et al. (2004), the alignment in combination with the feedback and feedforward, provided by the handle, input module (display or control panel) and nozzles, makes the interaction more intuitive.

This interface design, however, does not solve the ambiguity between input modes when pouring a drink. It is still unclear if something -and what will happen when the drink is poured from the pre-set or control input mode.

Another issue with this setup is the ambiguity of the generic array of controls. Due to the rotation of the input mode modules (display and control panel), the controls seem decoupled form the display. Additionally, the controls themselves don't express any specific functionality.

Iteration 2.5 – coupled controls and display

The changes made in order to couple the (feedback on) the display to the generic array of controls while also coupling the action to the function of pouring are embodied by the next iteration.

Action possibilities

This design employs a control panel that folds out from the side, so it aligns next to the display. By doing so, the control panel is activated, and pre-sets can be modified. To overwrite a pre-set, the user can push the control panel into the pre-set module, which represents the memory of the system. Overwriting a pre-set can be reversed by pulling the control panel back, literary reversing the function by reversing the action. The latest change in configuration is then "pulled out" of the pre-set module.

Flexibility vs Rich interaction

Since the control panel cannot be located underneath the selection handle, there will be no more ambiguity about the function of the pushing action to pour a drink. The way a pre-set is overwritten is inspired by the "Labelless" Rich interaction camera of Frens (2006) for which the display is pushed into the memory card in order to save a photo. The major difference is in the expressivity of the memory (card), which is implicit in for the coffee machine.

Since the selection handle can no longer be linked to the control panel, there is in this design no meaningful way to change the specificity of the controls that are offered. Also, the flexibility of the controls is at the expense of their expressivity. Their meaning completely relies on cognitive skills of linking the physical controls with functions on the display.

Iteration 2.6 – more expressive -and specific controls

By iteratively improving parts of the design, the major challenges are solved. At this point in the process, the major remaining challenges are offering the possibility to access more specific controls and better express the function of the dials on the control panel.

The way access to specific controls has been given throughout this process, is by offering a set of "control levels" which are ranked from most common to most specific controls. Controls offered in such a level can change based on how often and when they are accessed. As a result, certain parameters will be mapped on a higher or lower level.

Action possibilities

To enable access to the different control levels, the selection dial can be located above the control module again. Rotating it will change the level of specificity. The selection handle cannot be pushed down due to the physical constraint of the height of the module.

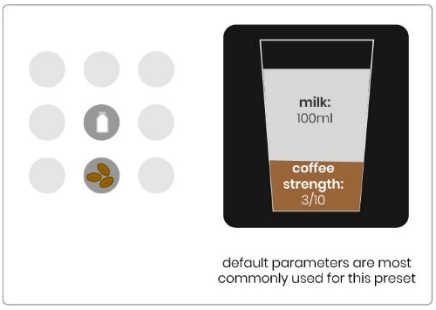
Flexible vs Rich interaction

The physical constraint that blocks the downward movement of the selection dial for the control module is perceivable. The functionality therefore becomes more expressive, as the physical state of the selection handle and constraints communicate action possibilities and the mode of use, i.e. Mode Relevant Action Possibilities (MRAPs) and Mode of Use Reflected by Physical State (MURPS) (Frens, 2006).

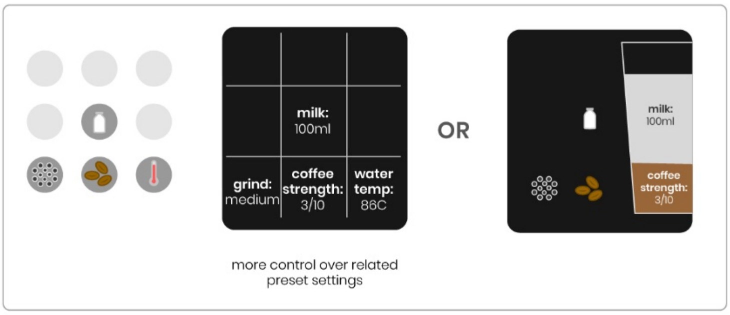
The little protrusion on the left side of the control module signifies and affords pulling and pushing. The action possibility of pushing is even more amplified by the indent on the pre-set module. The control panel will fit inside that indent. The control panel, however, is not in line with the MRAPs from Frens (2006). The panel is always visible, while it actually must only be visible when the selection handle is located on the control module.

The second remaining issue concerns the expressivity of the dials on the control panel. In this design, the individual dials are equipped with a small display. This display shows their function in terms of icons, e.g. coffee strength will be indicated by coffee beans, temperature by a thermometer. This makes the dials closer coupled to their function, while preserving the flexibility required by the way the machine adapts itself (by means of remapping functionality).

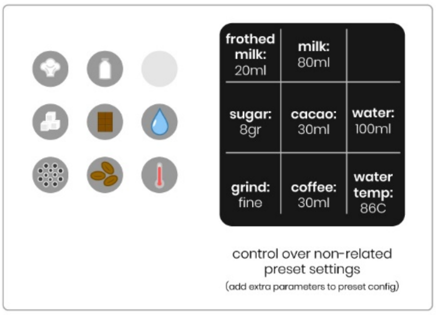
It could be argued that icons are still based on cognition, which is true, but recognition and linking icons to a meaning (i.e. function) is cognitively much heavier than spatial mapping on the separate display (Norman, 2013). What's more, after some exploration of user interfaces of the display, it became clear that the mapped parameters become heavily reliant on cognition once "deeper" levels of parameters need to be accessed. The visual link between controls and resulting configuration transforms to all text in order to fit all the information on the display. Therefore, a different coupling mechanism is required.



control level = 1
preset = “coffee_milk”



control level = 2
preset = “coffee_milk”



control level = 3
preset = “coffee_milk”