ExperimentSuite

a tool enabling the Data-Driven Design Process

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A tool enabling the Data-Driven Design Process

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Abstract

The development of smart connected prototypes is becoming part of the designers' toolbox. These connected prototypes allow collecting data about the way people use them. There is an opportunity to examine how is data collection beneficial already during the design process of a connected product.
The way to test the proposition of a connected prototype is by testing it with users. Therefore, companies setup home placement tests by multidisciplinary teams. The current home placement tests lack a tool that enables real time data collection, and real-time two way communication between the designer team and the participants of the home placement test.
This thesis proposes a home placement test management tool. Twelve main features are made possible by the proposed home placement test management tool during the design process of a connected product. These twelve features are introduced in three related areas. Firstly, it is discussed how the tool improves knowledge transfer between the participants of the home placement test, and among the creators of the home placement test. Secondly, it is discussed what enhancements does data collection and access to data bring to the design process. Thirdly, it is discussed how to design services for inter-connected products.
The findings of this thesis are based on a six months internship at Philips Design. The aim of the internship was creating a home placement test of a connected product that collects data about the product use by the participants. The work presented in this thesis is evaluated and examined based on a case study from the industry.

Keywords: design process, data, knowledge transfer, connected product, home placement test

Preface

In January, 2013 I applied for the EIT Digital Master School, a Europe-wide double degree programme created by the European Institute of Innovation and Technology. I have chosen the major, Service Design and Engineering because I wanted to become a person who does not only have a strong technical background but has a broader view and a solid base to make important decisions while creating digital services. I also had to choose two universities where I wanted to spend my two years of education.
In September, 2013 I arrived to Helsinki, Finland and started to study at Aalto University. This first year was a very unique experience and full of surprises. I found out what innovation and entrepreneurship means, how students can be one of the biggest driving force behind a country's aim to create 200000 jobs in the future, and how my passion and background could be used in an entrepreneurial team.
During the first year of the programme I had the opportunity to travel twice to Berlin to come up with innovative startup ideas, to Vilnius and Tallin to market the master school, to Stockholm to participate in a two weeks summer school about the Internet of Things, to Philadelphia to discover the field of an aging society, and finally to New York to learn how some of the world's best customer experiences can be used in Europe on a trip led by the former US Ambassador to Finland.
In September, 2014 I started to study in the Technical University of Eindhoven. During the second year of my studies I had the opportunity to learn more about the technical background of my field. Moreover, I was introduced to such emerging fields of Computer Science as Data Science. And thanks to my supervisor, Natalia Sidorova I had the opportunity to find an internship at Philips Design.
Working in a design environment is very unique. I am surrounded with people whose mindset helps me creating better working products which are tailored to their needs and they are very happy to use the outcome. Moreover, working in the design headquarter of a big company like Philips, was very unique for me because I was able to meet lot of influential people who sometimes used their precious time to give feedback on my work, which I am really thankful for.
This thesis would not have been possible without the helpful feedback and work of my university supervisor, Natalia Sidorova, my Philips supervisor Eva Deckers, and the team I joined inside Philips Design. I would like to thank them for all their support and help. I would also like to greatly thank the hard work of Janne van Kollenburg, my daily supervisor in Philips, who was always able to help in any matter, and made working on my project a very good experience. Another thanks goes for Sander Bogers, a PhD student from TU/e, who was always (also on weekends and nights) ready to discuss our project. Moreover, I would like to thank Maikel van Eck, another PhD student from TU/e, for giving his valuable feedback on the content of this thesis many times. Last but not least, I would like to thank my parents for all their hard work raising me and providing the best environment for being able to succeed in my life until this point, my brother and sister for keeping me company and experiencing life together, my grandparents for all their support and sharing their experiences, and my friends from all the continents of the world for entertaining me. A last special thank you goes out for Berkay Buharali, my friend who studied in the same programme, worked on the same project as me, joined me for several trips inside and outside The Netherlands, and happily listened to even the tiniest features that I developed for this thesis.

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Chapter 1

Introduction

1.1 Problem

“The designer's toolbox needs to support the rapid development of interactive prototypes to explore product behavior”, says Paul Gardien [8] in the article Changing your Hammer: The Implications of Paradigmatic Innovation for Design Practice. Moreover, these prototypes allow the monitoring and logging of user behavior and product use by data collection. It is possible to use the collected data to gain insights in the behavior of people, and thus creating a new, much better experience for the product.
However, there are different people with very different backgrounds involved in the process of developing a connected product. It greatly differs how a product designer, a data scientist or a person with a background in baby development look at the data collected during a home placement test where a product is given to possible customers.
Furthermore, the members of the multidisciplinary team creating a home placement test might lack the required technical knowledge for analysing the collected data, but they all require the insights that can be extracted from it. During the home placement test of a connected product there are two different kinds of data collected: qualitative and quantitative data.
To sum up, there are different data sources, and different people with different backgrounds who want to use these data sources in different manners. Therefore, there is a need for a service that helps in the organization, visualization, and analysis of all these different data sources to enable people with different backgrounds make the best usage of them and thus let companies develop better experiences for the end customers.

1.2 Research questions

In order to solve the problem defined above, the following three research questions were defined:

- How to improve the knowledge transfer in the design process of a connected product?
  - How to store and organize the collected data?
  - What kind of pre-processing of data is needed?
  - What kind of visualization is needed to help?
- How does data enhance the design process of a connected product?
  - Does data inspire people?
  - In which stages of the design process does data help?
  - Does data help the participants of the home placement test?
- How to design services for inter-connected products?

- Is it possible to simulate the connection between smart products?
- Is it possible to utilize previously collected data for a new research study?

1.3 Background

This thesis is based on my internship at Philips Design. I participated in a project related to a new connected product, a Smart Bottle. During this internship there were two home placement tests related to the Smart Bottle and in both tests the bottle collected data about the behavior of the participants. The aim of my involvement in this project was to help the team behind the project better understand the data collected by the bottle, while finding out how to use the learnings in future home placement tests of connected products.

1.4 Approach

The aim of the Smart Bottle project was to explore what becomes possible if data collection, monitoring and analysis happens from the beginning of the design process of a connected product. Therefore, the project was setup with this aim kept in mind. The expertise of the people required in the team were defined based on the goal of the project. Therefore, it was decided to hire two computer science master students (Berkay Buharali and me) with software development, data mining and process mining background. The involvement of new experts made it possible to setup the home placement test in a way that was not possible in Philips Design before. It was possible to develop a system that contained the tested connected prototype and made real-time data collection, and real-time two-way communication with the participants possible. This thesis introduces the developed system.
uBottle is a baby feeding bottle extended with a smart sleeve. This sleeve contains a small computer that can send data (e.g. temperature of the liquid inside the bottle, position of the bottle, etc.) to a smartphone, which sends the data to a Philips server. A user study involving 9 possible future customers was conducted. During this test feeding data was collected from 9 different smart bottles. This collected data is presented in the ExperimentSuite which was developed as the home placement test management tool for the project and is used as the dashboard for people who are involved in the SmartBottle project. The ExperimentSuite organizes the qualitative and quantitative data collected during the experiment and provides ways to extend the experiment with simulated data and data coming from other sources which was not collected during this experiment. The ExperimentSuite also includes the management of uBottle, and acts as the back-end of a developed mobile application to which the bottle is connected to. Furthermore, it has simulation capabilities. The uBottle project and the developed home placement test management tool helps answering my research questions in the following ways:

- It is used in the development of a connected product
- Based on it, research experiments and interviews with the members of the Smart Bottle team can be conducted
- It is possible to make research on the possible further development of the product

1.5 The structure of this thesis

This thesis proposes a solution to a problem affecting the design process of connected products. The solution is introduced by answering three research questions around three main areas concerning the design process of a connected product. The first main area is the knowledge transfer inside the team developing the connected product and between the team and the possible users testing the connected product. This area is introduced and examined on a general level in Chapter 3, while Chapter 6 analyzes the answers based on the uBottle project.

The second main area is the role of data during the design process of a connected product. This area is introduced and examined on a general level in Chapter 4, while Chapter 7 analyzes the answers based on the uBottle project.
The third main area is about designing inter-connected services. This area is introduced and examined on a general level in Chapter 5, while Chapter 8 analyzes the answers based on the uBottle project. Finally, the conclusions based on the general answers and the findings of the uBottle project are introduced in the last conclusions chapter together with future work regarding the findings of this thesis.

Chapter 2

Preliminaries

2.1 Design process of a connected product

Ian Bach [3], gave a talk in February, 2014 about designing connected products, lean hardware, and the future of discipline that bridges the physical/digital divide. Based on his talk, projects around connected products are interesting from a designer's point of view because there are many different parts that the designers can explore and use as inspiration for their projects. In a general scenario it is not enough to design the connected product itself, but it requires a mobile application, a server to communicate with, a web-based dashboard and an organizational tool for managing the data it produces. At the end of the process all the separated elements together create the product experience. (See figure 2.1). Ian Bach [3] describes the design process in the following

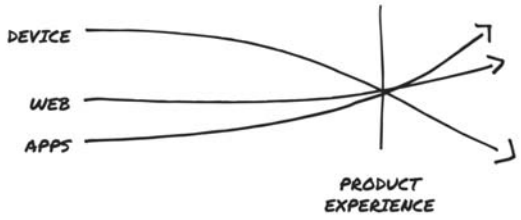

Figure 2.1: Elements of a connected product [3]

way: the designers first sketch a product idea on paper, then they create a prototype fast, test their assumptions regarding the prototype and the product experience, learn from their users and finally repeat the whole process again, until they can get an evidence of a value based proposition that they can deliver to the end-users. Ian Bach has mentioned in his talk that delivering this talk made him realize how close the industrial design world and the digital industry came to each other in the recent years.

2.2 Rapid Co-Creation

Rapid Co-Creation (RCC) [9] is, as introduced in the article of Paul Gardien and Ferdy Gilsing, a workshop method of Philips Design. The aim of the RCC is to help the company's designers collaborate more productively. The RCC is carried out by a multidisciplinary team that consists of

designers, technical, business and organizational experts (project, and product managers). It may also include external partners. The team explores technological and business feasibility around a new proposition of Philips. The duration of the process differs from project to project. It can be a 3-5 day hackathon, but can also take several months to come up with the outcome.

2.3 Home placement test

The Rapid Co-Creation process can contain a home placement test involving users of the tested product. In this case Philips Design provides access to the tested product (device, or service) to the participants of the home placement test. In return, the creators of the home placement test are interested in direct feedback from the users, the potential customers of the product. This feedback can be obtained through live interviews with the participants, through online questionnaires or through the tested product.

2.3.1 Wizard of Oz prototyping

Based on Kranz and Schmidt [11] Wizard of Oz prototyping is a kind of prototype that does not function without someone controlling the prototype itself. In the case of a home placement test this means that the researchers are provided with a Wizard of Oz control center from where it is possible to control the home placement test. This control can be on several levels. It is possible to remotely control connected devices, communicate with participants as if an advanced data analysis existed, while it is done manually, or anything else that is required for testing the offerings of the tested product. Paul Gardien also describes the usage of this technique, in the article Changing your Hammer: The Implications of Paradigmatic Innovation for Design Practice [8], in the section about design methods, tools and techniques. Based on the author this tool is used during the rapid development of experience prototypes.

2.4 Status of the uBottle project in February, 2015

Philips Design wanted to explore the opportunities around a smart baby feeding bottle. The aim of the project was to find out as much as possible about bottle feeding. There was an initiative during the project to start building a connected prototype and collect data as early as the first user test of the proposition. Therefore, the designers involved in the project decided to build a smart bottle prototype. This device was a 3D printed sleeve with an accelerometer, thermometer, and an SD card. The participants were asked to use the sleeve for all feedings, and manually log the details by hand as well. When Berkay Buharali and I joined the project, five participants finished the test and we were presented with their data stored on the SD cards. The cards contained all the feeding data in one file for each participant. Therefore, it was needed to pre-process the data. There was a big challenge that the timestamps were not showing the correct time and date, which made it very hard to separate the feedings from each other. Nevertheless, 183 feedings were separated, and the information gave the team behind the second iteration of the home placement test valuable insights to set the second home placement test up. In the first two months of the thesis the roles of Berkay Buharali and me were decided. The outcome of the decision was that Berkay Buharali will concentrate on the analysis of the data collected during the home placement test. He was developing the analysis motor of the home placement test and using data mining and process mining techniques to turn the collected data into information. My role was the development of the software tools enabling data collection and thus making the second iteration of the home placement test possible. The following chapters of the thesis are based on the second iteration of the uBottle home placement test.

2.5 The multidisciplinary team behind the uBottle project

The team behind the uBottle project consisted of people with different (technological) backgrounds. The findings of this thesis are mostly based on the input from all these different experts:

- Industrial designer: people with industrial design background were responsible for designing a hardware prototype and developing the software of it.
- People researcher: a people researcher is responsible for finding out what people think about the developed product, what value do they see in it.
- UX designer: a UX designer is responsible for the user experience of the prototype, making it as usable as possible for the users.
- Baby educational expert: a person with baby educational background is responsible for creating the educational and coaching content about bottle feeding and parenting in general for the participants of the uBottle test.
- Data expert: during the uBottle experiment the team collected data about the end-user behavior regarding bottle feeding, the task of the people with data background was to find out how to use the collected data, and make it meaningful for the other members of the team.
- Software developer: the people with this expertise were responsible for the software development regarding the system the bottle is connected to.

All the members of the team are referred to in this thesis as either creators of the home placement test, or researchers. In cases when a claim is in regards to a person with a specific background, it is noted to which background it is relevant for.

Chapter 3

Knowledge transfer in the Data Driven Design Process

This chapter is answering the question *How to improve the knowledge transfer in the design process of a connected product?*

3.1 Knowledge transfer

Based on L. Argote and P. Ingram [1] the creation and transfer of knowledge are a basis for competitive advantage in firms. The improvement of knowledge transfer inside a company can account to better flow of knowledge amongst the employees, and can improve the performance how the company works. According to the authors a current problem is that companies identify knowledge as a competitive advantage by itself, instead of trying to come up with new methods to develop, retain and transfer the acquired knowledge.

3.2 Home placement tests in the past

The young designers in Philips Design who carried out on average 2-3 home placement tests in the past described that the following steps were performed usually during these past tests: The designers created a prototype that was given to the participants of the home placement tests. During the whole time of the home placement test there was very limited interaction with the participants. Furthermore, the designers had no access to any collected information during the test. It was not even sure that the tested products were functioning and used by the participants of the home placement tests. In order to analyze the collected data at the end of the test manual work was needed. There was a risk of losing information due to misbehaving prototypes, or unexpected behavior on the participants' side. All in all, there is an opportunity to improve the process of home placement tests, by enhancing the knowledge transfer between the members of the team creating the tests and between the team and the participants.

3.3 Possible home placement tests now

There is an opportunity for a new kind of home placement tests where the data collection is real-time, the designers have access to all the information during the test and the tested products can change their functionality during the home placement test. Furthermore, it is possible to ask the most relevant questions right at the moment when the test is going on and the analysis of the test results does not only happen at the end of the test but already during the test. In order to carry out such a home placement test, there are a number of required developments that are needed to be done from a technological perspective. This new kind of home placement test

requires its own communication environment. In this environment the participants, the creators of the home placement test and the connected devices need to be integrated and have the possibility to communicate with each other. By using this new environment the knowledge transfer will be improved both inside the team creating the home placement test and between the participants and the team.

3.4 Knowledge transfer during the design process of a connected product

The creation of these new kind of home placement tests is part of the design process of a connected product. However, the creation of these tests involves several people with different (technological) backgrounds. These people are all experts of their own field but have limited knowledge of the other members' fields. There are designers, people researchers, people with business background, data experts, developers and other people involved in the process. They all bring different value for the project, and need to be able to understand each other. Moreover, the design process usually involves a testing period when participants of a home placement test generate quantitative and qualitative data by using the connected product. Quantitative data is the kind of data that is generated without the manual involvement of the participants, and qualitative data is the kind of data that is gathered through surveys, interviews, manual questions, observation.
Therefore, the first assumption of this thesis is that there is a need for a tool that can analyze, organize and visualize the data that is collected from different data sources.The second assumption is that using this tool enables better knowledge transfer inside the team creating the connected product, enabling the creation of a better end-user experience.

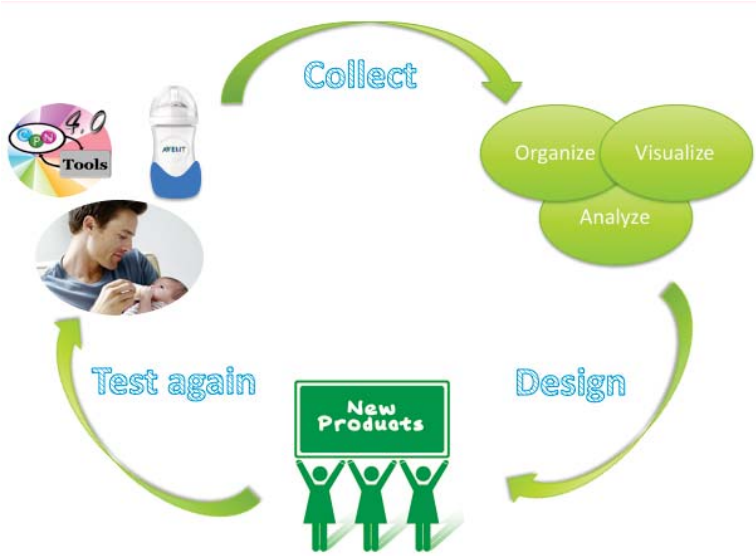

Figure 3.1: The relationship of data and the development of a new connected product

3.5 Insights from creators of previous home placement tests

In order to test these assumptions about the need for the tool described previously, and the fact that there is a need for real-time communication in the home placement test of a connected product, an online questionnaire was created. The online questionnaire was filled in by four people

who participated in the creation of previous home placement test(s). Based on the answers that arrived for the questionnaire, in previous home placement tests none of the respondents collected qualitative data during the tested product was in the participants' home. The respondents said it was not possible to ask triggered questions in previous home placement tests. Nevertheless, in most of the previous home placement tests it was possible to see some kind of visual information about the collected data afterwards. Moreover, the respondents mentioned that real-time communication with the participants of the home placement test is needed and would help a lot compared to previous home placement tests. Therefore, the survey indicates that real-time data collection, and real-time two way communication during the test were missing from previous tests and it is possible to give more access to qualitative and quantitative data during the test. Furthermore, it is needed to have visual information about the collected data.

3.6 System architecture for real-time communication

The creation of a home placement test management tool that is capable of carrying out these new kinds of home placement tests it is required that the following elements are connected with each other:

- Server: a server is essential to enable two-way, real time communication between the participants and the creators of the home placement tests
- Database: the database contains all the collected data of the home placement test
- Communication interface for the participants: the participants get a connected product at the beginning of a home placement test. It is possible to integrate a way of communication through the product itself, in case the product is directly connected to the server, and in case the product does not enable direct connection to the server, an intermediary device needs to be integrated in the system that can communicate with the server of the home placement test (for example a smartphone). In both cases, the devices need to be capable of receiving data from the server as well.
- Communication interface for the creators of the home placement test: the creators of the home placement test need to use a tool that can send messages to the participants and need to be able to access the messages that were sent by the participants to the creators

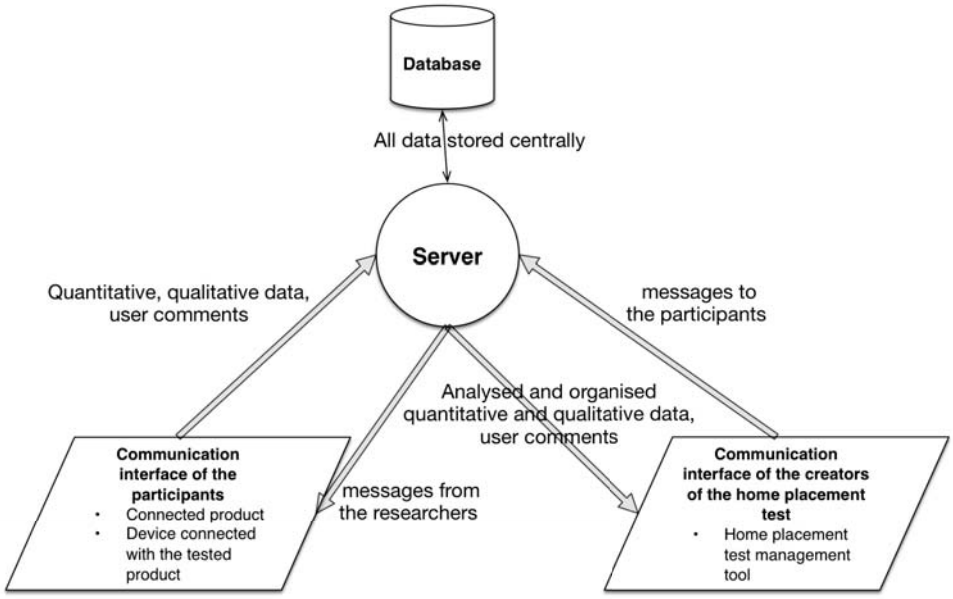

Figure 3.2: System architecture of the new kind of home placement tests

3.7 Home placement test management tool

Based on the interviews with the researchers who created the old kind of home placement tests and the requirements that were defined during the home placement test of Philips Design's uBottle project, a proposed home placement test management tool needs to contain four main elements: organization, visualization, analysis, and communication. Using these four elements the proposed management tool concentrates on enhancing knowledge transfer both internally between the creators of the home placement test (from now on researchers), but externally as well with the participants of the home placement test.

3.7.1 Communication

Whenever a person does not understand something the easiest thing to do is to ask a question and find out the answer. Therefore the creators of the home placement tests would like to be able to communicate with the participants during the time frame of the test and not only at the beginning and at the end of the test. This communication means sharing coaching information with the participants and asking questions as well. Moreover, whenever there is a problem with the tested product during the home placement test, or the participant realizes that he/she has a new idea that would be beneficial to share with the creators of the home placement test communication possibilities are needed as well.
All in all, a two-way communication between the participants and the creators of home placement tests can enable a more successful test because it becomes possible to ask questions right at the moment when a certain event is happening, the participants can get insights and help during the test, and the designers can adapt the test to the feedback and answers of the participants during the test. Communication is the main tool of sharing information among human beings since we started to talk. Therefore, communication is the main element of the knowledge transfer during the design process of a connected product.

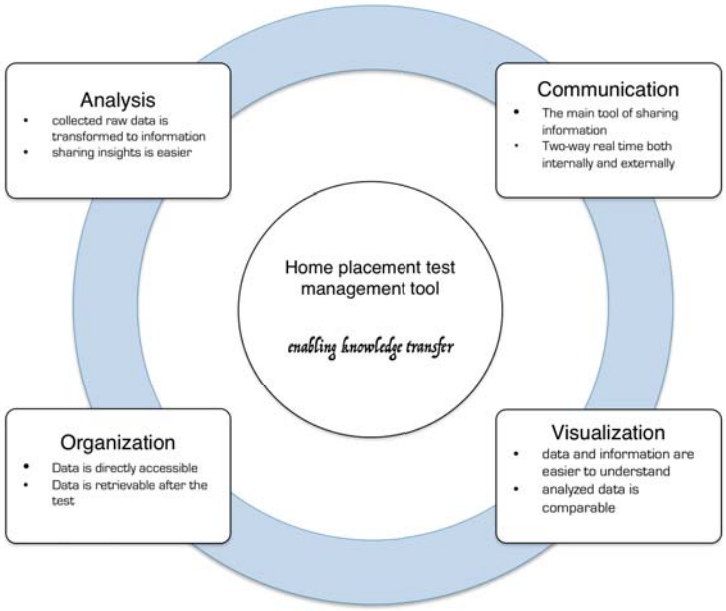

Figure 3.3: Knowledge transfer in the proposed home placement test management tool

3.7.2 Analysis

During the home placement test of a connected product it is possible to collect data from the sensors that were placed inside the connected product. However, all these sensor values provide raw data for the creators of the home placement test. This raw data is really hard to interpret, and do not help the creators of the home placement test to deliver the results that they want to achieve by the creation of the test. Therefore the data needs to be analyzed before it is presented to the researchers. The analysis can be as simple as counting the number of incoming data points, or with the usage of advanced algorithms it can translate the sensor values to human readable values.
All in all, the analysis of the collected information is needed in order to make it possible for the creators of the home placement test to understand the collected raw data. This helps researchers with not so advanced technological backgrounds to understand the collected data without the help of the developers of the connected product. The ability to present analyzed data to the researchers makes the knowledge transfer easier, and more understandable to the researchers.

3.7.3 Organization

During the home placement test of a connected product a significant amount of data is collected and analyzed. Therefore it is essential to organize the collected information and make it accessible for all the creators of the home placement test. The researchers can communicate with the participants of the test during the time frame of the test, therefore providing the needed information is needed as a source for communication with the participants. Furthermore, in the home placement tests now it is possible to ask qualitative questions from the participants at the moment when a certain action happens. In order to understand the answers of the participants the researchers need to have access to the relevant quantitative data as well. Based on the input of creators of previous tests they indicated a need for taking notes about the participants and having access to these notes whenever they want to communicate with the participant.
All in all, the organization of the collected data is needed in a central location in order to make

it accessible for all the creators of the home placement test, to help them interacting with the participants in a more personal way, and to make it possible to retrieve all the information after the end of the home placement test. This central organization makes the knowledge transfer faster and more efficient by giving access to all the creators of the home placement test to the same information.

3.7.4 Visualization

Based on the authors of the book, Readings in information visualization: using vision to think [5], there is a clear relationship between what we see and what we think. They are also quoting the known saying: "A picture is worth thousand words", in the case of abstract data as sensor values coming from a connected product, it is especially important to make it possible to translate the values to a more understandable form. Therefore, a home placement test management tool created for designers needs to contain visualization features as well.
All in all, the visualization of collected data is needed to make the analyzed, and organized data easier to understand for the creators of the home placement tests. The visualization enables the creators to get more insights about the collected sensor data, it is easier to find correlations between different sensor values and different participants as well. Visualization makes the analyzed data easier to understand, and more easily comparable, and thus helps in the knowledge transfer during the design process of a connected product.

3.8 Conclusions

Knowledge transfer is the basis of competitive advantage in firms [1]. This chapter is examining how to improve the knowledge transfer during the design process of a connected product and thus answers the first research question of this thesis. The home placement tests, which can be part of the design process of new products, in the past had more chance to fail because of the lack of real-time data collection, and communication. Nowadays, it became possible to create home placement tests where connected products send user-behavior in real-time to a group of researchers. However, these researchers have different (technological) backgrounds. Luckily, it is possible to create a home placement test management tool that is capable of analyzing, organizing and visualizing the incoming data from the connected product and enables two-way communication between the creators and the participants of the home placement test. Using this tool knowledge transfer between the participants and the creators becomes possible already during the test, while the creators of the home placement test can understand the collected data easier and more efficiently because they do not need to look at raw data but analyzed values which are turned into information. The analyzed data is organized and stored in a central location, that enables a faster way to communicate, and share information with each other. Finally, the analyzed data is translated to visual information that is easier to interpret and helps communication. Chapter 6 introduces the proposed tool in practice based on Philips Design's uBottle project.

Chapter 4

The role of data in the Data Driven Design Process

This chapter answers the second research question of the Master Thesis *How does data enhance the design process of a connected product?*

4.1 Role of data

Based on Michael Palmer [12] "data is the new oil" meaning that it could become the next driving force of the economy. However, the author also mentions that just like oil, if data is unrefined it cannot really be used. Therefore, the collection of sensor values from a connected product in itself does not change the design process, so the role of data has to be further examined. Based on the input from creators of previous home placement tests and my active involvement in the design process of a connected product four main roles of data were determined: enabling status monitoring, creating real-time tests, more iterations testing different value propositions and features of the connected product, and providing new insights into end-user, researcher and product behavior. In order to utilize data for all these roles during the design process of a connected product, a data-driven home placement test management tool is proposed to be developed.

4.1.1 New insights

The creators of the home placement test of a connected product have the aim to understand user behavior better by the collection of data from the participants. As it was introduced in section 3.7.2, the collected sensor values from the connected product are gathered and analyzed by the home placement test management tool. The collected data is then organized (see section 3.7.3), and visualized (see section 3.7.4). As it is presented in these sections these methods already help in the knowledge transfer between the participants and the creators of the home placement test, but as we could see in the blog post of Michael Palmer [12] this data is unrefined and there are methods to make it possible to use them in a more efficient way. As it can be seen in the master thesis of Berkay Buharali [4] data mining and process mining techniques are possible to use in the design process of a connected product. In the thesis it is explained which techniques are most useful, in my thesis I present what was needed to be developed to be able to carry out these techniques.

4.1.2 Status monitoring

Based on the proposed system architecture of a home placement test (see section 3.6 the elements of the system are only accessible for their users. This means that the tested connected product, and potentially another connected device resides in the participants' home, the server is located

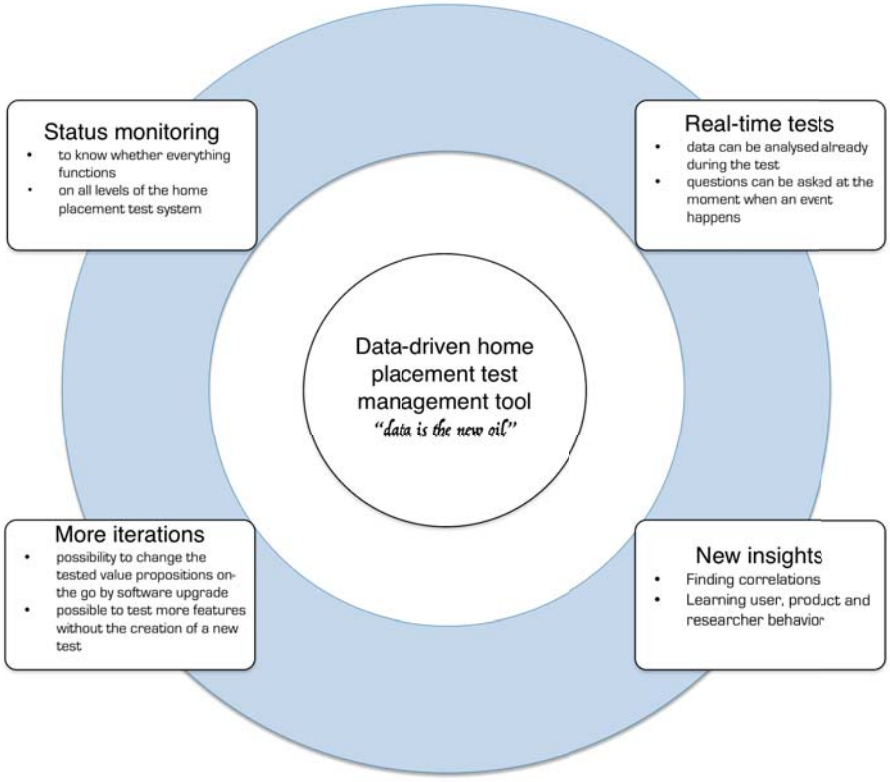

Figure 4.1: The capabilities of a data-driven home placement test management tool

remotely, while the communication interface of the creators of the home placement test runs on the server itself. Moreover, the communication happens through the server of the home placement test. Therefore there is a need to be able to monitor whether the components of the proposed system function properly. The correct functioning of the server is the most important, because this component is the main enabler of the real-time data collection and the real-time two way communication. The second most important thing is to be able to check that the tested connected product functions properly without the need to reach the participant of the home placement test on traditional communication channels and thus bothering him/her. Last, but not least the home placement test management tool running on the server needs to function as well, in order to carry out a successful home placement test.

4.1.3 Real-time home placement tests

Real-time home placement tests mean, that the tested connected product sends the data it collects directly to the creators of the home placement test, where it is analysed right away and presented to the researchers. Furthermore, during these tests real-time two way communication between the participants and the researchers is possible. All of these features are made possible by data collection. The knowledge transfer chapter contains a proposed system architecture for real-time home placement tests, and proposes a home placement test management tool with the most important features based on input from creators of previous home placement tests.

4.1.4 More iterations

Because data collection enables real-time two way communication during the home placement test of a connected product it is possible to increase the number of iterations of the test with one participant, and the number of tested features during the home placement test of the connected product. It is possible to include new features in the software of the connected product that can be remotely enabled during the time frame of the home placement test. Furthermore, it is possible to remotely upgrade the software of the connected product. This enables the possibility of changing the tested features during the time of the home placement test without replacing the connected product itself. Furthermore, it is also possible to change the behavior of the connected product per participant of the test and compare the results with each other.

4.2 Conformance checking

Based on A. Rozinat and W. M. P. van der Aalst [13] conformance checking is a method to give answer for the following question: Is there a good match between the recorded events and the process model? Events are recorded by logging information about a performed event in a process, while models are created by coming up with separate events and the order how these events build up the process. Conformance checking essentially is a check whether the real process (based on the event log) and the process model are aligned properly.
Conformance checking makes it possible to determine whether a process is happening the way the people creating the process model assume it does. This is useful during the home placement test of a connected product because this technique makes it possible to check whether the participants of the home placement test use the tested product as expected. Moreover, it helps coming up with a better value proposition for the product by providing evidence about which features and in which order did the participants used the tested product. Finally, conformance checking allows to find out if a certain event is taking much longer time to carry out than expected, and it helps revealing the cause of these errors.
In order to carry out conformance checking we need to have both a process model and a corresponding event log. Once these two elements are provided it is possible to replay the events in the order they happened and find out how the process differs from the assumptions of the creators of the model.

4.2.1 The enablers of conformance checking in the design process of a connected product

First of all real-time data collection, and two-way communication between the participants and the creators of the home placement test are the main enablers of conformance checking. Moreover, there are two more important actions in order to be able to carry out conformance checking. The creation of event logs and the creation of process models.

Creation of event logs

In order to be able to carry out conformance checking it is essential to create event logs. All the separate elements of a home placement management tool can create separate event logs. At each separate element of the home placement test management tool we need to decide what to log. The main elements of a home placement test management tool as proposed in 3.6 are a server, a database, a communication interface of the participants and a communication interface of the creators. Apart from the database event logs can be created for all other elements of the system.

- Server: the server is the most important element in the system that helps carrying out the home placement test of a connected product. Therefore, it is needed to monitor the status constantly during the time of the home placement test. In order to be able to monitor whether the server functions the following events need to be logged:

  - Whether the server is available
  - The performance of the server (CPU usage, memory usage, etc.)
  - Unexpected behavior (programming exception, unexpected restart, etc.)
  - The output of each server method that is possible to be called, the response of the server, and the time it took to carry out that action

- Connected product, and another potential connected device (from now on smartphone): the logs of the connected product and another potential connected device are needed to be created for two purposes. First of all, it should be possible to determine whether the devices function. Secondly the event logs should allow the creators of the home placement test to find unexpected end-user behavior. In order to be able to carry out these actions the following log events are needed to be recorded:
  - The connected product or the smartphone sent data to the server
  - The connected product or the smartphone received data from the server
  - The smartphone received data from the connected product (only in case a smartphone is needed for the home placement test)
  - The participant of the home placement test started an action that is possible to carry out with the connected product or the smartphone
  - The participant of the home placement finished an action that is possible to carry out with the connected product or the smartphone
- Home placement test management tool: logging the actions of the users of the home placement management tool is needed for two reasons: first of all the created logs enable to test whether the developed tool functions as expected. Secondly, it is possible to analyze and compare the end-user behavior of the users of the home placement test management tool. The following events need to be logged in order to fulfill these functions:
  - When the tool sends/receive data from the server
  - When the user of the tool starts/finishes a possible event

Creating models

In order to carry out conformance checking it is also required to create models. These models explain the user behavior related to the home placement test. The main requirement of creating models is determining the events that are contained in the process. After this step has been done, it is possible to create an order of the events. Based on the order of events the events can be connected with each other to make up the process model. It is also possible to visualize this model, and give a clear overview of the process for the creators of the home placement tests. Moreover, it is possible to create a separate model for all the different parts of a home placement test. It is possible to create a model explaining the behavior of the server, the communication interface of the creators and the communication interface of the participants. The creators of the home placement test are most interested in finding out unexpected end-user behavior, therefore, the most important model to be created is the model explaining the behavior of the participants of the home placement test. However, these models do not need to be created by data experts, an experience flow that the creators are able to come up with and is also possible to use for conformance checking after they have been translated to models that a computer can also understand. The model created by less technical people is usually based on their knowledge of the process. In the past it was only possible to acquire this knowledge through surveys and literature analysis. This means that most of the models are created manually. These manual models are reusable as a base for a next model, but it is relatively hard to change them. However, with the new home placement tests of connected products it is possible to log user actions automatically and there are several software tools that can automatically create process models based on the logged events. In this

case, carrying out conformance checking on both the models created automatically and manually, enhances the design process. More information about this can be found in the thesis of Berkay Buharali [4]

4.3 Conclusions

This chapter is answering the research question: *How does data enhance the design process of a connected product?*. In order to answer this question four main roles of data during the design process of a connected product were examined. The four main roles are: enabling status monitoring, creating real-time tests, more iterations testing different value propositions and features of the connected product, and providing new insights into end-user, researcher and product behavior. The four main roles were examined as features of a data-driven home placement test management tool. Chapter 7 introduces the proposed tool in practice based on Philips Design's uBottle project. Moreover, in this chapter it was shown that conformance checking, a process mining technique, makes it possible to provide the creators of home placement tests of connected products with information if the way the participants of the home placement tests use the tested product does or does not differ from the creators' own assumptions.

Chapter 5

Connecting devices with each other in the Data Driven Design Process

This chapter is answering the question *How to design services for inter-connected products?*

5.1 The Internet of Things

Based on Cisco's [6] prognosis there will be 50 billion connected devices by 2020. These devices will enable general things for their users. For example a person will be able to control his/her coffee maker from the smartphone, or turn on the lights in his house from another continent on Earth. Moreover, many of these devices already exist as consumer products. However, as Kevin Ashton [2] says in his article, That "Internet of Things" thing: "We need to empower computers with their own means of gathering information so they can see, hear and smell the world for themselves". Furthermore, if we are able to achieve this it is also possible to make the devices able to share all the collected values with each other and other connected services. As soon as we are able to do this, it is possible to create a system of inter-connected devices, and that is where the true value of The Internet of Things lies. In this case it is possible to for example connect the coffee machine with the light bulb and thus on a dark winter morning we will be able to wake up to the light bulb acting as the sun in our room and having prepared coffee when we arrive to the kitchen.

5.2 Prototyping tools for inter-connected services

Based on Matthias Kranz and Albrecht Schmidt [11], it has never been easier to build and deploy 'smart' prototypes. They have analyzed the perspectives on prototyping smart connected products both from the software and the hardware perspective. During the home placement test of a connected product it is also possible to use both hardware and software prototyping tools. A new software prototyping tool, an inter-connected home placement test management tool is introduced in the next section. Moreover, this chapter also describes hardware prototyping tools that are useful during the design process of a connected product.

5.3 Inter-connected home placement test management tool

In order to use the full potential of the Internet of Things trend during the home placement test of a connected product, an inter-connected home placement test management tool can be proposed.

The main aim of this tool is to make it possible to prototype or simulate the existence of new connected devices. This way it is possible to come up with rules and scenarios how should the inter-connected devices behave. In order to fulfill the main aim, the following features should be developed inside the tool:

- Direct connection to other devices
- External data sources
- Simulation
- Scenario planning

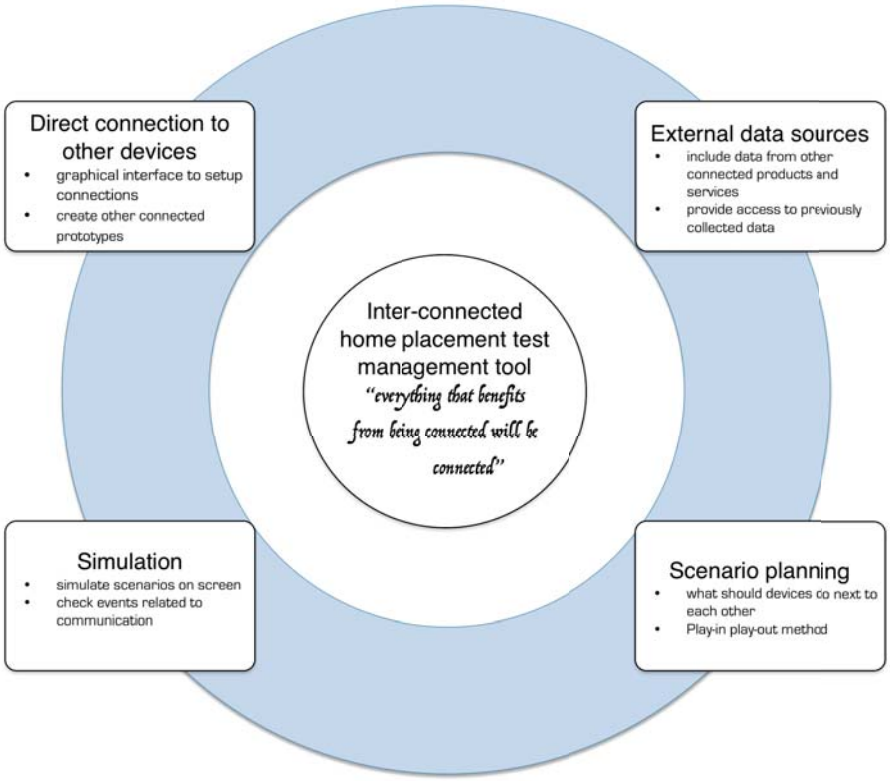

Figure 5.1: Inter-connected home placement test management tool

5.3.1 Direct connection to other devices

Providing the possibility to directly connect the tested connected product to other devices is essential in the proposed home placement test management tool. This enables the creators of the home placement test (from now on researchers) to explore the value the other devices can bring for the tested product, and the participants of the test can also provide feedback on the extended experience. However, this connection can be separated based on the time when it is happening during the home placement test and based on the place of the connection where it is happening. There are three points in time when it is possible to connect a tested connected product with other connected devices during the home placement test:

- Before the beginning of the test: it is possible to test multiple connected products together as part of a home placement test. In this case all the connected products need to have a prototype and the home placement test management tool needs to support all the produced connected devices
- During the test: it is possible to connect the prototype that is tested during the home placement test to other devices that the participant's own
- After the test: the team behind the home placement test can use the data collected during the test as input for simulation and based on the results of these tests the team can design new prototypes that can connect to the tested product

Furthermore, there are two places where the connection can happen between the devices:

- Local communication: the devices communicate with each other using a direct connection to each other or the local network of the participant
- Cloud communication: the devices are connected to the cloud and communicate with the cloud first, and the respective actions happen and are triggered by the cloud itself

All in all, the direct connection and the possibility to integrate the devices inside the newly built system is the main enabler of fulfilling the aim of the inter-connected home placement test management tool. Cloud, and local connection can be enabled before, during and after the test using the tool.

5.3.2 External data sources

Using external data sources can enhance the design process of a connected product. Using this technique it is possible to include data that is not collected by the tested device itself, but can be used directly at the moment when the participant is using the tested connected product. The usage of the external data sources is possible before, during and after the home placement test of the respective product:

- Before the test: in the proposed tool it is possible to integrate collected data from previous home placement tests. Therefore, it is possible to analyze this data in respect to the designed experiment
- During the test: it is possible to look at previously collected, and live external data sources. For example if the researchers want to find out whether the daily activity of a person has an effect on the usage of a connected cooking machine it is possible to provide the participants with an activity tracker, and analyze the incoming data to find correlations from the proposed tool itself
- After the test: it is possible to retrieve the collected the data after the test from tthe proposed tool

5.3.3 Simulation

Using simulation techniques it is possible to achieve the previously mentioned two features without designing and developing other connected products and services. In order to carry out simulation a similar kind of model has to be created as introduced in section 4.2.1. This model can be used for finding insights about the process how people use the tested connected product. Moreover, the same models can be extended with events which at the moment of creation of the model cannot be done with the tested product but it is possible to develop them. Using this technique it is possible to find out the feasibility of the development of these events. The newly created events can be related to other connected products and services, external data sources, or features of the tested product which are planned to be developed in the future. The advantage of using a simulation

technique is that defining these events in a simulation environment is much cheaper and faster than designing a new connected prototype or service. Using simulation can provide valuable insights to decide if creating the new connected product or service can help the end-users or the creators of the home placement test.
Furthermore, it is possible to generate data about end-user behavior instead of collecting it. In this case the generated data is based on the assumptions of the people who created the simulation models. Nevertheless, generating data can help designing inter-connected services, because it is possible to give an early overview about the behavior of an existing system, in case data collected from other connected products and services would be available.
All in all, a developed simulation environment needs to provide an easy-way for the researchers to play around with incoming and outgoing data sources, and potentially trigger device features as well. In case such a tool is available the researchers can find inspiration for new connected products and services without time and development costs.

5.3.4 Scenario planning

Paul J. H. Schoemaker [14] wrote in his article about Scenario Planning: "Among the many tools a manager can use for strategic planning, scenario planning stands out for its ability to capture a whole range of possibilities in rich detail". The same quote is true for the creators of a home placement test who want to design inter-connected services. Using scenario planning they are able to come up with possibilities to connect a tested product or service to other connected products and services in a very convenient way. In order to come up with scenarios first of all they have to use literature, user input and the work of user experience designers and people researchers. However, coming up with the scenarios in a written or a role played form is not beneficial enough for designing a new service. Therefore, the proposed inter-connected home placement test management tool should make it possible to plan scenarios. The main enablers of scenario planning are the previously introduced three features of the proposed tool: direct connection to external devices and services, external data sources and the ability to use simulation techniques. However, these three techniques by themselves do not allow a convenient way of scenario planning. Therefore, the tool needs to contain a drag and drop interface where the creators of the home placement test can visually plan their scenarios.
The tool uses the play-in/play out approach that was introduced in David Harel's article [10]. The approach introduced by the authors, helps a user and a system designer to come up with the functionality of a new system using a graphical tool. This approach is the same as providing the creators of the inter-connected services with a drag and drop visual tool inside the proposed home placement test management tool. During the play-in part it is possible to define use cases of the system. During the play-out part the designers can test these use cases using the tool without having the whole system developed. Nevertheless, this interaction helps the system designers come up with the required architecture, while the designers have a tangible user interface to test and come up with new ideas, realize unaccomplished proposed features, etc.

5.4 Hardware prototyping tools

The following hardware prototyping tools are useful for creating inter-connected services:

- Arduino is an open-source, programmable electronic board. It is possible to connect various kind of sensors to the board and program them to create very interesting products. There are official and Arduino compatible boards but given that the project is open-source anyone can build their Arduino.

- littleBits provides easy to use, electronic building blocks. It is possible to build these pieces together and create a functioning electronic prototype with input and output sensors without extensive knowledge of programming. Littlebits also provides a cloudBit that can help in creating prototypes that are connected to the Internet

- LightBlue Bean is an Arduino that contains a Bluetooth Low Energy chip and thus can communicate with other Bluetooth enabled devices (computers, smartphones, other LightBlue Beans, etc.)
- SparkCore is an Arduino that contains a WiFi chip. This chip enables the device to connect to the cloud developed by the SparkCore team. It is possible to program the device on the interface accessible from the cloud. Furthermore, it is also possible to define functions and variables in the program code. The functions can be remotely triggered, while the variables can be remotely read and written.

Figure 5.2: Light Blue Bean

5.5 Conclusions

This chapter examined the third research question of this thesis: *How to design services for inter-connected products?*. The findings revealed that in order to design services for inter-connected products, it is essential to provide designers with the required software and hardware tools. This chapter introduced a proposed inter-connected home placement test management tool, that helps software prototyping for inter-connected devices. The four main features that the proposed tool is capable of are the following: it provides the possibility to directly connect devices with each other, to include external data sources to be used at any point during the home placement test, to carry out simulations with existing and non-existing devices and data sources, and finally to let designers plan scenarios using a play-in/play-out approach. Moreover, this chapter introduced existing hardware prototyping tools that are able to communicate with each other and can be easily integrated with the proposed software tool. Using all the introduced tools it is possible to come up with inter-connected services. The designers get inspired and are able to use the full potential of the Internet of Things. Chapter 8 evaluates the proposed tool based on Philips Design's uBottle project.

Chapter 6

Knowledge transfer in the uBottle project

This chapter is analyzing the answers of the first research question: *How to improve the knowledge transfer in the design process of a connected product?* based on Philips Design's uBottle project. *Please keep in mind that this chapter is confidential.*

6.1 The uBottle home placement test

The uBottle project, Philips Design's smart baby feeding bottle project2.4, is a good example for the design process of a connected product. The team that created the project consists of people with different backgrounds. There are product designers, people researchers, data experts, educational researchers, and business people. Everyone has a different purpose why the collection of data is important during the project and wants to understand the collected information in a different manner:

- People researchers want to understand the behavior of the users of the connected product.
- Product designers want to create a more functioning, more suitable, improved product experience.
- Educational researchers need to understand the users to be able to provide relevant coaching information.
- Business people are interested in ultimately selling the product and making more money for the company.
- Data experts want to analyze the whole dataset and give relevant insights, correlations to other people. They are also interested in finding out process models to check for unexpected behavior either from a system perspective or from the perspective of the end-user of the product.

The team has decided to implement a home placement test in the same manner how it is explained in section 3.3. Moreover, as I described in section 3.4, there is a need for a tool that can analyze, visualize and organize the collected information. During the uBottle project I developed the first iteration of the ExperimentSuite that is a tool capable of carrying out the desired functionality.

6.2 Enabling real time communication in the uBottle home placement test

In order to achieve real time communication during the home placement test of uBottle, the team needed to come up with a communication scheme that complies with the system architecture explained in section 3.6. There are three main elements of the system:

- Server: running the node.js application containing the API to communicate with the mongoDB database, and the ExperimentSuite
- iOS device: running the uBottle application
- uBottle: running the software that is responsible for collecting data from all the sensors that the bottle contains

The different parts of the system are connected with each other in the following way (see also figure):

- From uBottle to iOS device: The uBottle is connected to the iOS device and they communicate via Bluetooth Low Energy
- From iOS device to the server: The iOS device sends HTTP requests to the application containing the collected data in the body of the request
- From server to the iOS device: The server uses the Apple Push Notification service to deliver content to the iOS devices

This communication scheme complies with the system architecture introduced in section 3.6.

Figure 6.1: The communication scheme from uBottle to the server

Figure 6.2: The communication scheme from the server to the participants' iOS devices

6.3 ExperimentSuite - a home placement test management tool

The overall goal of the ExperimentSuite is to provide a general tool for managing home placement tests of connected products. The tool was developed with the intention of combining three major functionalities (organization, analysis and visualization) while enabling two-way, real-time communication with the participants of the home placement test.

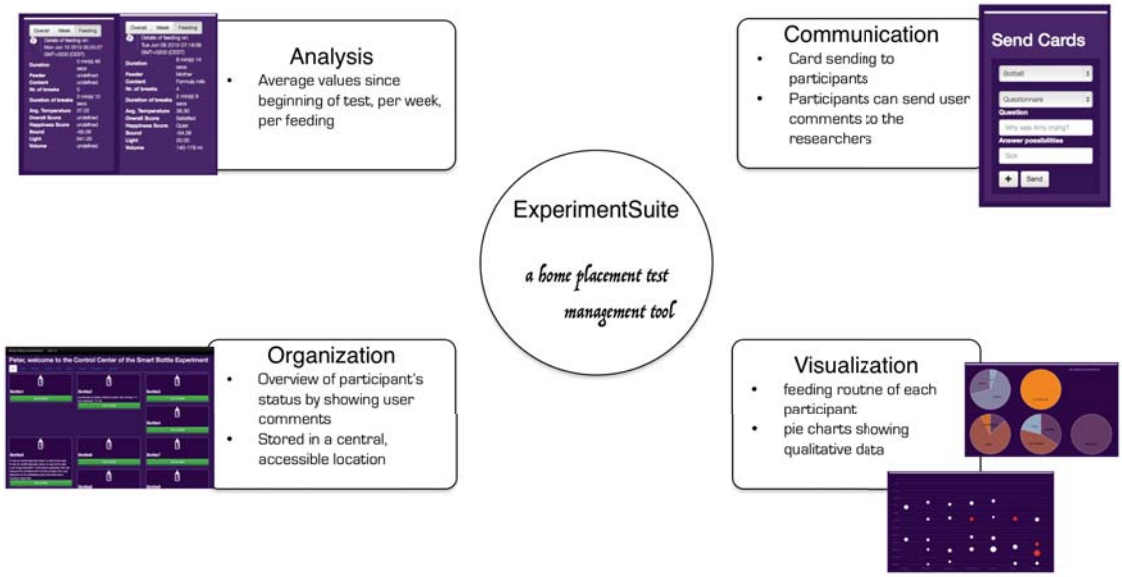

Figure 6.3: ExperimentSuite - the home placement test management tool of the uBottle home placement test

6.3.1 Communication

The ExperimentSuite allows a two-way communication between the researchers and the participants of the home placement test. The participants of the home placement test can send user

comments from the iOS application which are shown in the ExperimentSuite. The researchers are notified about new user comments via email and they can indicate that they read the user comments so other researchers know that someone has already seen the feedback or complaint that arrived from the participant.
The researchers can send content to the participants as well. This content is shown on cards in the iOS application that the participants use. At the beginning of the test the following type of cards were defined:

- Questionnaire card: This type of card allows the researchers to ask questions from the participants. It contains a question and pre-defined answer possibilities from which the participant can choose one. The researchers can also define an "Other" field which the participants can use to give answers that can not be found in the pre-defined list
  An example that can be seen on the screen in figure 6.4, is a questionnaire card asking for the reason of interruptions during the feeding.

- Education card: This type of card helps the researchers to send coaching messages to the participants. It contains a header describing the content of the card, the educational content, reference to the source of the content, an image that is shown in the newsfeed of the participant, and it is possible to define the background color to be shown in the iOS application behind the content of the card.
  An example that can be seen on the screen in figure 6.4, is an education card with the title: "Getting hot?", this card explains the parents what to do in case of hot weather conditions, like during one of the weeks of the home placement test.

- Insight card: This type of card lets the researchers send insights to the data collected about the participant. It contains a header, the description of the insight, the value of the data the researcher wants to give insight, and the unit of the data (for example, the researchers can send out a card containing the average duration of feedings during the week of the home placement test).
  An example that can be seen on the screen in figure 6.4, is an insight card that tells the average number of breaks to one of the participants of the home placement test.

- Half Manual card: This type of card helps the researchers to send out an image of pre-defined size. The image can contain any kind of content that the researcher wants to share with the participant.
  An example that can be seen on the screen in figure 6.4, is a half manual card saying "Cheers" that was sent out after the tenth successful feeding detected by uBottle.

- Half Full Manual card: This type of card is very similar to the half manual card but the researcher can choose what content is shown after the participant clicks on the card in his/her newsfeed. The researchers have two choice for this content, they can create an image that is shown on the full screen of the iOS device, or define an url that is loaded when the participant clicks on the sent out image.
  An example that can be seen on the screen in figure 6.4, is a half full manual card saying "Being creative" that was sent out on another warm day telling parents that it is possible to give breast milk ice lollies to the babies.

Moreover, the ExperimentSuite contains a cardbank. It is possible to see previously sent cards for each participant, and to track whether the participant has already clicked on the card in his/her newsfeed. It is also possible to resend these cards to the same participant or to other participant(s).

6.3.2 Analysis

The iOS devices collect all sensor data from the uBottle but do not analyze this data, instead they send any collected data based on the following logic:

Figure 6.4: Cards sent by the users of the ExperimentSuite

- The uBottle was placed on the charging dock, therefore it triggers that data collection needs to be finished
- The uBottle did not send data for more than 15 minutes to the iOS device

When the data arrives to the server it is stored in the feedings table of the database and the analytics motor is called. This motor is responsible for determining whether the incoming data is a feeding or not. More details about it can be found in the Master Thesis of Berkay Buharali [4]. Once the motor decides that the collected data can be considered as a feeding, it determines the duration, the average temperature, the average light and sound levels, the number of interruptions, the duration of the interruptions and the position of the bottle during the feeding. A new entry in the summaries table of the database is created containing these average values, and we send after feeding questionnaire to the participants of the home placement test. The after feeding questionnaire is asking for who fed the baby, what was the content of the bottle, how was the mood of the baby after the feeding, how was the mood of the parent after the feeding, and finally what was the amount of the food they fed the baby with. After parents answer this questionnaire the analytics motor carries out a more detailed analysis, and if the number of interruptions is over a pre-defined threshold the reasons for this are asked from the participants.

6.3.3 Organization

The data that is collected and analyzed needs to be organized in a central place inside the ExperimentSuite. This way it is possible to give access to the qualitative and quantitative data at the same location for all the creators of the home placement test. The creators have access to all previous communication with the participants, and can take notes about the participants which information they can use to provide better content for the participants and better test their assumptions about the specific participant. It is also possible to find correlations between the parameters of a feed using the collected quantitative data, and finding out what happened at a certain point of a feed using the collected qualitative data. Moreover, it is possible to use the tool for retrieving all the collected data after the end of the test.
In order to make the organization of data possible the following features were developed in the ExperimentSuite:

- Control Center: The Control Center of the ExperimentSuite aims to give an overview about the status of all the participants. Each user of the ExperimentSuite (from now on: researchers) can get an overall overview on all the participants and by selecting their own name, they are also able to see which participants are they responsible for during the test. Due to privacy reasons, the participants are listed by the number of the bottle they got for the test. Below the number of the bottle, the researchers can see all the unread user comments that were sent by the participant. By clicking on the button "Go to bottle" the participants can access the dedicated dashboard of the participant.

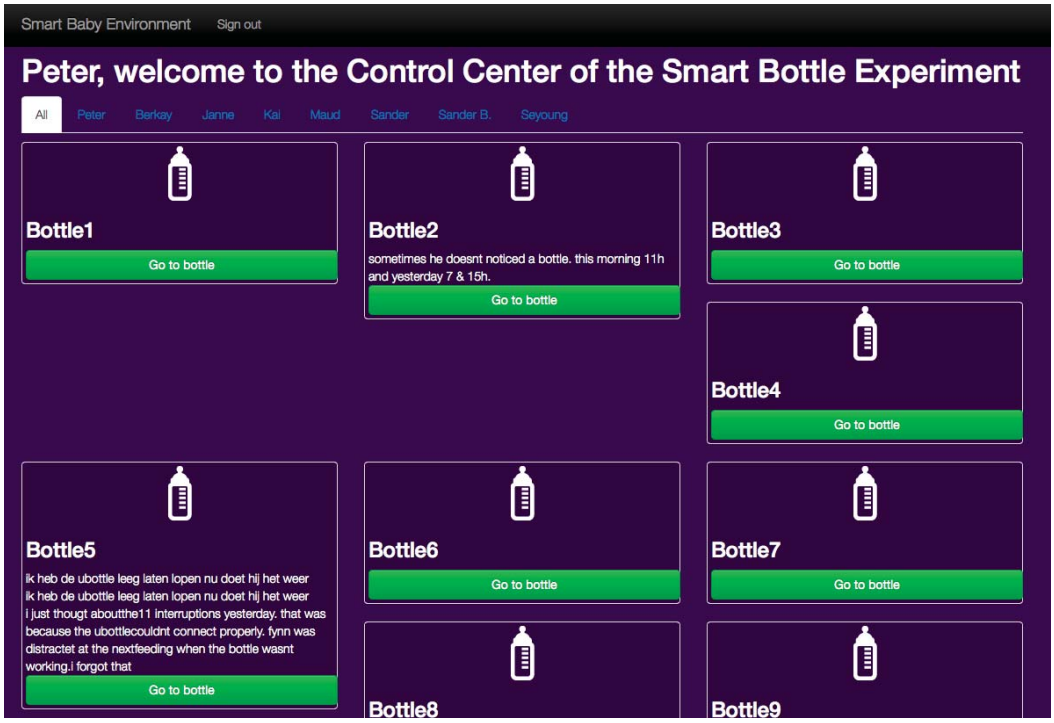

Figure 6.5: The control center of the ExperimentSuite

- Participant Dashboard: The Participant Dashboard is the main communication and learning interface. The whole dashboard can be divided into the following smaller sections regarding the organizational features:
  - Data overview: In this section of the dashboard the researchers can get text based insights about the data collected from the participant. The researchers have the option to look at the overall average values from the beginning of the home placement test, to look at the weekly average values or to gather insights about the data collected per feeding. The quantitative and qualitative data are both shown at the same place
  - Researcher notes: the researchers have the option to take notes about the participant. These notes are saved and can be read and modified by the other researchers as well. It is most useful for having fast access to information that the researchers learnt about the participant during the test and is relevant for communicating with the participant
  - Communicational history: the researchers have access to all the communication that happened between the participant and them during the timeframe of the home placement test

- Access to the collected data using HTTP requests: this feature enables that other tools can also use the collected information by calling the developed methods of the back-end application

6.3.4 Visualization

My initial assumption before the start of the home placement test was that designers who were the main users of the ExperimentSuite understand visual information better than text-based data. Therefore the visualization is one of the most important feature of the ExperimentSuite. There are two kind of graphs integrated inside the ExperimentSuite:

- Feeding routine graph: The graph shows the weekly feeding routine of the participant. The x axis shows the days of the week, and the y axis shows the time of the day. The size of the circles indicates the duration of the feeding. If a circle is red on the graph, the participant did not answer the after feeding questionnaire, and thus the feeding lacks qualitative data. If a circle is magenta, the feeding is selected by the researcher and the respective information is shown in the data overview part of the screen. The graph shows data that was collected during one week, and a box below the graph lets the users change between weeks

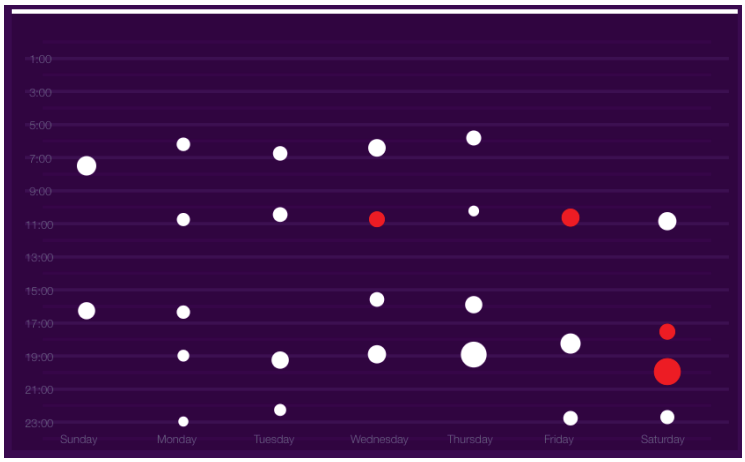

Figure 6.6: The routine graph of a participant

- Overview of qualitative data on pie charts: this graph gives an overview about the collected qualitative data of the participant since the beginning of the home placement test. There are five pie charts which show the answers to the after feeding questions (feeder, content, happiness score, overall score and volume)

At the moment the visualization features provide an overall picture about the feeding routine and the collected qualitative data of the participant. However, other creators of the home placement test developed smarter visualization tools for the researchers, and it is possible to integrate them in the ExperimentSuite.

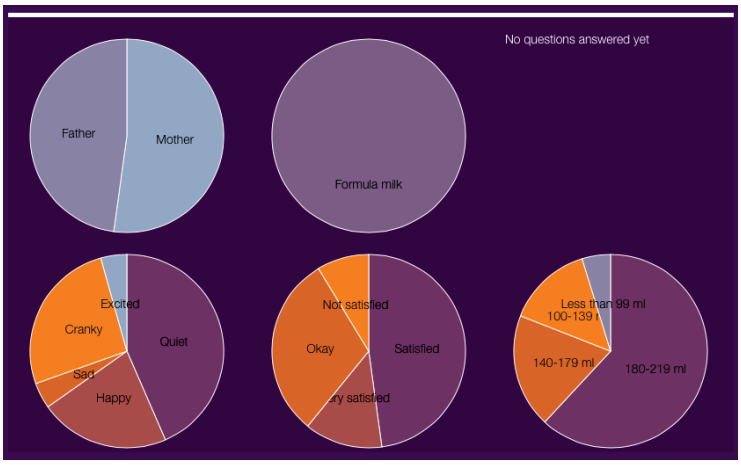

Figure 6.7: Overview of the qualitative data of a participant

6.4 Conclusions

In the chapter about knowledge transfer, a home placement test management tool was proposed to enhance the knowledge transfer during the design process of a connected product. However, the development of such a tool is only possible by making real-time data collection and two-way communication between the participants and the creators of the home placement test possible. This chapter described how we created a system for the uBottle home placement test, where uBottle, the connected product communicated with an iOS device, that communicated with a server, and the server was capable of communicating with the iOS device as well. The chapter described a developed home placement test management tool, the ExperimentSuite that analyzed, organized and visualized the collected sensor values from the uBottle, while it also enabled a two-way communication between the participants and the creators of the uBottle home placement test.

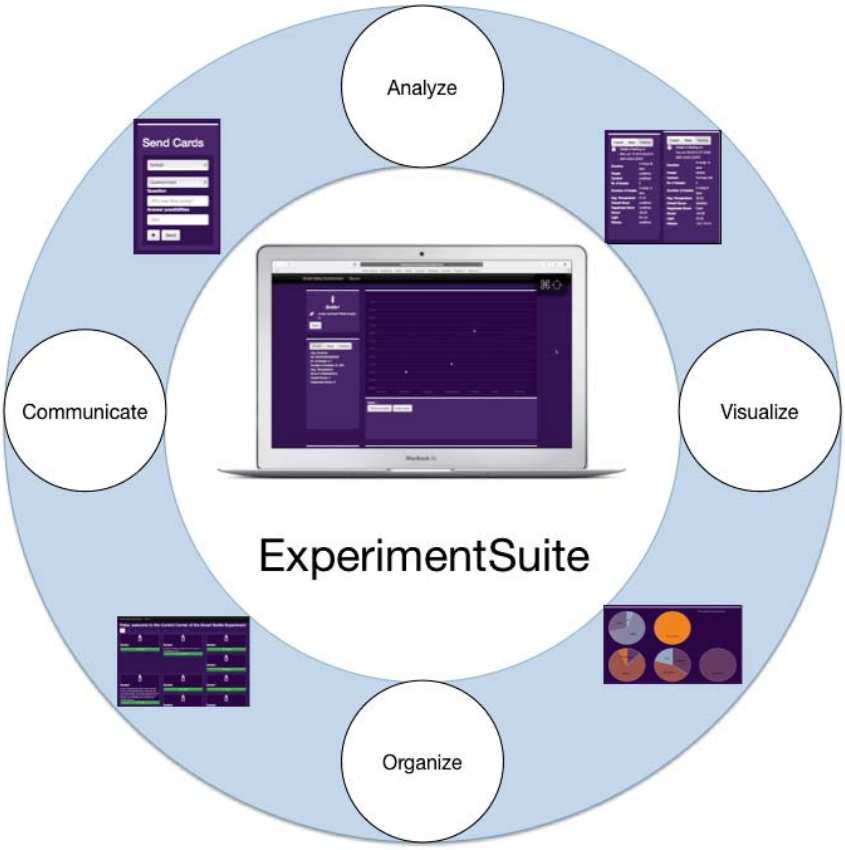

Figure 6.8: ExperimentSuite - a home placement test management tool

Chapter 7

The role of data in the uBottle project

This chapter is analyzing the answers of the second research question: *What is the role of data during the design process of a connected product?* based on Philips Design's uBottle project. *Please keep in mind that this chapter is confidential.*

7.1 ExperimentSuite - a data-driven home placement test management tool

The uBottle home placement test was part of the Rapid Co-Creation process (RCC) 2.2 about a smart baby feeding bottle by Philips Design. The uBottle home placement test was unique because it allowed real-time data collection and analysis for the researchers involved in the RCC. In this chapter we show that data enhanced the process with the following features:

- Data inspired the researchers and the participants of the RCC to come up with better designs, connected services, providing useful feedback, so all in all to come up with a better product experience.
- Data helped getting more detailed information about the behavior of the participants of the home placement test.
- Data helped comparing the researchers' assumptions (models about bottle feeding) to what is happening in reality (recorded events from the parents).
- Data allowed the team to find out more about the working techniques during the home placement test of a connected product.

7.1.1 New insights

At the end of the first iteration of the uBottle home placement test marketing experts, people researchers, designers, technical experts, bottle feeding researchers, and data experts participated in a two days workshop that aimed to define the second iteration of the home placement test. Before the workshop Berkay Buharali and me were asked to prepare a presentation about the data collected during the first iteration of the home placement test. We prepared this presentation with the assumption that raw data is not that interesting for this group of people. Therefore we concentrated on giving an overview on the analyzed data, talking more about summaries, possibilities during the second iteration, creating connected services and provided one slide (see figure 7.2) about the overview of the collected data during the first iteration of the home placement

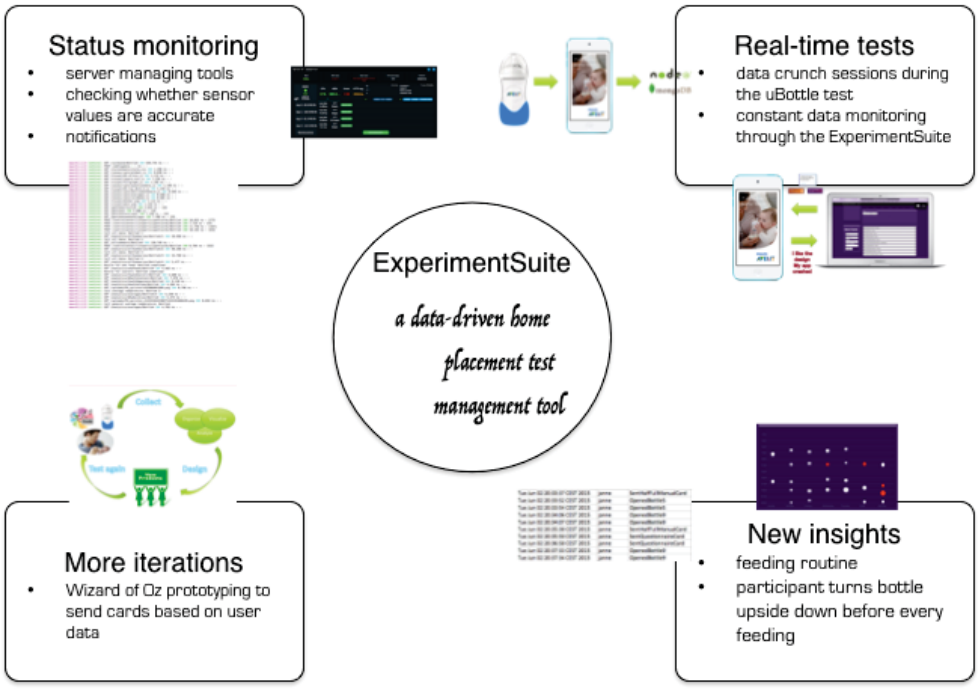

Figure 7.1: ExperimentSuite - a data driven home placement test management tool

test. As it can be seen this slide provides average position, temperature and duration values, alongside with how many feedings is it based on. Our assumption that this slide was the least interesting part of the presentation could not have bean less correct. This single side initiated a 10 minutes discussion in which everyone participated. Using this knowledge led to the decision that the ExperimentSuite does not only contain visual information about the collected data but also provides three kind of overview tables. (Overall, weekly and per feeding overview).

	Nr. of feedings	Avg. Temp.	Avg. Duration	Avg. X	Avg. Y	Avg. Z
Participant 1	15	24.78	319.73	9.11	-18.23	14.93
Participant 2	25	31.66	577.280	-36.18	-56.82	98.45
Participant 3	24	29.32	941.29	35.96	25.83	-149.94
Participant 4	21	33.024	291.190	-7.06	26.173	-93
Participant 5	14	31.06	319.5	-7.05	1.32	103.04

Week 1

	Nr. of feedings	Avg. Temp.	Avg. Duration	Avg. X	Avg. Y	Avg. Z
Participant 1	Failed data collection					
Participant 2	11	32.52	588	-3.86	54.28	117.07
Participant 3	23	31.16	968.91	49.5	-43.69	-133.85
Participant 4	25	33.174	277.68	4.130	10.707	-47.98
Participant 5	25	26.93	279.28	-27.17	-0.66	80.616

Week 2

Figure 7.2: Overview of the collected data during the first iteration of the uBottle home placement test

Gathering data inspires the creators of a new connected product, but it also inspires the participants of the home placement test, the parents. During the first iteration of the home placement test parents only had one chance to have a brief look at the collected data during the final interview of the test. Nevertheless, the same parents who told the people researcher team that they are not very much interested in data about their feeding routine got very excited when they were presented with actual tangible information about the position, temperature and duration of their own feedings. By looking at the tables and graphs which they were presented they started to recall memories about the specific feedings and it helped them giving better ideas for the designers. Therefore we decided that during the second iteration of the home placement test parents would have much more feedback about their feedings. We implemented four overview graphs (routine, timeline, volume, comparison between feeders duration) and parents could use the application to look at them any time they wanted. Moreover, the researchers sent insights, and coaching messages based on the data of the participants. One participant was interested in the relationship between the noise of the environment and the interruptions that happened during the feedings (see figure 7.3). In the final interview we found out that the participant had a feeling that the noise level of the feeding environment was not very good for her baby but she kept it as a feeling. However, after seeing the sent out card, she decided to change the noise level of the environment, lowered the surrounding noises during the feeding and the number of interruptions during her feedings started to lower as well.

Figure 7.3: The relationship between noise level and interruptions during one week feedings of a participant

All in all, as it can be seen data inspired everyone who was part of the uBottle home placement test. It has played a significant role of understanding bottle feeding and using this knowledge designing the new iteration of the home placement test. Furthermore, it provided value for the parents who participated in the home placement test. They also started to understand more about their own feeding behavior and data helped them providing feedback to Philips.

7.1.2 Status monitoring

Testing whether the server works

The server of the experiment was responsible storing and analyzing the feedings. It was built in node.js and we used a mongodb database to store the data. We also needed to use a production environment, that allowed multi-threaded execution of the node.js application. This node-module was PM2. PM2 provides a way to run a server without down-time, this means that when there is an exception it automatically restarts the application. Furthermore, PM2 also made it possible to store and retrieve the logs generated by the application. The program separates the normal output logs from the errors that occur during the execution of the application. (An example log of adding a new feeding can be seen on Figure **??**). It also has a feature of showing these logs when

we are logged in to the server via SSH connection, therefore, we used this feature to check the server behavior real-time. Furthermore, the developers of PM2 created Keymetrics.(An example of the Keymetrics screen used for analysis can be seen on 7.4) We used Keymetrics, to check the performance of the server. The most useful features of this web-based tool for our project were:

- Checking the CPU and memory load of the server
- Checking the slow routes of the application: it gives a detailed overview of how much time does it take to perform HTTP requests for the application. This tool helped us repairing the application when it was not behaving as expected, and saved us much amount of time
- Restart, reload and graceful reload of the server: during the test we were developing new features and fixing errors, node.js requires an action to use the newly developed files. Restart and reload stop the running processes and restart/reload the application, whereas graceful reload waits for the processes to finish before reloading the files of the application. Moreover, we also needed to use this feature when the server experienced sudden high load of data, because the iOS devices of the participants decided to send historical feedings again and again to us
- Notifications about unexpected events: PM2 sends emails when an exception in the Javascript code happens, or the server, where the application runs, goes offline. This is very useful to take immediate action and have as less down-time as possible

Figure 7.4: The Keymetrics dashboard showing the status of the server

Given that the server element of the home placement test was one of the most crucial ones, we needed to use these techniques many times. Furthermore, the designers, the researchers and the participants of the home placement test could not tell the reasons of a sudden error, they could only report unexpected behavior. One of the most reported ones was that the iOS application showed a message to the participants saying the server is offline. However, the server was not offline in reality, only it was very slow.
All in all, checking the log files of the uBbottle server was very useful and important for the success of the home placement test. It gave indications of malfunctioning and helped recognizing if there was a problem with one of the components of the home placement test. However, most of the work was done manually and could only be carried out by the developers of the sever application or in rare cases by the server provider. In the future, it would be possible to implement a more intelligent technique that sends notification when there is some unexpected behavior in a similar way how PM2 does it. A very useful functionality would be to receive notification when a bottle sends data multiple times. We already implemented that these feedings are not analyzed more times and parents do not get after feeding questions more than once, but it would be even more useful to be notified about this malfunction and take action as soon as possible. Moreover, during

one weekend we experienced the loss of many feedings because our database storage was over the limit. Another useful feature would be a notification service that helps in understanding and repairing problems with the database.

Testing whether the participants' side of uBottle works

The uBottle that the participants of the second home placement test got contained a Bluetooth Low Energy enabled Arduino computer, that made it possible to communicate with the also given iOS devices. However, because the bottles were not directly connected to the internet we needed to come up with a possibility of remotely checking whether the bottles work without disturbing the participants. Therefore we implemented a logging mechanism inside the ExperimentSuite and the iOS application alike. The following log events were created during the home placement test:

- addFeedingCalled: this log event means that the participant is sending a chunk of data to our server
- Receiving: this log event means that the iOS device of the participant is receiving data over Bluetooth from the uBottle
- App active: this log event means that the participant opened the main screen (the newsfeed) of the iOS application
- App inactive: this log event means that the participant closed the application and navigated to the home screen of the iOS device
- SentAfterFeedingFor¡idOfFeeding¿: this log event means that the uBottle server sent an after feeding questionnaire for the feeding with the respective id
- read¡typeOfCard¿: this log event means that the participant clicked on the respective type of card in his/her newsfeed
- answeredQuestionnaireCard: this log event means that the participant answered a questionnaire card in his/her newsfeed

Fri May 22 16:12:18 CEST 2015	App active
Fri May 22 16:12:23 CEST 2015	readHalfManualCard
Fri May 22 16:12:28 CEST 2015	readHalfManualCard
Fri May 22 16:12:29 CEST 2015	addFeedingCalled
Fri May 22 16:12:31 CEST 2015	readHalfManualCard
Fri May 22 16:13:53 CEST 2015	App active
Fri May 22 16:14:19 CEST 2015	Receiving
Fri May 22 16:16:02 CEST 2015	App inactive
Fri May 22 16:16:05 CEST 2015	App active
Fri May 22 16:32:35 CEST 2015	addFeedingCalled
Fri May 22 16:33:44 CEST 2015	SentAfterFeedingFor555f3dc39b040e2d3007958b
Fri May 22 16:35:14 CEST 2015	App active

Figure 7.5: The log events of the uBottle and the iOS application

Using these logs we were able to find unexpected behavior of the iOS application and the bottle without directly communicating with the participants. It was most useful in the following situations:

- We saw that the log of the bottle does not contain any receiving event, therefore we knew that the bottle of the participant has problems with connecting with the iOS device, in this case either a detailed technical support session over phone, or a replacement of the uBottle was carried out
- We saw that there are multiple addFeedingCalled events were logged in a very short amount of time. This was caused by two issues. First of all any touch to the bottle generated data for us, and the method was called to send any kind of data. However, it could also happen that

the iOS application randomly decided to send historical data multiple times to the server again and again. This issue could also be seen and analyzed (time of the events) from the logs generated by the iOS devices

- We saw that the participants do not read the cards that the Wizard of Oz researchers send out from the ExperimentSuite. However, it turned out that the cards have never arrived to the participants' newsfeed
- Using the event logs we were able to check whether the participants opened the application at all

All in all, the bottle logs we stored in the database were very useful to carry out real-time data collection. However, checking the logs required manual work from the developers and could not be carried out by the Wizard of Oz researchers themselves. Therefore, in a future iteration of a home placement test the following events can be automated and the system can send notification emails both for the developers and the researchers.

- A participant is not active for a certain amount of time
- The iOS application is misbehaving
- The hardware given for the experiment has problems

Testing whether the ExperimentSuite works

The ExperimentSuite of the second home placement test is the Wizard of Oz control center of the experiment. In general, this is where the researchers can check the feeding routine of the participants and communicate with the participants. Checking whether the ExperimentSuite was easier than checking whether the uBottles and the iOS applications work because all the users of the ExperimentSuite were located in Philips Design. Nevertheless, during the weekends the home placement test did not stop and therefore we needed a method to detect problems happening during this period of time. We had two logs which were useful to carry this out. First and mostly we used the server logs, secondly we collected usage data per user of the ExperimentSuite.
The following log events were created per researcher:

- Logged in: this log event means that the user of the ExperimentSuite logged in to the dashboard
- Logged out: this log event means that the user of the ExperimentSuite logged out from the dashboard
- Opened¡bottleName¿: this log event means that the user of the ExperimentSuite opened the dashboard of the respective bottle
- Sent¡typeOfCard¿: this log event means that the user of the ExperimentSuite sent the respective type of card
- WroteResearchComment: this log event means that the user of the ExperimentSuite wrote a researcher comment about the participant

Using these two logs we could determine if one function showed unexpected behavior. For example, the researchers sent out a card to the participant, however it never arrived on the participant's iOS devices. Unfortunately, at the moment these logs could not help us finding the real cause of the problem, but could help us determining in which part of the system has the problem occurred. For example in the case of the card sending problem it turned out that the problem was with the iOS device and not with the implementation of how we send out the cards. Nevertheless, we managed to use these two logs for fixing most of the issues that occurred in relation to the ExperimentSuite.

Tue Jun 02 20:33:37 CEST 2015	janne	SentHalfFullManualCard
Tue Jun 02 20:33:52 CEST 2015	janne	OpenedBottle5
Tue Jun 02 20:33:54 CEST 2015	janne	OpenedBottle5
Tue Jun 02 20:34:06 CEST 2015	janne	OpenedBottle9
Tue Jun 02 20:34:07 CEST 2015	janne	OpenedBottle9
Tue Jun 02 20:35:38 CEST 2015	janne	SentHalfFullManualCard
Tue Jun 02 20:35:59 CEST 2015	janne	SentQuestionnaireCard
Tue Jun 02 20:36:58 CEST 2015	janne	SentQuestionnaireCard
Tue Jun 02 20:37:33 CEST 2015	janne	OpenedBottle9
Tue Jun 02 20:37:34 CEST 2015	janne	OpenedBottle9

Figure 7.6: The log events of the users of the ExperimentSuite

Checking whether the sensors inside the bottle work

The uBottle contains a Bluetooth Low Energy Arduino and there are several sensors attached to it, in order to carry out data collection. These sensors are the following: light, weight, sound, accelerometer, and thermometer. The data is sent to a Philips server via an iOS device. In the beginning of the home placement test a manual calibration of the devices was carried out. During this test the researchers collected reference values of all the sensors, and manually logged them. Furthermore, this way it was possible to check that everything is setup correctly and that we delivered working prototypes to the participants of the home placement test.
However, during the test we needed a way to check whether the sensors kept providing the expected values. This check could be carried out by both the users of the ExperimentSuite or the developers of the tool. The ExperimentSuite can show collected data in three different ways. The Wizard of Oz researchers can see an overview of all the feedings from a participant, the data collected during a specific week of the home placement test. The Wizard of Oz researchers mainly use this tool to get inspiration for the coaching and insight messages they want to send and for the questions they want to ask from the participants of the home placement test. Nevertheless, this interface is a possible way to check whether the sensors inside uBottle are sending the expected values.
Moreover, the developers of the system can check the sensor values in two more places. It is possible to directly look at the collected data inside the mongoDB database, or to use the log of the server that contains all the interactions that were made with the server from the users or the iOS devices.
During the test the weight sensor failed to provide the expected values. This was due to a problem during the calibration. Furthermore, each weight sensor had a separate algorithm to translate its values to milliliters but during the test we did not implement these equations inside the server of the uBottle home placement test.
All in all, knowing that the sensors inside the uBottle were working was very important for the success of the home placement test. There are methods to check this before, and during the test. The ExperimentSuite and the uBottle server made it possible to check it remotely. This steps enables the enhancement of the design process of a connected product with a constant check on the quality of the collected data.

7.2 New insights to end-user behavior by conformance checking

As introduced in section 4.2 conformance checking is a process mining technique that can be used to determine whether a process is happening the way the people creating the process model assume it does. In the case of the uBottle project this thesis examines how the technique can be used in connection with two elements of the home placement test. First of all, for checking how parents feed their babies compared to what designers think. Secondly, for checking how the researchers use the dashboard.

7.2.1 Checking how parents feed their babies compared to what designers think

During the first experiment of the uBottle home placement test the designers of the experiment have created a diagram about the feeding experience of the parents. It is based on research and on-site interviews with parents. Based on the results three clearly separated stages of bottle feeding were defined. First of all parents prepare the bottles and the content. During this stage the main steps consist of washing the bottle, preparing the bottle, preparing and heating the content, and optionally adding vitamins. Secondly, the parents feed their babies. During this step the parents monitor the environment, the bottle, the content and most importantly their baby. Finally, the feeding experience finishes with cleaning and storing the bottle. This is also the moment when parents need to sterilize their bottles.

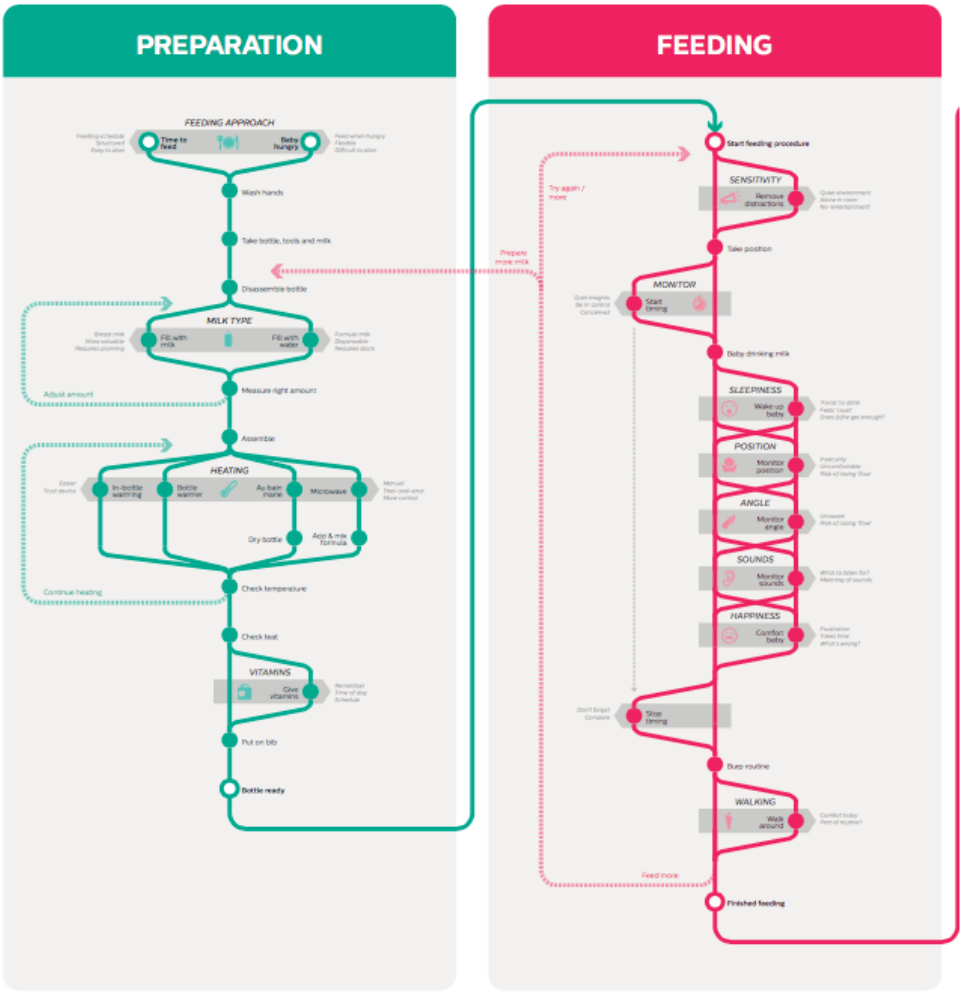

Figure 7.7: Feeding model defined by the designers

Using the bottle logs and the data collected during the experiment it is possible to compare the model that was defined by the researchers and what happened in reality during the experiment. Based on this comparison there is a possibility to discover unexpected activity from the parents.

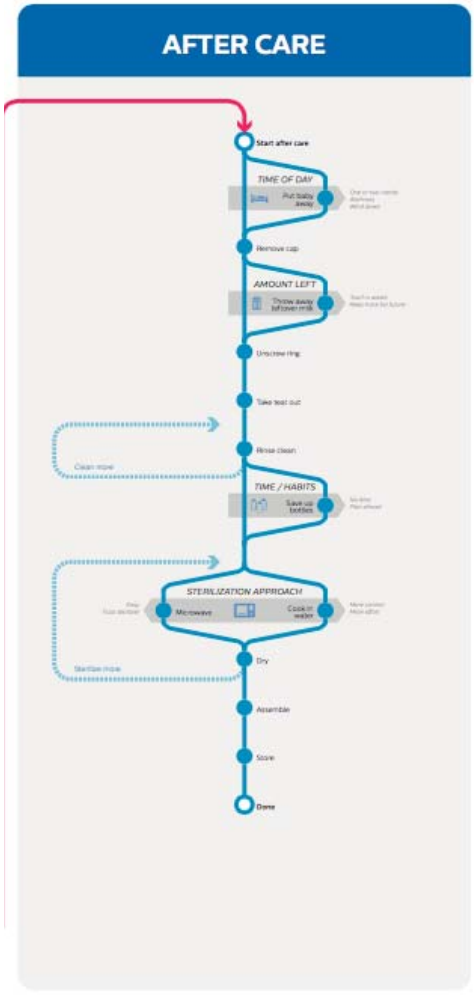

Figure 7.8: Continuation of the feeding model defined by the designers

One example is that one participant of the home placement test started every feeding with turning the bottle upside down, then left it on the kitchen table, picked up the baby and started feeding. However, this is only a simple example. Berkay Buharali [4] uses data mining and process mining methods to determine new events during the home placement test of uBottle. Finding these new events enhances the design process of a connected product. From the designers point of view the following new things are possible after discovering the new events:

- It is possible to ask questions about what happened at a certain point of time, this helps understanding user behavior better
- It is possible to determine which sensors are the most relevant to include inside the uBottle. For example, if it turns out that parents are always checking the content inside the bottle for a significant amount of time then the light sensor can help them coming up with a faster decision
- The designer learns a new possible way to use the connected product and therefore is able to come up with a new feature, or a better design

- An event log suggests that the parents are doing something during the feeding and making it automatic would help them a lot. (E.g: during every night feeding the parent leaves the bottle for 5-10 minutes on the table that could indicate he/she is making a coffee, the uBottle can send a signal to turn on the coffee maker)

All in all, this part of the conformance checking is one of the most significant way how data enhances the design process of a connected product. The main aim of the home placement test from the designers' perspective is understanding end-user behavior and coming up with a better product experience. Checking whether the participants of a home placement test behave as the designers could define it in a model gives a new perspective to the home placement test. Realizing that there are events that can be detected by the designed connected product helps creativity and makes the test more successful.

7.2.2 Checking how the Wizard of Oz researchers use the dashboard

The dashboard of the uBottle home placement test is a tool for gathering insights about the participants' feeding routine and communicating with the participants based on this acquired knowledge. The dashboard is used as a Wizard of Oz prototyping tool. Based on Kranz and Schmidt [11] Wizard of Oz prototyping is a kind of prototype that does not function without someone controlling the prototype itself. In the case of uBottle, this meant that the researchers sent out the educational, insight content and asked the questions with manual analysis of the data. The analytics motor of the uBottle server could detect insights about the incoming data, but the Wizard of Oz researchers found the correlations of sensor values manually. Nevertheless, each researcher had a different way of working:

- All the researchers were assigned to 2-3 participants at the beginning of the home placement test. Some researchers sticked to the plan and only checked their assigned participants, but many researchers opened participants that were assigned to other people
- The amount of time a researcher spent on a participant's page differs
- The researchers were asked to use their own usernames to login to the ExperimentSuite. However, the password was the same for everyone and thus some people did not select their name for logging in
- Some users of the ExperimentSuite had the task to communicate with their participants whereas other ones only used the tool to get an overview about the home placement test and whether all the parts of the experiment are functioning
- In the middle of the test the user logs, the bottle logs and the server logs together indicated that the researchers check the incoming feeding data much later than it arrives. Therefore an email notification was implemented to notify the researchers about incoming data. The results were very promising, the researchers opened the dashboard more times and interacted with their participants more

All in all, the dashboard of the uBottle home placement test was one of the most important parts. Checking the way how it was used was helpful for keeping track of the status of the test. It was also possible to come up with new functionality based on findings that were gathered during the test. In the future, it is possible to create a more detailed analysis of the collected user logs, and with the help of these logs coming up with a better functioning dashboard that is more suitable for the researchers.

7.3 Conclusions

This chapter presented how during the uBottle test data was used to enhance the home placement test of this connected product. The findings of this chapter rely on the features of the

ExperimentSuite, a data-driven home placement test management tool. First of all the team and the participants used the tool and the setup of the experiment to find and deliver new insights. Secondly, this tool made real-time data collection, and two-way communication possible, while we were capable to monitor the status of each component of the home placement test. Last but not least using conformance checking it was possible to gather initial insights both about parents' feeding and the researchers' working behavior. All in all, this chapter showed how is it possible and why is it beneficial to extend the ExperimentSuite to become a data-driven home placement test management tool.

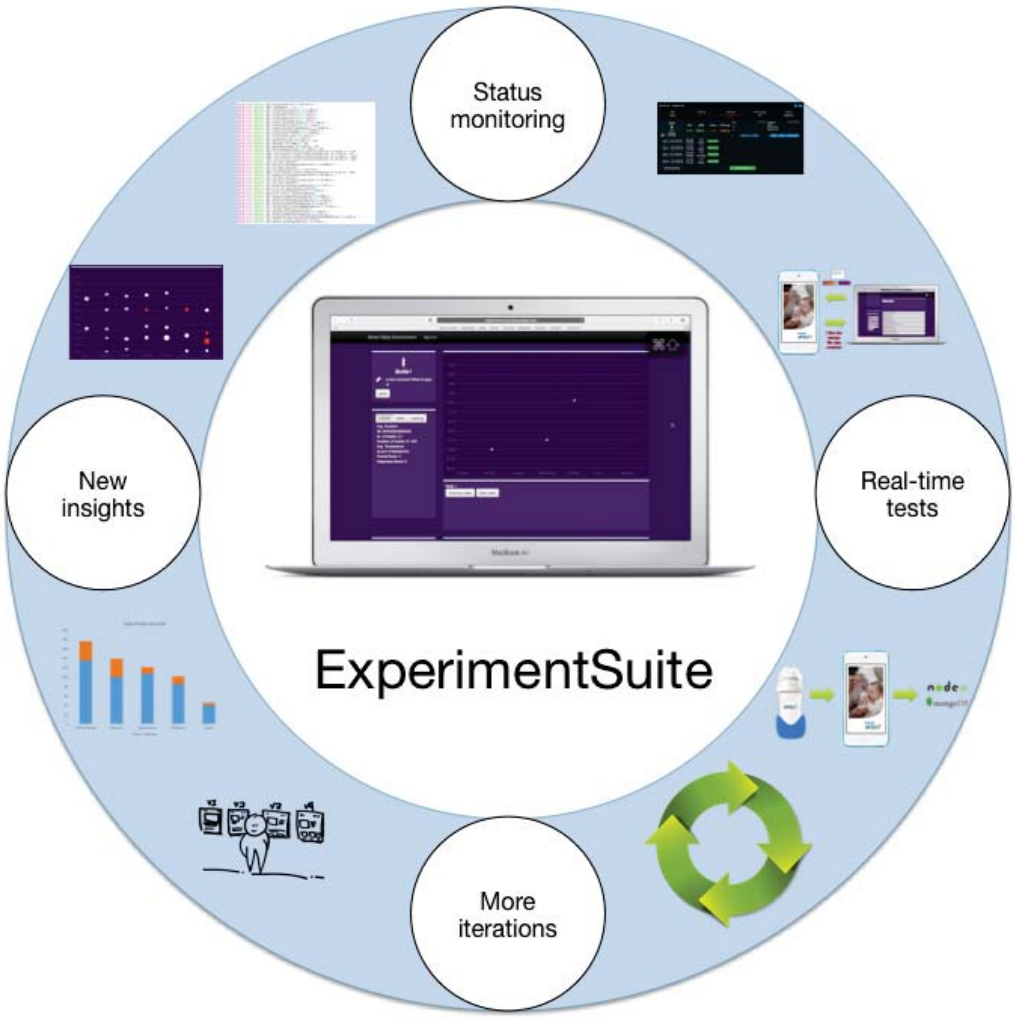

Figure 7.9: ExperimentSuite - a data driven home placement test management tool

Chapter 8

Connecting devices with uBottle

This chapter is analyzing the answers of the third research question: *How to design services for inter-connected products?* based on Philips Design's uBottle project.
Please keep in mind that this chapter is confidential.

8.1 Existing software tools for connecting devices with each other

Two software tools can be helpful for the home placement test of a connected product. These are the following:

- IFTTT stands for If This Then That, and it is a cloud service that lets its users to define rules in the following pattern. Once a specific event happens in connection to a supported product or service, then a triggered event of another supported product or service happens. IFTTT supports littleBits and SparkCore out of the hardware prototyping tools introduced that makes it possible to use for the home placement test of a connected product
- Node-RED is a visual tool for wiring the Internet of Things. The interface works with a drag and drop feature. On the interface it is possible to select connected hardware devices, APIs and online services. These building blocks are called nodes. The nodes can have input node(s) and/or output node(s). The users of the tool can trigger the events by clicking on triggering buttons, or by setting up remote connections to other online services and/or APIs, these remote connections can trigger events as well
- Alljoyn is an open source initiative led by Qualcomm. It is a system that lets devices communicate locally with each other. Speakers, light bulbs and other connected devices are able to recognize the services of each other and trigger each other's functionalities using Alljoyn without leaving the local network they are connected on.

8.2 Integrating existing software tools in ExperimentSuite

Currently, only the littleBits API is integrated in the ExperimentSuite. However, the following integration possibilities were determined for the existing software tools.

8.2.1 IFTTT

Unfortunately IFTTT is not possible to integrate neither in the ExperimentSuite. IFTTT requires the development of channels that contain triggering and activated events. However, in order to create an IFTTT channel a development team needs to closely work with the IFTTT team. Nevertheless, IFTTT is suitable for home placement test creator teams for very early experimentation

with their first connected prototypes when the team used SparkCore or littleBits, because both of these hardware prototyping tools have their own IFTTT channels already.

8.2.2 Node-RED

It is possible to integrate Node-RED in the ExperimentSuite. In this case the application runs on the server which runs the ExperimentSuite itself. The researchers use the standard Node-RED graphical user interface, but the tool can contain new customized nodes for all the other connected devices, online services and APIs that the researchers need access to. The only drawback of the integration from the uBottle perspective is that because Node-RED would run on a server in an external location the uBottle cannot connect to the server by Bluetooth Low Energy. Nevertheless using the proposed direct websocket connection from the iOS device it is connected to, it is possible to use uBottle's full potential

8.2.3 Alljoyn

Alljoyn is the most difficult to integrate in the ExperimentSuite. It has to run on the local network, therefore there is no viable option to carry this integration out.

8.3 ExperimentSuite - an interconnected home placement test management tool

The ExperimentSuite makes it possible to design services for inter-connected products. As proposed in the previous chapter it proposes solutions for four main features. At the moment, not all the features are integrated in the existing iteration of the tool, section 8.2 examines the feasibility of integration for each feature.

8.3.1 Direct connection to other devices

uBottle

Firstly, the possibility to connect the uBottle to other devices is examined. The uBottle prototype contains a LightBlue Bean, an Arduino computer that also contains a Bluetooth Low Energy chip for communication. There are two possible directions for connecting the prototype to other devices. The first possibility is to connect the uBottle directly to the device that is taking care of the communication between the devices (e.g. to a computer that is running Node-RED, as the LightBlue Bean has Node-RED integration). On Figure 8.1 an example of a Node-RED flow can be seen, that enables setting up the environment based on the feeder's activity, and the data coming from the uBottle. During the usage of this flow, the uBottle needs to be connected to the computer that is running Node-RED.

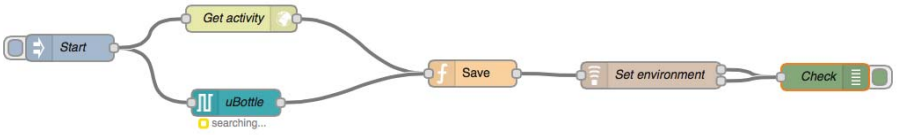

Figure 8.1: Example Node-RED flow containing uBottle

It is also possible to integrate uBottle using the API of the ExperimentSuite that was developed for the uBottle home placement test. However, at the moment it is only possible to reach the data after the iOS device that the uBottle is connected to sent the sensor values to the Philips Server

(see the communication overview on figures: 6.1 and 6.2). Nevertheless, it is possible to create a websocket connection from the iOS device that could stream the values live in Node-RED, and thus connect this stream of data to other connected products, like littleBits, SparkCore, other LightBlue Beans, Philips Hue (a WiFi connected light bulb), etc.
Furthermore the possibility of integrating the uBottle in the Alljoyn ecosystem was examined. However, from the technical perspective it turned out to be very hard to implement at the moment. See more results of the hackathon in 8.4

ExperimentSuite

There are two possibilities to access external devices directly from the ExperimentSuite. Many hardware prototyping tools and connected commercial products offer a cloud based API. Using these API access points it is possible to send an HTTP request directly by Javascript from the ExperimentSuite. This way the creators of the home placement test are able to control other connected products directly from the ExperimentSuite itself. As introduced in section 7.2.2 the ExperimentSuite is using the Wizard of Oz prototyping technique (see section 2.3.1). By integrating other connected devices in the ExperimentSuite it is possible to extend the Wizard of Oz prototyping with enabling the researchers to control these devices remotely. Therefore, for example it is possible for the researchers to turn on the coffee maker in the morning for the parents once they see that they did a feeding, but the necessary computational logic does not need to be developed for the home placement test. At the moment, the ExperimentSuite is capable of turning on littleBits when a feeding arrives to the Philips Server.

8.3.2 External data sources

At the moment the ExperimentSuite only contains data that is sent by the iOS devices which are directly connected to the uBottle protoypes. As it was introduced in section 6.3 the Experiment-Sutie makes it possible to organize, analyze and visualize incoming sensor values. However, there is a big opportunity to take into account external data sources that affect the feeding routine as well. It is possible to integrate APIs and online services in Node-RED, and send this data to the ExperimentSuite. After this integration it is possible to give an interface for the researchers to find correlations with these other values and find out what other factors affect a feed apart from what is collected already during the home placement test. All in all, this integration is needed for data that is not controlled by the creators of the home placement test (e.g. weather information), or results of earlier tests (e.g. Philips has data about babies from another iOS app they developed). Moreover, the ExperimentSuite has an API endpoint and it is possible to access the collected raw and analyzed data after authentication. This API is used by the iOS application to show trends about the feedings of the participants.

8.3.3 Simulation

Simulation can play an important role in the home placement test of a connected product. It is possible to simulate an environment and manually trigger events to inspire the creators of the home placement test and test the behavior of the devices before developing a connected prototype. In order to handle simulation a system based on the article Comms/CPN: A Communication Infrastructure for External Communication with Design/CPN [7] was used. The authors created an example using a Java server, and an example Petri-net. In order to integrate this solution in the ExperimentSuite a direct connection from the Java server needs to be made to the Philips Server running the ExperimentSuite. After this integration the external data sources and the direct connection to external devices can be used to experiment with the developed simulation tool.

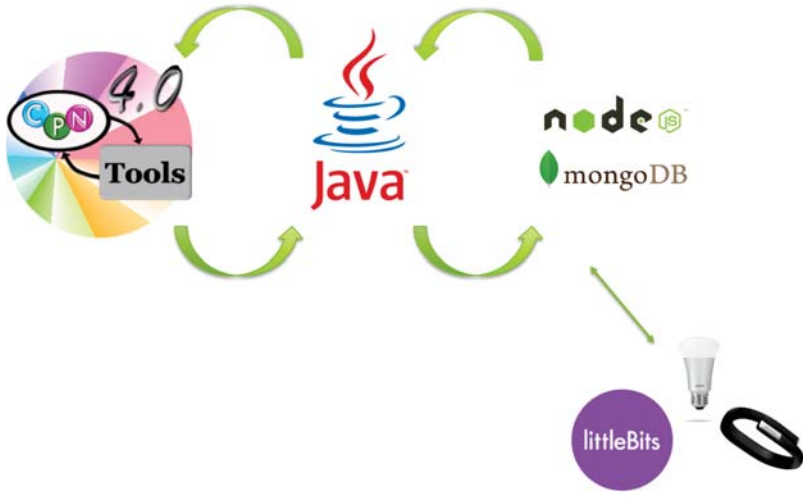

Figure 8.2: Simulation in ExperimentSuite

8.3.4 Scenario planning

Direct connection to other connected devices, external devices, and simulation all together help the researchers to come up with scenarios where the uBottle would be useful part of an ecosystem of products. The first time when the uBottle team participated in two days scenario planning was during an in-house hackathon in Philips Design about the propositions of Alljoyn. For more details about the hackathon can be found in section 8.4.

8.4 Alljoyn hackathon

The team behind the uBottle home placement test participated in an Alljoyn hackathon organized by Philips Design. In the two day hackathon the aim of the team was to come up with possible scenarios where uBottle would be useful in the house. The first result of the hackathon was that the team recognized that Alljoyn is not a prototyping platform and therefore there is a need for an inter-connected home placement test management tool. This confirms the findings of this thesis as well.
Moreover, the team examined the possibilities of using external data sources. It was determined that light, humidity, temperature, sound levels could be gathered from smart devices and sensors in the house. It would also be beneficial to gather insights about the parents' activities before feeding. All in all, knowing the results of previous feeds, together with the current situation it would be possible to use this information to provide an environment that helps parents providing a better feed for their babies, thus resulting in a better product experience regarding uBottle. I made a demo that was capable of controlling Philips Hue lights in the house and connected speakers to setup the environment. The environment also changed based on which room the parent wanted to use the bottle. However, at the moment the team and I decided to use Node-RED instead of Alljoyn for the purposes of the demo. Nevertheless, I examined the possibility of Alljoyn integration inside Node-RED and it seemed to be possible using a chat application. All in all early results regarding the hackathon showed the potential in connecting the uBottle with other devices, but a lot of technical, business and ideation work is needed possibly involving the usage of the ExperimentSuite, to figure out the scenarios where the connection is beneficial for the end-users and Philips as well.

8.5 Conclusions

This chapter introduced existing software tools for connecting devices with each other. Two out of the three introduced tools were determined to be less beneficial for the design process of a connected product in Philips Design. Nevertheless, Node-RED is a tool that can be integrated in the ExperimentSuite. Firstly, using this integration and other implementable features, the ExperimentSutie can become capable of connecting the uBottle and/or other connected prototypes to other connected products, online services and APIs. Secondly, it is possible to integrate external data sources in the home placement test management tool. Thirdly, an integration of a simulation environment was proposed. Finally, the tool became complete by the explanation how it can be used for scenario planning. Last but not least, the learnings of an Alljoyn hackathon the uBottle team participated in Philips Design were presented. All in all, this chapter showed how is it possible and why is it beneficial to extend the ExperimentSuite to become an inter-connected home placement test management tool.

Chapter 9

Conclusions

This thesis is based on my internship at Philips Design. During a six month internship I was working as a member of a multidisciplinary design team that was exploring the opportunities around a smart baby feeding bottle. The team carried out two home placement tests during the project. I joined the team after the first iteration of the home placement test. After several weeks of work the following three research questions were defined:

- How to improve the knowledge transfer in the design process of a connected product?
- How does data enhance the design process of a connected product?
- How to design services for inter-connected products?

In this thesis the three research questions were answered through three iterations of a proposed home placement test management tool. Twelve main features of the tool were examined in this thesis. This chapter evaluates how each feature of the ExperimentSuite, the proposed home placement test management tool helps the design process of a connected product. The evaluation is done in four sections, one section for each research question, and finally an overall evaluation of the ExperimentSuite is presented.

Figure 9.1: ExperimentSuite - from sketch to prototype

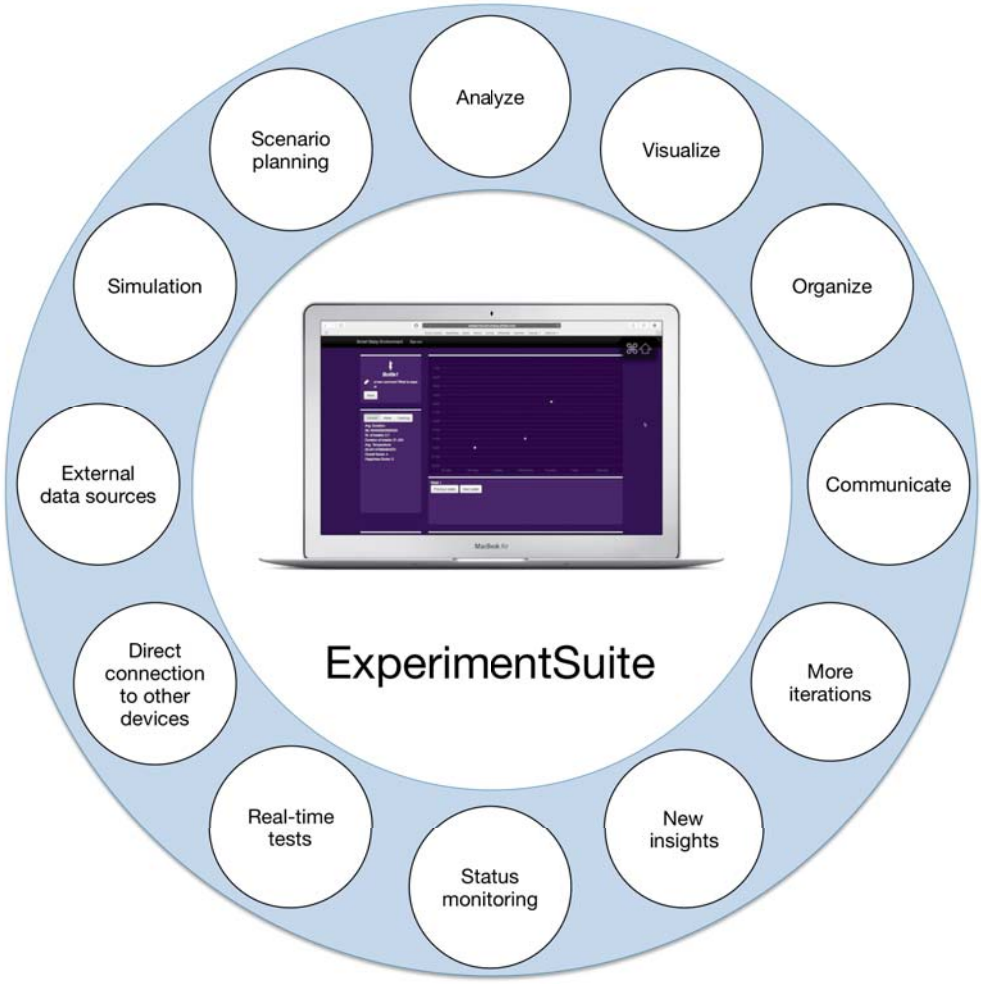

Figure 9.2: ExperimentSuite - a data driven, inter-connected home placement test management tool

9.1 Improved knowledge transfer

The first research question of this thesis was examining how to improve the knowledge transfer in the design process of a connected product. The outcome of this examination revealed first of all that there are two levels where the knowledge transfer needs improvements. First of all, the members of the creator team of the home placement test need to have a better overview of the home placement test. Secondly, the communication between the creators of the home placement test and the participants needs to be improved compared to earlier home placement tests. Based on these requirements a home placement test management tool allowing real-time data collection and real-time two way communication was proposed. The tool contains four main features which improve the knowledge transfer on both of these levels connected to the home placement test. These four main features are that tool can analyze, visualize and organize the collected data, while allowing communication.

9.1.1 Analyze

During the uBottle home placement test an iOS device sent sensor values to a Philips Server. These server values were analyzed as soon as they arrived to the server. This way not the raw data values are presented for the researchers but values which are much easier to interpret. All the users of the ExperimentSuite said that it was useful to see analyzed quantitative and qualitative data together. Five out of the seven users said that they looked at feedings without qualitative data as well.
All the users said that the way how the analysis was done should be used in the future as well. The users also provided very good suggestions for improvements. They want to see more information about feedings. They want to be able to compare feedings with each other. Furthermore, the users want to be able to look back how a feed builds up, possibly this could be done based on the event logs introduced in Berkay Buharali's thesis [4].

9.1.2 Visualize

The designers in the team behind the uBottle home placement test understand visual information better than text-based data. Therefore visualization is a key feature of improving knowledge transfer. It is easier to interpret the collected data by visual means than looking at the numbers. Therefore, visualization features were implemented as part of the ExperimentSuite. All the seven users of the ExperimentSuite said that the feeding routine graph of the participants gave an overview about the participant. The dot sizes on the graph showed the duration of the feeding of the participant and 6 out of 7 users said that it was clear for them. The ExperimentSuite provided overall pie charts as well. However, two users did not look at these graphs which showed the overview of the qualitative data collected after feedings from the participants. All the users said they used the visual information to communicate with the participants of the test.
Six out of the seven users said they would recommend the visualization features of the ExperimentSuite for a future test. They have also mentioned that there is a lot more how the tool can be improved. Based on the results of this thesis and the usage of the ExperimentSuite in practice, Sander Bogers, a PhD student from TU/e, who was also a member of the uBottle team developed a more advanced visualization tool to compare all feedings with each other based on all the possible characteristics of feedings. The ultimate goal is to closely integrate this tool in the future iteration of the ExperimentSuite.

9.1.3 Organize

The multidisciplinary team behind the home placement tests all have different incentives when they create a home placement test. Therefore, it is a requirement to provide a central location to store and organize the collected data during the home placement test of a connected product. In that case all the creators of the home placement test have individual access to the collected data and can analyze it in their own pace and style. Each member of the uBottle team had their own access rights to the system and could work alone with the ExperimentSuite. Five out of the seven users found it useful that the ExperimentSuite showed which participants they were responsible for. 6 out of 7 people looked at the comments that the participants sent to us. 5 out of 7 people took notes about the participants, and the same people report that having access to these notes helped them to get a better overview about the participant.
6 out of 7 users recommended to use the organizational functions in a future home placement test. They have also provided valuable feedback on possible improvements in the future. The users want to have a more detailed overview about what is happening with the participants of the test and who requires special attention. The note taking feature needs to be improved as it was very basic in this version of the tool, and the organizational features were not yet connected to the collected data of the participants.

9.1.4 Communication

The biggest improvement during the home placement test of a connected product is that it is possible to implement two-way, real-time communication between the creators and the participants of the home placement test. The ExperimentSuite contains a card sending functionality. The cards contain coaching, and insightful information and can also be questionnaire cards to ask for more information from the participants. The participants are also able to send user comments to the creators from the iOS application. Furthermore, the ExperimentSuite contained a card bank for each participant. This was an overview of all the previously sent cards to that participant.
6 out of 7 users the card sending and card bank functionality of the ExperimentSuite during the uBottle home placement test. The users said it was very easy to use, and it was very good that they could use pre-defined templates for the card sending feature. All the 7 users recommended to use the communication features of the ExperimentSuite in a future test. Additionally, the users would like to have a preview option before sending the cards. The cards should be more related to the collected data of the participants. Users also suggested a redesign for the type of cards that are available in the ExperimentSuite.

9.2 Role of data

The second research question of this thesis was examining how data enhances the design process of a connected product. The outcome of the examination was that real-time data collection greatly enhances the design process and makes it possible to setup home placement tests which were never possible in the past. Based on the outcomes of this research question four more features were proposed for the home placement test management tool that turn it into a data-driven home placement test management tool. First of all, it is essential that the tool can make the home placement tests become real-time. Moreover, three new features were introduced: providing new insights into end-user behavior, real-time status monitoring of the home placement test, and giving a way to go through more iterations of testing the value proposition of the connected product by making it possible to update the software of the connected product and the home placement test management tool itself.

9.2.1 New insights

The main aim of gathering data on the first place during the home placement test of a connected product is to get new insights. Many aspects for new insights were introduced in this thesis. Data provides new insights for the participants and the creators of the home placement test alike. It is possible to understand end-user behavior better using the ExperimentSuite and other visualization tools, process and data mining techniques.
This thesis showed that both the participants and the creators of the home placement tests are inspired by the collected data. Parents told us during the evaluation interviews that even though they had an assumption that data about their feedings would not be very useful once they saw it their opinion changed. 5 out of 9 participants changed their feeding routine based on the insights they found out during the three weeks of the home placement test. For several members of the uBottle project this was the first time they saw actual collected data. Therefore, they were already satisfied with the results of the first home placement test, and were even more satisfied with the second one.
In the respective chapter it was also shown that using conformance checking it is possible to see how the participants of the home placement test feed their babies compared to the assumptions of the creators of the home placement test. And furthermore, using the developed logging features of the ExperimentSuite it was possible to gather insights about how the researchers used the tool.

9.2.2 Status monitoring

Given that the team designing a new connected product produces a "smart" prototype that is connected to a home placement test management system, there is a need for the possibility to monitor the status of the connected devices, the ExperimentSuite, and the server that the whole experiment depends on. This thesis showed that it was really beneficial for the uBottle home placement test to always have an idea about the status of the participants. This is especially beneficial because the team and the participants do not reside at the same place during the time of the home placement test.
Based on the input from the users of the ExperimentSuite further possibilities to be able to know that all the participants the researchers are responsible for are doing okay during the test would be needed to develop in a future iteration of the tool.

9.2.3 Real-time tests

A survey conducted among five people, who participated in the creation of previous home placement tests showed that it was not possible before to collect qualitative data from the participants of a home placement test real-time, especially not as triggered events (in the uBottle home placement test it was possible to send questionnaire card any time, and if parents had more interruptions than a certain threshold during a feed, an automatic questionnaire card was sent to ask for further details about what happened). This thesis showed the possibilities and the benefits of creating real-time home placement tests. It also examined the important role the ExperimentSuite plays for the creation of the real-time tests.

9.2.4 More iterations

Given the fact that the connected prototypes can be remotely updated and the home placement test management tool can also be further improved during the timeframe of the home placement test. It is possible to carry out tests which contain more iterations during the same amount of time as tests took previously. The uBottle project took three weeks and each week the team tested a different service level and therefore a different value proposition connected to uBottle. Many participants of the test noticed this change. However, because of technological difficulties the first service level (only showing an overview on the collected data of the participant) was in place for longer time than planned and the differentiation between the second and the third service level of the test was not so clear at this point. Furthermore, at this point the software of the iOS devices could not be remotely updated without some data loss and thus the team did not use this feature. Moreover, the software of the uBottle was impossible to remotely update. Nevertheless, the uBottle home placement test validated that data enables more iterations during the design process of a connected product.

9.3 Designing services for inter-connected devices

The third research question of this thesis was examining how to design services for inter-connected devices. The motivation behind this research question was Cisco's [6] prognosis that by 2020 there will be 50 billion connected devices. However, the true value of connecting these devices lies in allowing them to communicate and share the collected data with each other. The outcome of the examination of this research question was that there is a need for an inter-connected home placement test management tool that enables coming up with inter-connected devices. In order to use the full potential of a proposed tool, it should contain the ability to carry out four main features. These four main features are providing a direct connection to other connected devices and services, the ability to use external data sources inside the tool, the ability to use simulation techniques and finally, being able to plan scenarios using the tool and a play-in/play-out approach.

9.3.1 Direct connection to other devices

In order to design services for inter-connected products the home placement test management tool needs to provide a possibility to test how one connected product works together with another one. The thesis proposed the integration of an existing software tool, called Node-RED (developed by IBM), and introduced several commercial products that can be used to create connected hardware prototypes. Using this tool it is possible to easily setup the connections between the devices, and the tool runs on the same server as the ExperimentSuite. Unfortunately, the uBottle cannot be directly connected, only through the iOS device. Nevertheless, the integration of Node-RED gives enough possibilities for the users to come up with ideas around connecting devices with each other. The tool uses a drag and drop interface that is possible to explain for people with less (technological) background as well, but the tool can be very customized for the other experts.

9.3.2 External data sources

Experimenting with external data sources is beneficial in the design process of a connected product because it enables designing reactions to what happens in the environment without the need to develop the facilitator of data collection. Nowadays, many other connected commercial products and services provide their own APIs which can be beneficial to use. Node-RED provides a way to integrate online services and APIs as well. Moreover, the during the uBottle home placement test the team designed a system that is capable of giving access to the collected data to other projects that want to use it by the development of the uBottle API.

9.3.3 Simulation

Simulation techniques can be beneficial to come up with ideas around non-existing connected products and services. The thesis proposed an implementation that uses CPN tools and a Java server that can communicate with the ExperimentSuite. Unfortunately, the uBottle project did not use this feature and apart from early experiments there is not much information available about this feature yet. Nevertheless, the fact that it is technologically feasible makes it possible to test it in the future.

9.3.4 Scenario planning

It is not enough that the designers are able to make the link between different connected devices, include collected data from other devices, and use all of it in a simulation environment. Therefore, using the proposed inter-connected home placement test management tool it is possible to plan scenarios. The uBottle team participated in an Alljoyn hackathon. The outcomes of the hackathon showed that this feature is promising to use. It helps to come up with business value propositions related to the bottle, and makes it easy to demonstrate it to decision makers.

9.4 ExperimentSuite

All the 7 users of the ExperimentSuite said that the tool should be used in future home placement tests. Most importantly it was one of the first home placement tests in Philips Design where real time, two-way communication and data collection was possible. The participants of the home placement tests were provided with valuable insights about their behavior, while the creators of the home placement test had an easy way to provide them with more information than what was included in the iOS application by default. This was possible because the researchers had relevant insights to send to the participants. All the users who used the ExperimentSuite and participated in previous home placement tests (5 people) said that the ExperimentSuite was better than any other tool they used in the past. The users analyzed 365 feedings from 9 participants during the 3 weeks test, and in return they sent 287 cards to the participants.

9.5 Future work

9.5.1 ExperimentSuite

The aim of the ExperimentSuite is to become a general home placement test management tool inside Philips Design. In order to achieve this it must be examined what are the parts which are reusable as they are and what are the parts that need to be developed again. Moreover, it must be examined whether the current technologies used for the development of the software tool are suitable for a future project as well.
During the uBottle project the ExperimentSuite was used as the home placement test management tool for a connected product. However, in other projects more connected products and/or online services are tested. Therefore it has to be determined what are the exact needs of these projects and find out what parts of the ExperimentSuite are reusable.
Some simulation techniques were examined regarding the ExperimentSuite however, neither the uBottle project, nor the ExperimentSuite have used any of them. Therefore, it is suggested to analyze the possibilities and the gains using simulation techniques for future projects and how to integrate it in a useful way in the ExperimentSuite
Chapter 8 introduced the ExperimentSuite as an inter-connected home placement test management tool. However, at the moment the ExperimentSuite is lacking the integration of the introduced software tools. A future project with a home placement test of more than one connected product can give the opportunity to carry out this integration.
The seven users of the ExperimentSuite also suggested many improvements regarding usability and functional features of the software. In case of further development, these will be the first improvements to be made.

9.5.2 Way of working

The uBottle project showed the importance of having people with development and data background integrated in the multidisciplinary Rapid Co-Creation team behind projects similar to uBottle. Therefore, in the future other teams can also hire members with similar background. The fact that the developers and data experts are internal in the team speeds up the development of the home placement test and makes it possible to have more iterations and it is easier to customize the used tool for the exact needs of the project.
Furthermore, there are other findings about the way of working that can be implemented. One being the fact that as an intern I was a full member of the team and this made me motivated to work better. And last but not least working at the same place with the core team during the internship also made the uBottle project more successful.

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