The Modular Electronic Health Record Dashboard: A Novel Approach to Interoperability and Usability

Master thesis Computer Science

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Abstract

Electronic health records have transformed the way care is delivered. Compared to the old paper medical record, there are many benefits to be gained. These benefits include a higher quality of care, increased adherence to medical guidelines, and a reduced amount of medical errors. Also, costs can be saved. The rise of mobile technology can further benefit the health care sector by allowing care delivery from a distance.

There are also disadvantages associated with digital health systems. One example are its high acquisition and maintenance costs. Other cost increases are associated with the training of the medical staff to work with the software. This adaptation period is responsible for a loss in productivity. Another unintended consequence of these systems is an increase in medical errors. A prototype was designed to tackle these last two drawbacks in particular.

A lack of system interoperability and good usability are to blame for some of the drawbacks of electronic health record systems. The ability of a system to communicate with other systems is defined by its interoperability, whereas usability refers to the ease of use and learnability of a system. The design of the prototype describes a modular dashboard wherein the clinician can freely choose its functionality according to his/her workflow. Interoperability was provided by having a loosely coupled back end and a base component to speed up front end development. Several principles defined by literature were kept in mind to provide good usability.

Six individuals participated in a usability test of the prototype. The participants were spread across several health care units, such as nursing and emergency response. The results indicated that the dashboard had good usability, together with many opportunities to improve. However, the interoperability aspect could not be tested. Based on these results, several topics of future work were highlighted.

Contents

1 Introduction

As of today, most health institutions use a digital system to manage health records. These systems are designed to improve the quality of care on many levels compared to paper-based records. The recent advancements of mobile technology can improve the care quality even further.

To start, digital systems help with the capture of accurate and complete data, increasing its quality. Devices communicate directly with the system to store new data values. Also, manual data input can be checked against several rules to ensure it is correct and complete. This kind of error prevention is not possible on paper.

The storage of medical information in a digital format is also much more convenient. First, it is easier to create a backup of the record, preventing data loss. Second, the data is easier accessed. It is essential that the required data to provide care is always available. This cannot be guaranteed for data stored on paper, as it is only available on one location at a time. Increased accessibility also benefits the public health sector. For example, a large data set can be built from several repositories, which may uncover a looming epidemic.

In terms of security, a digital system can automatically log all access attempts and changes made to a record. For paper records, this is significantly more difficult to log. Also, an access control system can enforce strict privacy rules that determine who gets access to what data. As soon as a paper dossier leaves its secure storage facility, the privacy is in the hands of the person who retrieved it.

Technological advancements have increased the feasibility of providing care at a distance. For example, a smartwatch can record the heart rate of a person and send it to the caregiver on a regular basis. If there are any abnormalities, then the caregiver can contact the patient to schedule a visit. This prevents the scheduling of regular visits to perform these checkups in person, saving resources of both the patient and the caregiver.

Based on these benefits, it is without question that the electronic health record is a necessity to provide high quality of care. However, there are also several drawbacks related to digitalization. The transition from paper to digital records is a very costly endeavor. These costs include staff training, the process of converting the paper records to a digital format, and the acquisition and maintenance of the system. Also, the chance that a data breach occurs increases as the records are easier accessed. There are also other concerns such as interoperability. It is important that different kinds of devices and software can communicate with each other. For example, data transfer on paper occurs in case a device can't interface with a software package, which we want to avoid.

In this thesis, we explore the current use of electronically stored medical data in the health care industry. Based on our findings, we propose a solution to some of the negative consequences associated with electronic health record systems. This text describes the process of the design, implementation, and evaluation of this solution.

First, we present a thorough background of the electronic health record. It covers topics such as its components and the impact it has on the health industry. Hereafter, we discuss software interoperability and usability, which are very important topics in the context of health care. The recent advancements of mobile technology made remote care delivery a more feasible alternative to traditional care delivery. This evolution is of importance for future health systems, which we discuss in the telemonitoring section. To conclude this chapter, the last section describes the implications of digitally stored records on data privacy and security.

The next chapter explains the design process of a prototype to solve some of the issues mentioned in the background chapter. First, we sum up these issues. Hereafter, principles that guide the design process are explained. This led to the creation of personas and scenarios. These artifacts illustrate how our solution will work in practice. Before the development of the prototype started, a concrete specification of the application was created which describes its structure and components.

The start of the implementation phase involved choosing the frameworks and libraries best suited for our application. First, we describe the reasoning behind these choices, whereafter the structure and components of both the back and front end are explained. To showcase the result, we provide screenshots for all the components of the front end.

After the development of the prototype ended, a usability test was designed. We explain the purpose of such a test and who it targets. Hereafter, the concrete structure of the test is specified. The next sections describe the recruitment process and the results of the usability test. Based on these results we draw conclusions which indicate several topics of interest for future work.

2   The Electronic Health Record

Health information systems have become an integral part of health care. They support patient care as well as administrative and financial tools. At the heart of these systems lies the electronic health record. An electronic health record (EHR) is a repository of electronically maintained information about an individual's health status and health care, stored such that it can serve multiple legitimate uses and users of the record [1]. An EHR system provides tools to manage and interact with these records. These tools include reminder generation, data analysis, order entry, and decision support. It helps the clinician to organize, interpret and react to medical data. A record where a person manages his or her own health information, is called a personal health record [2]. We will focus on the electronic health record and the systems that interact with it.

The purpose of this section is to provide a general overview of electronic health records. First, we describe the issues surrounding paper which ultimately led to the development of the first digital health systems. Hereafter, we define the five essential components of an EHR system. Section 2.3 describes the impact of EHR systems by listing benefits and drawbacks. The next two topics of discussion are interoperability and usability. Recent technological advancements led to new methods to deliver care, such as telemonitoring which we discuss in section 2.6. To conclude, we briefly mention privacy and security concerns associated with digitally stored medical data.

2.1   Moving away from paper

For modern medicine, traditional paper-based medical records are not suited for today's world filled with technology. The drawbacks of information on paper are obvious when compared to digitally stored information.

Storage   Paper records need to be stored in a safe location and require a lot of physical space. Also, the organization of these records is difficult, doubly so when the records are fragmented across multiple locations. This is a process that wastes time and therefore increases health care costs. It is also possible to lose paper records. For example, should this happen to lab results, tests have to be redone which again wastes time and increases costs. Finally, the amount of paper added to the records on a weekly basis is substantial and consequently very eco-unfriendly [3]. The ink and paper costs should not be underestimated. Storing data in a digital format solves these issues, but raises several other questions: do we store the data on premise or in the cloud? What is our backup policy?

Data quality   Medical information stored on paper is static and requires more effort from clinicians to process it. For example, a clinician has to compare two manually filled-in paper charts in order to assess the recovery of a patient. What if the data is illegible due to poor handwriting? What if data is incorrectly read

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from the computer display or simply not written down? Such medical errors directly impact the quality of care that is delivered [4, 5]. Digital records allow computation such as data aggregation, data processing and statistics generation. Also, a summarizing paper noted that the use of EHR systems leads to more complete, accurate, comprehensive, and reliable data compared to paper-based records [6]. This is the result of system functions that detect incorrect data input and ensure that all data fields are filled in.

Medical data such as x-ray images are captured at a very high resolution. Software tools can view these images without much loss in quality, while printed images are subject to significant quality loss. Images can be printed, but other data types cannot. To bundle this kind of data with a paper dossier, a physical medium such as the aged compact disc is required. Again, this raises several storage and transportation issues which the EHR avoids.

Accessibility   Paper records are location-bound and are often only accessible by one person at a time. Transporting paper records requires a lot of manual work in which the clinician sends either the original or a copy of the record. Another option is to convert the paper record to a digital format. One study described that updating several copies of medical records was a very cumbersome process for clinicians [7]. If a copy of a record is updated, how can these changes be reflected to the original and the other existing copies? How many copies are in circulation and where are they located? Converting the paper records to a digital format raises other questions: where are data values entered inside the digital system? What if there are extra notes scribbled on the document? What if values are missing, but required by the EHR? Data exchange and saving changes seems simpler for digital records, however interoperability of different systems is complex. This is discussed in section 2.4.

Security   While paper records can be safely stored under lock and key in any particular room, several security issues still exist. For example, the storage location can be broken into. This allows the perpetrator to retrieve, alter, or destroy critical medical information. Other possibilities of data loss include flooding and fires. These are scenarios that can't be predicted and can happen at any time.

A common strategy to recover from data alteration and data loss, is to create regular backups. However, for paper medical records this is not feasible. These data sets include thousands of individual papers. The resources required to create copies of such a large data set is enormous and increases the ecological footprint of the institution substantially. This isn't an issue for digital records, but in this case other privacy and security issues arise. These are discussed in section 2.7.

Electronic health record systems solve many of the aforementioned problems associated with the use of paper. However, there are other factors responsible for the continuing presence of paper in clinical environments. Three categories

are predicted to be the cause of paper generation: policy requirements, suboptimal system design, and flaws in the user interface of the EHR system [3]. The referred study focused on user interface flaws and highlighted the following issues:

- Cumbersome interface design leads to handwritten notes on paper.

- The EHR system is not well integrated into the clinical workflow. This leads to paper-based workarounds which *do* align with the workflow.

- The visual organization of the data in the EHR system is incompatible with the mental model of the clinician, which leads to manual transformation of patient data.

Notice that these subcategories all relate to usability and human-computer interaction issues. The study interviewed twenty individuals concerning the use of paper in their workflow. Afterwards, the researchers categorized recurring paper-based workaround strategies found during analysis. This resulted in the following 11 categories, ordered by descending frequency of use:

- Efficiency: enhanced perceived or actual efficiency when using paper.

- Workarounds related to the clinician's knowledge of the health system, skill level with technology, and ease of use of the health system. For example: paper is used because it is simpler than the software.

- Memory: cases where paper is used as a reminder tool.

- Sensorimotor preferences: paper serves as a means of having something concrete to deliver or to quickly jot down some notes.

- Awareness: paper helps clinicians be aware of new information.

- Task specificity: cases where the health system lacks specificity, is not customizable, or sends too many alerts (alert overload).

- Task complexity: paper processes are used because the health system does not support it. An oncology order is an example of a complex task, tailored specifically for each patient, which a simple EHR system may not support.

- Data organization: paper may present information better compared to a cluttered computer screen.

- Longitudinal data processes: in case tracking data over time is easier to do on paper.

- Trust: paper is used as a form of proof which health software can't provide.

- Security: using paper to avoid the use of an insecure system.

While these workarounds can improve efficiency, they also circumvent the health system and its safety checks, which leads to medical errors. However, they also imply that the EHR system is not in line with the workflow of the clinicians. Several of these workarounds are caused by poor usability, which is the topic of discussion in section 2.5.

2.2   Components

As mentioned before, storing medical information is not the only use of EHR systems. They consist of many functional components which ultimately determine how well they perform in health care. Shortliffe and Cimino's work "Biomedical Informatics" defined the following five components as essential [1]:

Integrated view of patient data   An EHR system must allow the storage of a wide range of data types. These include text, numbers, images, video, and other data formats. A lot of paper may be generated in case the system doesn't support a common data type, as described in section 2.1. Data standards were developed to store and exchange both simple and complex data types, ranging from systolic blood pressure values to x-ray images. Section 2.4.1 gives more information surrounding standards.

Clinician order entry   The procedure in which the clinician enters treatment instructions is called order entry. An order entry system assists the clinician during the decision-making process to ensure that the instructions are correct. As a result of more complete and correct data, fewer medical errors are made. Paper is also avoided because different care settings can exchange these orders via the EHR system.

Clinical decision support   A decision support system aids the clinician by suggesting actions when certain situations occur. If for example, a patient is due for vaccination, the system displays a pre-filled order dialog to remind the clinician. The system can do this for a bulk of patients, which saves time that otherwise was spent on performing manual checkups. Decision-support implementations benefit from artificial intelligence. As such, these systems are often complex, due to the many parameters that are involved in the decision-making process.

Access to knowledge resources   Clinical questions often arise during the clinician's workflow. Instead of asking colleagues or searching through multiple manuals, the clinician can turn to the EHR system for information. Digital systems can easily access large sources of information. Also, if the EHR system is context-aware, searching for the required information takes even less time.

Integrated communication and reporting support   Communication lies at the heart of health care delivery. It is common for patients to receive care

from several clinicians spread across multiple institutions or departments. The availability of communication tools in an EHR system directly affects the quality of care as paper is avoided. These tools should support common standards to facilitate interoperability and efficient data exchange, which is discussed in section 2.4.

All aforementioned components should be present in health software. This example of a simple prescription management tool features all five components:

- Present a list of medication currently taken in a clear manner.

- Create, edit, or remove prescriptions.

- Provide alerts for drug-drug and drug-allergy interactions. Suggest medication dosage with respect to parameters such as weight.

- Provide extra information regarding medicines, such as side effects.

- Send prescription orders to the pharmacy.

Prescription management is an example of a tool commonly found in EHR systems. Many more examples are given in section 3.4. Ideally, a single software package provides all the necessary tools. If some functions are still missing, institutions may deploy other applications to fill these gaps. In such cases, there is a need for interoperability, discussed in section 2.4.

2.3 Impact

The transformation of the health care industry towards the use of technology has a profound impact on many aspects, such as finances and efficiency. As mentioned in section 2.1, paper is not reliable nor durable to provide efficient care. The identification and research process of all the potential benefits and drawbacks of EHR systems is not simple. There are countless of practices, small and large, providing many different types of care. As a result, most studies focus on one care setting at a time, such as the intensive care unit of a hospital. Therefore, the effects of an EHR system found in one care setting should not be generalized to the others.

One study conducted in 2011 summarized literature which studied the benefits and drawbacks of EHR systems in different care settings [8]. This study served as the primary source of information for this section. First, we describe the advantages of EHR systems on several outcomes, whereafter we describe the disadvantages.

2.3.1 Potential advantages

The positive impact of EHR systems was studied for clinical, organizational, and societal outcomes. We now explain and list the observed benefits of each outcome.

Clinical outcomes   Measurable changes observed in quality of care are related to this outcome. Quality of care can be defined as "doing the right thing, at the right time, in the right way, for the right person, and having the best possible results" [9]. Quality of care includes six dimensions [10]. However, research focused mainly on the following three: effectiveness, efficiency, and patient safety.

EHR systems lead to increased adherence to evidence-based clinical guidelines, resulting in more effective care [8]. There are three possible reasons that explain why clinicians don't follow these guidelines: either they don't know them, don't know it applies to the patient in question, or have insufficient time. An EHR system tries to overcome these issues. Computerized alerts are also linked to the improvement of care effectiveness. EHR systems are associated with keeping test redundancy to a minimum [8]. Redundant testing is inefficient, costly, and time-consuming.

Studies found that the use of EHR systems resulted in a significant reduction of medical errors. This directly improves patient safety. However, a few studies discovered that the error rate in fact rose, which we later discuss as an unintended consequence of EHR systems.

Organizational outcomes   The billing system provided by an EHR system increases revenue [8]. Reasons for this are a decrease in billing errors, and the improved ability to capture and track bills. EHR systems also avoid many costs. Two examples of such cost savings are as follows: the printing and managing records is no longer necessary, and as previously discussed, less redundant tests are performed. Other benefits include better operational performance, improved legal and regulatory compliance, and fewer malpractice claims.

Societal outcomes   The increased availability of data improves the ability to conduct research. This also helps the public health field in monitoring diseases and with the detection of looming outbreaks. The use of EHR systems is also linked to increased physician satisfaction [11], which is a detrimental factor to improving quality of care.

2.3.2   Potential disadvantages

An EHR system provides several financial benefits. However, it also introduces new financial issues. The adoption and implementation of an EHR system has high upfront costs which involves the purchase and installation of hardware and software, conversion of paper records to digital ones, and user training. Now that EHR systems are common, acquisition costs saw a significant decrease.

Once an EHR system is acquired, it needs to be maintained. The evolving nature of technology requires frequent hardware replacements and software updates. Consequently, users need additional training to adapt to these changes. This also leads to revenue loss due to a decrease in productivity. The high upfront and the ongoing maintenance costs are considered to be the largest barrier to the adoption of EHR systems [12].

The use of an EHR system may cause some unintended consequences [13], such as an *increase* in medical errors. Poor system usability, lack of training, and lack of system integration are possible causes of this rise [14]. Usability is the topic of section 2.5. Another unintended consequence is that an EHR system may evoke negative emotions due to workflow disruptions and adaptation difficulties. To conclude, clinicians may become overdependent on technology. Institutions should guarantee their ability to provide care in case there are technical issues.

2.4 Interoperability

Health institutions often deploy several systems to satisfy all their requirements [15]. As a result, data is spread over several repositories which opens up the possibility of data duplication and synchronization issues. If two systems are unable to communicate with each other, clinicians may resort to paper workarounds as mentioned in section 2.1. Sensory data also needs to find its way into the health record of the patient. If the measuring device has no means to directly send its data to the EHR system, then clinicians are forced to do this manually. Therefore, system interoperability is very important in a health care setting.

Interoperability is "the ability of two or more systems or components to exchange information and to use the information that has been exchanged" [16]. To go into more detail, previous research divided interoperability into four concepts [17]:

- Technical interoperability: moving data from one system to another.

- Semantic interoperability: allow the sender and recipient to understand the same data in the same way without ambiguity.

- Process interoperability: when people share a common understanding across a network, systems interoperate, and work processes are coordinated.

- Clinical interoperability: the ability for two or more clinicians in different care teams to transfer patients and provide seamless care to the patient.

Health care systems and devices should implement standards to achieve interoperability. If every application stores data in its own proprietary format, many point-to-point interfaces need to be created to allow communication. The left graph of figure 1 illustrates this. However, if systems adhere to a common standard by which they communicate, this is avoided. On figure 1 the standard is indicated by the star in the middle of the right graph. The next section briefly describes standards.

2.4.1 Standards

When excessive diversity creates inefficiencies and affects effectiveness, standards are required [1]. A hospital contains many independent units spread
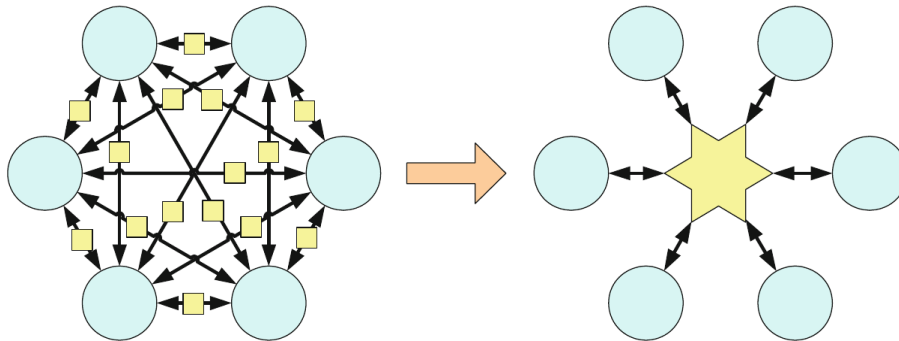
Figure 1: Comparison of communication by point-to-point interfaces and standards.

across primary, secondary, and tertiary care. These units use software best fit for their practice and all record different types of data. For example: the admissions system records patient diagnosis, the pharmacy records prescriptions that were handed out, and the laboratory system records test results. Inevitably, transfer of data between these units is required.

To coordinate multiple systems, data must be exchanged. Nowadays too many different systems exist to create point-to-point interfaces for. Standards try to resolve this issue by defining guidelines that software systems should adhere to in order to communicate data. An efficient standard requires that data is easily stored and presented towards the users of an EHR system. Also, security measures, such as authentication and access control, should be interwoven with these standards.

The use of standards in an EHR system leads to better interoperability which in turn leads to lower development costs. Over time, the continuous addition of proprietary data structures leads to difficult to maintain software and a higher risk of critical bugs. New medical devices and software that comply to standards prevent this. However, there is currently no regulator that enforces the use of existing standards. As a result, good interoperability lies in the hands of the software vendors.

We close this section by giving two examples of standards. First, the most commonly used set of standards is Health Level 7 [18]. These message-based standards provide a framework for the exchange, integration, sharing, and retrieval of electronic health information. Second, DICOM is used for the communication and management of medical imaging information [19]. DICOM allows the exchange of persistent objects, such as images, which is not possible with HL7 messages.

2.5   Usability

We define usability as follows: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [20]. As the health care sector deploys more and more devices and software solutions, it is of importance that these are usable. In case they are, fewer medical errors are made which improves patient safety and increases the efficiency of clinicians. Systems with poor usability may have the opposite effect, increasing the amount of errors [14]. This also leads to more paper generation as clinicians want to circumvent the poorly usable system, as mentioned in section 2.1. Mobile technology seen today features smaller screens and receives input primarily via touch. These devices ask for completely different user interface design principles. However, no research concerning mobile device usability in health care settings was found.

Problems detected at the start of the development cycle are less resource intensive to solve. They may expose fundamental issues which would have been a lot costlier to deal with at later stages of development. Therefore, it is important to conduct usability evaluations early in the development phase to ensure that the health systems are developed in a cost-effective manner that results in an efficient, effective, and useful product [21]. Usability is difficult to evaluate in the health care sector, due to the specific needs that many different work environments require. By providing customization options, each care setting may tailor the system to their wishes. However, this kind of flexibility may create other usability issues.

Several methods exist to evaluate usability. An expert review is an example of such a method in which an expert evaluates the usability. A heuristic evaluation is similar in this regard as it consists of several experts evaluating a system. However, this method tests a system against a set of predefined usability heuristics. To give an example, Jakob Nielsen created 10 usability heuristics that are still widely used today [22]. The heuristics are described in appendix A.1. It should be noted that expert reviews identify *predicted* usability issues. To have a better chance of identifying issues that may arise during real use, an actual end user should evaluate the system. However, conducting such tests are costly in terms of time and resources, which may not be feasible. To conclude, previous research described the following 14 usability principles, which are similar to Nielsen's heuristics, for the design of EHR systems [23]:

1. *Consistency*: design consistency and standard utilization.
2. *Visibility*: system state visibility.
3. *Match*: system and world match.
4. *Minimalism*: minimalist design.
5. *Memory*: memory load minimization.
6. *Feedback*: informative feedback
7. *Flexibility*: flexible and customizable system.
8. *Message*: useful error messages.
9. *Error*: use error prevention.
10. *Closure*: clear closure.
11. *Reversibility*: reversible actions.
12. *Language*: user language utilization.
13. *Control*: user control.
14. *Documentation*: help and documentation.

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2.6 Telemonitoring

At the start of 21st century mobile phones were small bricks with functionality limited to calling and text messaging. Today, smartphones are used to navigate the internet, play games, watch media, and so forth. These recent technological advancements bring many new opportunities which may transform the health care industry. An example of such an opportunity is telemonitoring. Monitoring patients at a distance through the use of information technology is called telemonitoring [24]. Here, the patient uses monitoring devices to gather data which in turn is sent to the health care provider.

While many health conditions can be monitored, telemonitoring is most prevalent in chronic disease management. Chronic diseases are defined as long-lasting health conditions and include the following four major types: cardio-vascular disease, cancer, diabetes, and chronic obstructive pulmonary disease (COPD) [25]. Cardiovascular disease is the leading cause of death world-wide [26]. Together with cancer, these two diseases accounted for almost half of all deaths in the United States of the year 2015 [27]. Speaking of finances, 86% of all health care expenditure went towards patients suffering from one or more chronic conditions [28]. The prevention of chronic disease and improving the management thereof after onset, will yield significant benefits.

These conditions often occur as a result of an unhealthy lifestyle [29]. There-fore, it is very important to spread awareness on healthy habits. Suggestions often include the following: avoid smoking, maintain a healthy weight, exercise daily and limit the time spent sedentary, and maintain a healthy diet. These lifestyle changes become even more important during chronic disease management.

The management of chronic diseases may benefit greatly from telemonitoring. Patients have access to care while having the comfort of their homes. As a result, the patient saves time and costs associated with consultations. Relatives of the patient may also be more at ease as they know the caregiver is monitoring the situation. On the other end, health care institutions save resources as care is delivered without having the patient visit [30].

At its core, telemonitoring relies heavily on interoperability as it has the potential to add many different devices to the health care infrastructure. The caregiver should be able to receive, read, and react to this data. Interoperability should already be accounted for in case the device was specifically engineered for the health care sector. However, a smartphone for example, is built for general use and not necessarily for health care. As such, these devices rely mainly on software and other connected devices to allow telemonitoring. On the other hand, extra attention must be given to usability as the telemonitoring devices often have small-sized screens. Good user interface design will lead to higher user satisfaction and may therefore impact the patient's adherence towards the management process.

2.7   Privacy & security

Privacy refers to the desire of a person to control the disclosure of personal health and other information [1]. On the other hand, confidentiality is the ability to control the release of personal health information to a care provider under the agreement that the information will not be spread or used further. Security is the protection of privacy and security, which is achieved through policies, procedures, and safeguards.

We can ask several questions related to health information data access and storage: who owns the data? Is it the health provider or the patient? Who can read data? Who can write data? Can someone access specific health information without consent? In order to deal with the some of the challenges concerning data access and storage, these questions need to be answered [31].

Medical data access raises several privacy concerns. For example, the research of the medical data of a large population may uncover looming threats or an epidemic. However, this is only possible if researchers have free access to this data, as it is not feasible to ask every individual of a population for consent. However, medical data should not be too accessible. As more and more people gain access to health data of the population, the chance of data misuse or unauthorized access increases. Therefore, striking a balance between free information access and protection of privacy and confidentiality is difficult. An argument that promotes free access is to anonymize the data by removing identifiers such as the person's name. However, the individual pieces of information can still reveal the their identity.

Compared to paper, access to digital repositories of health records is easier. This calls for extra security measures to prevent unauthorized access. To gain access to certain records, clinicians are required to authenticate themselves. Also, access control should be present. This security technique limits access to certain data based on the privileges associated with the authenticated user. Whether the authentication succeeds or not, the audit system will always record the attempt. Such systems need clear rules and policies defined by the institution on who can access what. Data encryption is mandatory, which makes the data unreadable should data breaches ever occur.

To further prevent malicious use of health data, institutions should educate their staff to make them aware of the privacy rules and policies that are in place. Appropriate punishments should be in place should someone violate these rules.

This concludes the literature overview on the electronic health record. A lot of information was presented during this chapter. Given this information, we can now design an application to resolve several issues surrounding this topic, which is the focus of the next chapter.

3 Design

This section describes the design process that was followed to create the application featured in this thesis. First, we propose a solution for several issues highlighted in the literature review. Based on the proposal, additional literature was reviewed to guide the design of the prototype. Section 3.2 describes these guiding principles. The first step of the design process led to the creation of several personas and scenarios, found in section 3.3. Hereafter, we define the functionality of the prototype with the help of a small brainstorm session. To conclude, we present a concrete specification of the application.

3.1 Proposal

The literature review indicated that several issues arose after EHR systems were installed. In this section we gather those issues and propose a solution that resolves them. During the definition of our solution, arguments are given as to why certain choices are made.

Current issues In some cases, the use of an EHR led to an increase in medical errors. Research showed that poor usability was one of the causes for this rise [14]. Another study found that the use of paper workarounds was also responsible for this increase [3], which again hints at a system with poor usability. However, the use of these workarounds also indicates that the system is not in line with the workflow of the clinician.

The installation of a new EHR system disrupts the current workflow significantly [8]. Large updates to an existing system may also cause disruptions. Clinicians need extensive training in order to work efficiently with the new system. If there is insufficient training, more medical errors may occur. It takes time to become accustomed to these changes, which leads to a temporary loss of productivity. This adaptation process may be difficult for some individuals and can spark negative emotions.

Telemonitoring increases the need for interoperability, as mentioned in section 2.6. The adoption of this care delivery method has the potential to add many different devices and software packages to the health care infrastructure. This ranges from wearables on the patient side to monitoring software on the caregiver side. There is a need for efficient communication not only between patient and caregiver, but also between several caregivers. Therefore, having a monitoring application for each individual measuring device on the patient side is undesirable.

The usage of many health software applications next to each other may negatively impact usability. Switching between these applications that feature different designs can lead to confusion and therefore increases the chance of medical errors. This is avoided by having common design principles shared across these applications. However, this is in the hands of the software vendors.

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Solution   We propose a EHR web application featuring at its core a customizable dashboard. The clinician may freely place and arrange modules on the dashboard, similar to placing widgets on the homescreen found within the Android OS. This customization element is key, as it allows the creation of dashboards that fit the workflows of the clinicians. In case the workflow changes, the clinician can change the dashboard accordingly. Behind-the-scenes, creating new modules for the dashboard should be a straightforward process. In terms of usability, the modules share a clear and concise design, and the dashboard can adapt to different screen sizes. We now go into more detail.

The choice of creating a web application was quickly made, since these applications are cross-platform out of the box. Updating the application is done by simply refreshing the web page. The development and extension of native applications for several operating systems is very costly as multiple teams of developers are needed. Also, recent web technology advancements allow much more complex applications to run straight from the browser. To give an example, Microsoft provides a web app version of its Office Suite. Section 4.1 describes the choice for a web application in more detail.

The dashboard presents a novel approach regarding interoperability. Instead of providing interoperability for multiple standalone applications, the dashboard is continuously expanded with new modules. In other words, applications are plugged in as new modules of the dashboard. As such, telemonitoring can serve as such a module, due to its reliance on interoperability. This module-based approach has several benefits:

- There is no need to switch between multiple standalone applications, which may have completely different designs.

- Clinicians only need to learn to use the modules that are required for their workflow, instead of a complete software package.

- Many different workflows can be supported by using a combination of modules.

- The dashboard can easily adapt to workflow changes by allowing the addition and removal of modules.

- Module updates do not affect other modules or the dashboard, preventing total workflow disruption.

Several of these benefits result in a lower loss of productivity as a result of workflow disruption. To guarantee a streamlined user experience throughout the dashboard, new modules inherit a template which determines its appearance. Changing this template, will change the appearance of all the modules. Also, dashboard will be designed with touch technology in mind to prevent usability issues such as the fat-finger problem and screen clutter.

In practice, vendors develop modules according to guidelines defined by the dashboard application. Integrating new modules into the dashboard still requires some work from the institution's IT staff, but no where near as much

when integrating a standalone application. Once the module is integrated, it can be seamlessly updated. The dashboard also has the ability to import patient data.

In the end, the dashboard application features cross-platform availability, easy extension of functionality, a usable and customizable interface, and a simple learning process. At this stage, additional literature was consulted to facilitate the creation of an effective design.

3.2 Guiding principles

The translation of the aforementioned proposal to an intuitive prototype is guided by several principles. It was paramount during the design and implementation phases that the final prototype provided a positive user experience. This final prototype is the result of a series of steps influenced by the MuiCSer framework. First, we explain the framework and where our approach differs from it. Hereafter, several design principles are mentioned that serve as helpful guidelines during the design process of a dashboard application.

3.2.1 MuiCSer

This section describes the MuiCSer framework, designed for user-centered software engineering processes in a multidisciplinary context [32]. This framework focuses on optimizing the user experience during the entire software engineering cycle to ensure that the needs of the end user are fulfilled. By combining user-centered design methodologies and software engineering principles, the user experience of the final product can be improved substantially. Given the multidisciplinary context of this thesis, MuiCSer served as a point of reference during the development process up to the implementation of the prototype explained in section 4.

The MuiCSer process is summarized in figure 2. After each phase, the result is evaluated, verified, and validated to ensure that the required functionality is present. In turn, the received feedback can be used to reiterate over the previous phase. On the figure, this is denoted with the light blue arrows, while the single dark arrow represents the overall direction of the process.

However, we will not follow all the steps of the process. The ones we do follow, will be adapted to speed up the development process. The cycle of repeated evaluation and iteration is time consuming. Given the broad spectrum of possible end users, such as nurses and general practitioners, the choice was made to only evaluate the high fidelity prototype via a usability test. The other artifacts that resulted from some of the MuiCSer steps, were iterated upon without involving the end user. What follows is a brief description of the steps that we will follow:

New or legacy system The MuiCSer process starts with either an existing system in need of improvement, or with a new system which needs to be built
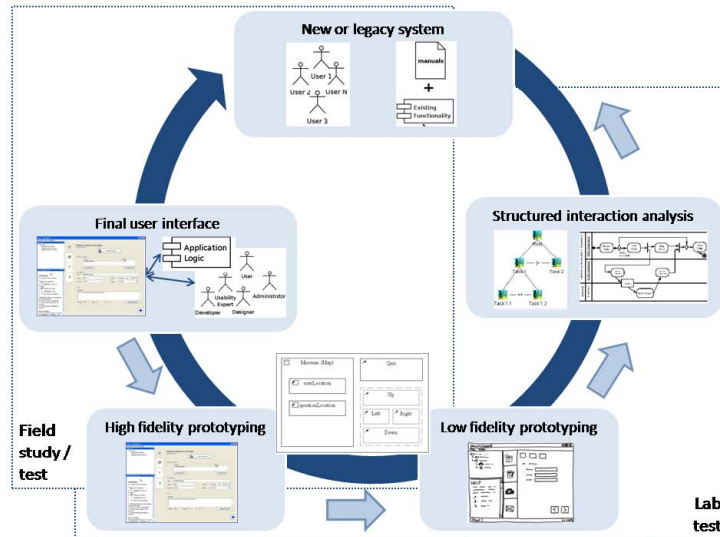
Figure 2: The MuiCSer process.

from the ground up. This requires an analysis of the tasks and needs of the user, as well as the objects and resources required to perform these tasks. Personas and scenarios are the resulting artifacts of this phase. First, personas describe the personalities of the potential end users, including their hobbies, skills and the environment they surround themselves in [33]. The goal of a persona is to uncover behavior patterns which can be of use when designing a user interface. Second, scenarios tell stories describing the use of a fictitious system from the point of view of a persona [33]. To summarize, personas and scenarios try to sketch the usage of the system for which a design must be made. These artifacts are found in section 3.3.

Low fidelity prototyping Paper sketches and mockups are examples of low fidelity prototypes. Without spending too much time and resources, presenting these prototypes to the end user or customer can yield valuable feedback. However, there is often no functionality present. Typically multiple versions of these prototypes are created until the customer is satisfied, after which the development of a high fidelity prototype starts. Low fidelity prototypes were created for all modules defined during the brainstorm session and some of them are found in section 3.5.3. Changes were minimal after each iteration, because they were not evaluated by the end user. However, every iteration tried to improve the usability of the prototype.

High fidelity prototyping The development of high fidelity prototypes requires a lot more effort compared to low fidelity prototypes, as they offer func-

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tionality closely resembling the final product. However, the end user can now test both the design *and* the functionality. This yields much more meaningful feedback. Section 4 describes the development of the high fidelity prototype. Later in section 5, the evaluation of the prototype and its results are presented.

The steps "structured interaction analysis" and "final user interface" were not followed in this thesis. During the interaction analysis, task models are created. These are of use to define an interface that supports the models. We conducted a brainstorm session instead to define common tasks in an EHR system, described in section 3.4. No final user interface was developed as this requires much more development work and long-term end-user testing. In the concluding chapter, the next steps towards a final prototype are mentioned.

3.2.2 Dashboard design

The proposal mentions a dashboard. However, dashboards are used in many contexts. Common examples include a car speedometer and stock analysis. In computer networking, dashboards are used to quickly interpret network traffic. In our case, we want to empower the user to create his or her own dashboard. To facilitate this goal, several design principles should be kept in mind.

While some dashboards provide fancy graphics, many miss the key point of what they are supposed to accomplish. The primary goal of a dashboard is clear communication, which is achieved through effective design. A formal definition is as follows: "A dashboard is a visual display of the most important information need to achieve one or more objectives; consolidated and arranged on a single screen so information can be monitored at a glance." [34]. This definition contains four key characteristics:

Dashboards are visual displays. It is important that data is represented visually. Graphics such as charts allow more efficient communication compared to textual information. For example, trends and outliers are easier spotted in a line chart when compared to a table containing the same data. Instead of using different visualizations for the sake of variety, one should *always* choose the visualization which best suits effective communication of the data in question [35].

Dashboards display information needed to achieve specific objectives. The data that is shown, must be relevant to the job at hand. Sometimes data needs to be aggregated from multiple sources after which it can be tailored according to the context wherein it must be presented. This manner of processing data yields effective data visualizations.

A dashboard fits on a single computer screen. In order to see as much information at a glance, scrolling should be prevented. If multiple screens are present, then it is no longer a single dashboard. This leads to another question: what type of display is the information shown on? In today's world, computer

displays come in many shapes and sizes. Therefore, a responsive layout can be very beneficial, but scrolling becomes inevitable as the screen decreases in size. As an example, it is impossible to present the same dashboard built for a Full HD monitor on a smartphone display. While the latter display may have the same resolution, the content will be too small to read comfortably.

Dashboards are used to monitor information at a glance. Important data should be immediately noticeable, whereas specific details should be hidden. Therefore, by summarizing or aggregating the data a more effective visualization may be achieved. However, if the user wishes to view the detailed data, the dashboard should provide means to do so. Also, careful thought must be given to what information is of importance so it is never hidden.

To create an effective dashboard, the user-base must be well known and understood. What type of users are we dealing with? What are their characteristics? These are important questions to ask, as one user may not comprehend one visualization while the other can. Therefore, the focus should be put on the user during the design of the dashboard [36]. We can ask the following questions to better understand the needs of the user:

- What metrics does the user need to see?

- What context does each metric require to make it meaningful? Do we need to visualize the variance, target to reach, trend...?

- What visualization best communicates the metric?

On that end, sketches and mockups are helpful during the design process. Multiple iterations each incorporating feedback received from the users, ensure that the end result is satisfactory.

3.3 Personas & scenarios

The first step of the MuiCSer framework involves the creation of personas and scenarios. These artifacts should give us a better understanding of the end users and how they will use the dashboard application. Each persona and scenario pair tries to highlight problems the users face and how the new system tries to solve them.

3.3.1 Jake

Persona Jake is a 25-year-old male who currently works as a nurse at the hospital in his city. He has been working there for four years and lives alone in his apartment. Still being a young adult, Jake grew up with technology. As a result, he experiences no difficulties when using new software on his computer or smartphone. His hobbies include music, playing the guitar, and video gaming.

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Currently, the workflow at the hospital is dated. A new health information system was introduced to summarize and gather all medical data in a single program. Because this is an all-in-one system, a lot of features that Jake does not need still clutter the screen. Navigating the system is difficult and customization is not present. Jake wishes to only view the features he uses most while hiding the features he does not need.

Scenario   Jake starts his first day using the new system by reading the manual that is accompanied with it. He starts the application which shows a list of patients for which he can create a personalized dashboard. When Jake opens the dashboard associated with a patient, he notices that many modules can be selected.

After adding a few modules to the dashboard, Jake has all the functionality he needs to do his work. During this process, he added a wrong module which was easily removed. Hereafter, Jake resizes and moves the modules until he is satisfied with the layout. Over time, Jake updated the dashboard of several patients by adding a module due to changes in his workflow. All he had to do was to open the module list and select the module he needed.

By examining the new module Jake quickly notices that it looks similar and is customizable in the same manner as the other modules. Jake feels he is in control of the system and convinced it will boost his productivity.

This scenario highlights the benefits of customization. Hiding unwanted and adding useful components allow for a clear dashboard to be displayed. The user is in control and is able to quickly view data of importance.

3.3.2   Dan

Persona   Dan has been a general practitioner ever since he graduated from university. He is on the job for 21 years by now and the preferred doctor in his town. Throughout the years Dan used a multitude of systems and he is always on the lookout for better ones. Because he has been a general practitioner for such a long time, he has 500 patients that visit him at least twice a year. Some patients, especially the elderly, visit Dan monthly.

Most of Dan's patients visit for illnesses such as fever and a cold. To diagnose these illnesses, a description of the patient's symptoms suffices most of the time. Dan adds each diagnosis to the electronic health record of the patient. However, if a patient with a history of blood pressure issues visits, Dan has to perform a more complex diagnosis involving historical data. In the current system that Dan uses, it is very difficult to search for and work with this data. But what bugs Dan the most is that he has to do it every time this patient visits.

Scenario   Dan tries a new health information system which allows customization for each specific patient. Because the diagnoses of most patients are different from each other, Dan creates a default module group which is displayed for each patient. This configuration is overridden if that patient already has

a specific configuration. The default module group includes past diagnoses, known allergies, patient information (blood type, last weight, height...), and the medication the patient currently takes.

The first patient of the day describes what sounds like a fever. Dan confirms this and hands the patient a prescription. The diagnosis and prescription information are added to their respective modules. Dan did not need other health data to perform the diagnosis. Therefore, Dan does not change the configuration of this patient.

The next patient, an elderly woman, visited Dan for the second time this month. Dan knows from the past that it will probably be a heart related issue. Dan searches for a 'heart' module and adds it to the configuration of the elderly woman. Now both the default module group and a heart rate module are present, which is unnecessary according to Dan. He removes some modules of the default module group. Now, the next time the elderly woman visits, that configuration will be automatically loaded.

One specific patient had broken his arm three times in less than a year. When the patient came for a routine visit, Dan immediately added a module to easily view x-ray photos and view them in a timeline.

Providing customization options as described in this scenario has immediate benefits. Initially, it will take some time to configure each dashboard for all the patients, but the system will try to make this process quick to complete. Once the configuration is finished, time spent during a consultation can decrease dramatically.

3.3.3   Emily

Persona   Just like Dan, Emily has been a successful general practitioner for quite some time. However, she has different needs of an EHR system. Between each patient visit, there is a period of time in which Emily does not know what happens to patients regarding certain parameters. For example, if a person regularly measures his heart rate and blood pressure because of cardiovascular disease, then it is important that the doctor is made aware of these values. If Emily notices a negative trend, she can contact the patient to schedule an early consultation.

In this case, Emily would like to visually see the progression of the heart rate and blood pressure values. Also, easy side-by-side comparison of both parameters would be useful. Currently, she needs to navigate from one screen to the other to do the comparison.

Scenario   Emily recently received notice of a new platform that allows 3rd party applications to easily integrate with it. Now, a mobile application can send new values towards the platform. This allows Emily to monitor the patient remotely, which saves precious time for both parties. The platform can be customized to display multiple charts of data values.

A patient who recently had a cardiac arrest is continuing rehabilitation at home. However, the patient has chest pains and pays Emily a visit. She tells the patient to regularly measure his blood pressure and heart rate, and to take note of these values in a mobile application. After they have scheduled the next visit, the patient is sent home. As the next few weeks pass by, Emily notices a climbing trend on this patient's blood pressure chart. She tells herself to regularly check up on this patient as there is currently no reason to panic.

After another two weeks, Emily takes another look at the blood pressure data. The chart clearly shows that the blood pressure values keep rising. Emily decides to call the patient to schedule an early visit. The system helped Emily to intervene as soon as the situation seemed to worsen.

This scenario gives an example of how telemonitoring can be integrated into the dashboard platform. As mentioned in section 2.6, the onset of a disease can be detected when a caregiver can monitor the patient at home.

3.3.4 Anna

Persona   Anna is a software engineer working at the local hospital. From the early 2000's, she was responsible for the integration of health software systems. As such, she has experienced the continuous change associated with health software firsthand. Each unit of the hospital uses different software, while they all share a central system to view patient records. The interoperability of these applications is one of Anna's responsibilities.

As time goes on, new software and medical instruments that improve certain workflows are purchased. Sometimes these replace old systems, otherwise they are added to work alongside them. Both are becoming increasingly difficult to do, as the codebase of the EHR system grows. When an older system gets replaced, Anna has to weed through the code and delete little pieces, hoping other parts wont break. It is a frustrating task as often band-aid solutions are applied.

Scenario   A new EHR system was installed that should improve integration of other applications. Anna skims through the documentation and starts the transition process. She quickly notices that for each application she needs to create a back end data structure and a module that represents it in the EHR system. The new EHR system integrates new modules with minimal downtime.

After the initial transition period, everything is put into place. Not soon after, new bedside monitors with accompanying software were purchased. These replace the old bedside monitors and consequently, the software. As a first step, Anna reworked the back end data structure to work with the readings from the new device. The data of the old device is converted to the new data structure, so no data is lost. Anna designed the new module to be similar in appearance and functionality. After implementing the module, the staff barely notices any change and workflow resumes with minor disruption.

This persona and scenario highlight the importance of interoperability. Significant time and effort can be saved if this process is simplified. Also, maintenance is easier due to looser coupling of the modules.

3.4 Module selection process

In order to test our prototype, the dashboard needs to feature several modules. However, we want to provide general functionality and avoid workflow-specific functionality in order to appeal to a broad audience for the usability test. Literature was consulted to find general components which EHR systems often provide. Based on the several lists existing research gave us, a brainstorm session was conducted which determined the modules we will develop for the dashboard. First, we present the several lists of common components found in literature, whereafter we describe the purpose and the results of the brainstorm session.

3.4.1 Common components of EHR systems

Many different EHR systems exist and they all offer a different feature set. This gives health institutions a several options on which one to install. However, each EHR system provides some core features which are an absolute necessity in health care. In this section we list the EHR system features found by each study, which lay the foundation of the brainstorm session.

Hillestad R., Bigelow J., Bower A. et al. (2005) provided a very general list of components [5]:

- Show information during order entry.
- Telemonitoring for chronic disease management.
- Alerts and reminders system.
- Workflow guidance.
- Reduce adverse drug effects.

Hsiao C., Hing E., and Ashman J. (2014) went into more detail compared to the previous list [37]:

- Computerized provider order entry for medications.
- Drug-drug and drug-allergy interaction checks.
- Generate and transmit permissible prescriptions electronically.
- Record patient demographics, including smoking status.
- Maintain up-to-date problem list of current and active diagnoses.
- Maintain active medication list.
- Maintain active allergy list.
- Record vital signs.
- Ability to generate an electronic copy of health information.
- Generate clinical summaries.
- Exchange key clinical information.
- Supports data privacy and security.

Elnahal S., Joynt K., Bristol S. et al (2011) went into even more detail. They revealed the following four categories of EHR components [4]:

- Clinical documentation: patient demographics, physician notes, nursing notes, problem lists, medication lists, discharge summaries, and advanced directives.
- Results viewing: lab reports, radiology reports, radiology images, diagnostic test results, diagnostic test images, and consultant reports.
- Computerized physician order entry: lab tests, radiology tests, medication, consultation requests, and nursing orders.
- Decision support: clinical guidelines, clinical reminders, drug-drug interaction alerts, drug allergy alerts, drug-lab interaction support, and drug dosing support.

To conclude, the **National Center for Research Resources (2006)** described the following key components and sub-components [38]:

- Administrative system components: registration, admission, discharge, and transfer of patients, and links from the patient to resources such as observations, tests, procedures, evaluations, and diagnoses.
- Laboratory system components: integrate orders, results, schedules, and billing.
- Radiology system components: order data, interpretations data, patient data, imaging, patient tracking, patient scheduling, results reporting, and image tracking.
- Pharmacy system components: prescriptions filling and payment forms.
- Computerized physician order entry: service ordering, customized order sets, alerting, and results reporting.
- Clinical documentation: capture of clinical notes, patient assessments, clinical reports, and flow sheets of vital signs, in- and output, and problem lists.

3.4.2 Brainstorm session

This section describes the brainstorm session which intends to group the components described in the previous section to form categories. From these categories we pick several modules which we will then implement in our prototype. An ideal tool for this situation are affinity diagrams. These diagrams help to categorize and sort a large amount of ideas by grouping the similar ones together and identifying relevant topics [39].

Result   Figure 3 shows the affinity diagram that was created. It highlights the following four categories:

- **Medication**: all components related to management of medications and prescriptions. These are: adherence, reduce adverse drug effects, drug-drug interaction alerts, drug-allergy interaction alerts, record patient medication list, order prescriptions for pharmacy, drug dosing support, and computerized medication order entry.
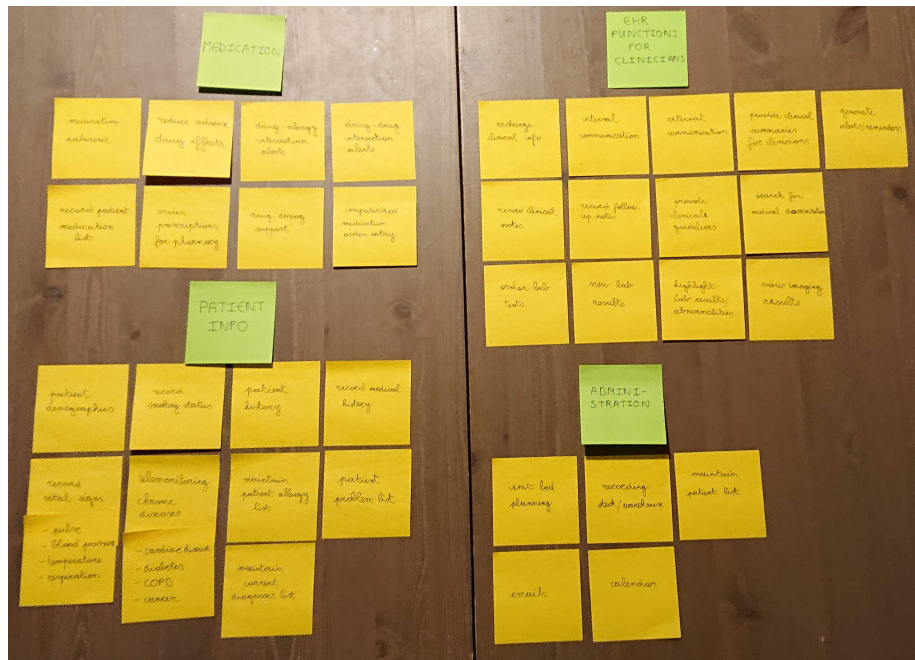
Figure 3: The affinity diagram created during the brainstorm session.

- **Patient information**: components that are related to the management of general patient data. These are: patient demographics, smoking status, patient history, medical history, record vital signs data (pulse, blood pressure, temperature, respiration), telemonitoring (cardiovascular disease, diabetes, COPD, cancer), allergy list, problem list, and a current diagnoses list.

- **Clinician-specific functions**: general components that a clinician uses, but are not related to a patient. These are: exchange clinical information, in- and external communication, view clinical summaries, generate alerts/reminders, record medical and follow-up notes, view medical guidelines, search for medical documentation, order and view lab results, highlight lab result abnormalities, and view imaging results.

- **Administration**: maintain patient list, bed planning, stock and warehouse management, emails, and calendar.

Some components such as reminder generation may be a feature found throughout an entire EHR system. On the other hand, it may only be a function of one specific component within the EHR system. Literature repeatedly highlighted medication management as an important component of an EHR system, which is also the reason why it is a category. We chose to implement the following modules in our prototype:

- Patient information: displays demographic information concerning an individual.

- Prescription list: create, update, and remove prescriptions, view the current medication scheme of a person, and provide warnings about potential drug interactions.

- Allergy list: create, update, and remove allergy entries.

- Vaccination list: create, update, and remove vaccination entries.

- Workflow: create workflow schedules for a patient. For example, performing checks at certain points in time can be defined here.

- History: view the medical history of a patient. This module records all changes made to the medical record of the patient.

- Telemonitoring: view data over time for the following parameters: blood pressure, blood sugar, heart rate, blood oxygen level, and weight.

3.5 Application specification

During this section we will describe the different components of the dashboard prototype. This specification should clearly indicate how the application is structured and how it will be used. First we describe the dashboard as a whole, after which we go into more detail for each module.

3.5.1 General structure

After the application finished loading, the user is greeted with a login screen. Once the user successfully authenticated, the patient list is shown. This list shows basic information of all the patients available to the user. It is possible to sort and filter this list. Selecting a patient opens the dashboard and loads its corresponding configuration.

Dashboard The dashboard consists of two panels. A small panel on the left hand side features the patient information module. Smaller versions of some modules can be added to the panel that each display a concise summary. Generating a summary is not relevant for every module, which is why some of them will not have smaller counterpart. The smaller modules can only be vertically arranged and resized. Due to the limited size of the left panel, these modules will take up the entire available width. In case the display of the device is small, the left panel is automatically hidden to give more space to the main panel. Pressing a button in the top left corner will show the summarizing panel on top of the main panel. By supporting smaller screen sizes, the application can be used on mobile devices such as tablets.

The main panel fills up the remaining width of the display. Modules can be freely placed on this panel. Here, modules can be resized both horizontally

and vertically. By providing resize capabilities for the modules, an even larger variety of display screens can be supported. If the screen width changes, then the modules will be rearranged automatically to fit on the new display.

Layouting   It is possible to create a module layout for each patient. Initially, the dashboard will be empty for all patients. Therefore, the user will need to add modules and arrange them on the dashboard. The layout automatically saves after each change. Dragging modules will push the others aside to give the user a preview of what will happen. Once the module is released, the layout is rearranged.

3.5.2   Modules

We now describe the functionality of each component chosen after the brainstorm session. For each module we describe its goal, functions, and whether it has a small version or not.

Patient information   This module displays some basic demographic information of the patient. It is always found at the top of the left panel and it can not be removed, because this is information you should always have access to. However, it can be resized to a smaller version to give more space to other modules on the panel. We intend to show the following information for each patient: first and last name, gender, date of birth, national identification number, blood type, height, address, phone number, and smoking status. The small version shows only the full name, date of birth, gender, and blood type.

Prescription list   The prescription list module shows an overview of all the patient's prescriptions during a certain period. The user can create, update, or remove prescriptions. In order to create a prescription, the user has to select a start and end date, a medicine, and the dosage. The dosage can be set for the morning, noon, evening, and bedtime. This is in line with weekly pill boxes that help patients adhere to their medication scheme. Interactions between prescriptions are highlighted if their time periods overlap. When the user clicks on a prescription, the following information regarding the medicine is shown: a description, side effects, and the medicines it interacts with.

A small version of this module shows the medication scheme of the patient of today. This list only shows the medicine and the dosage. Prescriptions can not be added, updated, or removed from this small version. The sole purpose of this module is to give a summary. As such, the detailed information of the prescriptions are hidden.

Allergy list   The allergy module presents a list of all the allergies the patient has. This module allows the user to create, update, or remove allergy entries. The following information has to be entered for every allergy: name, description, diagnosis date, allergy type, and the severity. Based on literature, the following

allergy types can be chosen: food, skin, respiratory, and drug allergy [40, 41]. In case an allergy does not fall within these four types, the user can indicate this. Allergies can be detected via IgE testing. The higher the IgE concentration, the more severe the reaction to the allergy. After consulting literature, five levels of severity can be selected, ranging from 1 (mild) to 5 (severe) [42]. The cited source describes seven levels, with level 0 meaning allergy absence and level 6 meaning extremely severe. These two were omitted as absence to an allergy isn't recorded and level 5 also indicates an extreme severe reaction. This module also has a smaller version, which only shows the severity, name, and type of the allergies.

Vaccination list   This module is similar to the allergy module, but instead stores vaccination entries. The user can add, update, or remove vaccinations. For each vaccination the disease name and description must be given. Optionally, a date of a future vaccination shot may be entered. Historical vaccinations shots can be added as sub-entries of the vaccination description. These entries contain a description and the date the shot was administered. The smaller version of this module will not show these entries, but only shows the diseases for which the patient is vaccinated and the future vaccination dates.

Workflow   Clinicians need to follow certain procedures. The workflow module is a tool to describe these procedures. For example, a patient has received an artificial hip. During the rehabilitation process, the patient has to reach several goals over the next few weeks. A day after the operation, the patient must be able to sit up straight. The patient should be able to stand the next day. These goals can be written down in the workflow module.

Using this module, users can define workflows and share them if desired. For each new workflow the user must indicate whether it is created specifically for this patient and if the user wants to share the module with other users of the dashboard platform. A workflow consists of a series of steps, which in turn may have sub-steps. Each workflow has a name and a description. The steps of the workflow also have a name and description. However, sub-steps only have a description.

History   As the user adds, updates, or removes data from the record of the patient, log entries are generated for the history module. It is important to have a historic view of the patient's medical record, which is the primary goal of this module. Each log entry contains information on what changed, what type of operation was executed (create, update, delete, import), from which module it originated, and the date it happened. The user can filter the history entries to only show certain operations or modules where changes occurred. There is no small module present for this module, because this data is difficult to summarize.

Telemonitoring   To conclude, the telemonitoring module will provide a visual display of date concerning the vital signs. The goal of this module is to help the

user to identify trends and to compare data of different parameters with each other. The module will generate a chart on which the data is plotted given the selected time period. The following five parameters can be monitored: blood pressure, blood sugar, heart rate, blood oxygen, and weight. These parameters were chosen since they can be measured from home and are closely related to the four chronic diseases described in 2.6.

The user can choose to plot up to two parameters on the chart, in order to view their data in relation to each other. Comparing data from the same parameter, but for different time periods is possible by adding two instances of the module to the dashboard. For example, by placing them next to each other, differences are easily spotted. A small version of this module shows the number of data entries and statistics (lowest, highest, and average value) for the selected parameters from a chosen start date until now.

3.5.3   Low fidelity prototypes

After the specification of the modules, paper mockups were created. These went through several iterations and in the end served as a starting point for the development of the user interface of the high fidelity prototype. As mentioned before in section 3.2.1, the mockups did not change dramatically after several iterations. However, if the mockups were evaluated by the end users, this might not have been the case. Every iteration tried to improve the usability by keeping the previously mentioned guidelines in mind. Some mockups were digitalized to show them in this work and are found below. Note that they are very basic. They mainly indicated what type of data to show, such as a table, an indented list, or a chart. Improvements to the visualizations were made during the development of the high fidelity prototype, which is described in the next chapter.

Allergies	⚙ ✕	
Allergy	**Type**	**Date**
Cats	Other	14/12/2004
Hives	Skin	23/04/2002
Cow milk	Food	02/02/1998

Figure 4: Low fidelity prototype of the allergy module.

Figure 5: Low fidelity prototype of the workflow module.
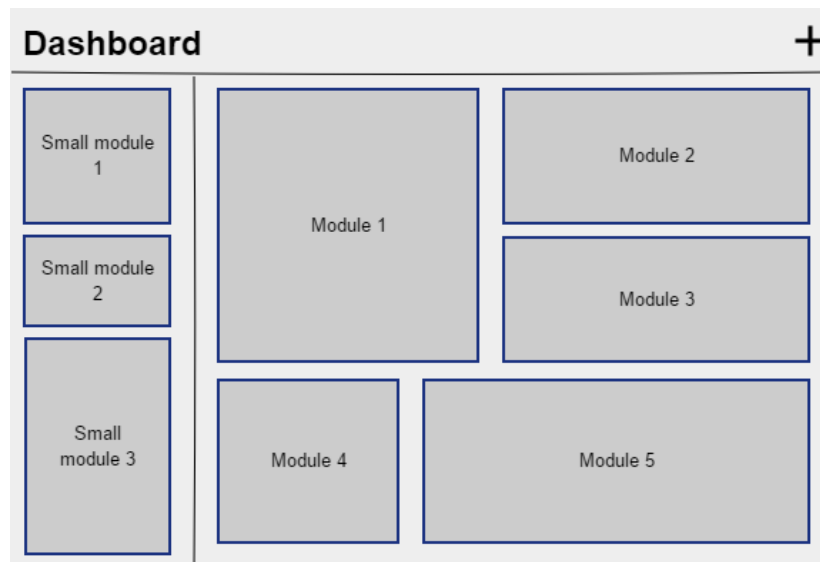

Figure 6: Low fidelity prototype of the entire dashboard structure.

4   Implementation

This section describes the implementation process. The design highlighted the usage of the dashboard through its personas and scenarios, while the low fidelity mockups gave an early glance at its appearance. At its core, the strength of the application revolves around its extensibility and usability. Therefore, a lot of thought went into choosing the best libraries to provide these features.

First, an overview of the entire application is given, after which we go into more detail. The dashboard consists of two major parts common to web development. The back end is described first. This section explains the reasoning behind the chosen technology stack and the general structure. We also specify the back end structures and REST API calls for each module and component which the front end has access to. For the front end, we explain how the Polymer 3 library supports our modular design and its underlying principles. Hereafter, other libraries used during the implementation, the general front end structure, and the resulting dashboard and its modules are explained.

It is without question that during the implementation small changes were made to the design. These changes are documented for both parts. During the entire development process, only basic authentication was implemented. The implementation of standards, privacy rules, and security techniques do not contribute towards the goal of the dashboard we defined in the design section. Therefore, we consider these topics out of the scope of the prototype.

4.1   Overview

The first major choice that was made, was the type of application to develop: a native application or a web application. It was a relative simple choice, but nonetheless an important one. Native applications are developed, in most cases, for one type of operating system. If a vendor wants to support both Android and iOS devices, two separate applications need to be developed. This requires more developers to not only create the application, but also to maintain it. Another drawback of native applications is the update process. This process often requires the reinstallation of the entire application, which is very disruptive and difficult to do in a care setting.

Web applications saw a surge in popularity. Compared to their native counterparts, web applications today are becoming increasingly similar in terms of functionality and design. Office Online from Microsoft is a good example showcasing this, which features many functions found on the desktop versions of the Office Suite. While these web applications also require updates, these happen on the server side. When the user refreshes the web page, the latest version of the application is automatically retrieved. This simplifies the roll-out process significantly. Also, all operating systems that support web browsers, are capable of running this type of application. This includes mobile devices. As a result, developers only have to develop one application. However, the variation in screen resolutions and aspect ratios calls for a responsive design.
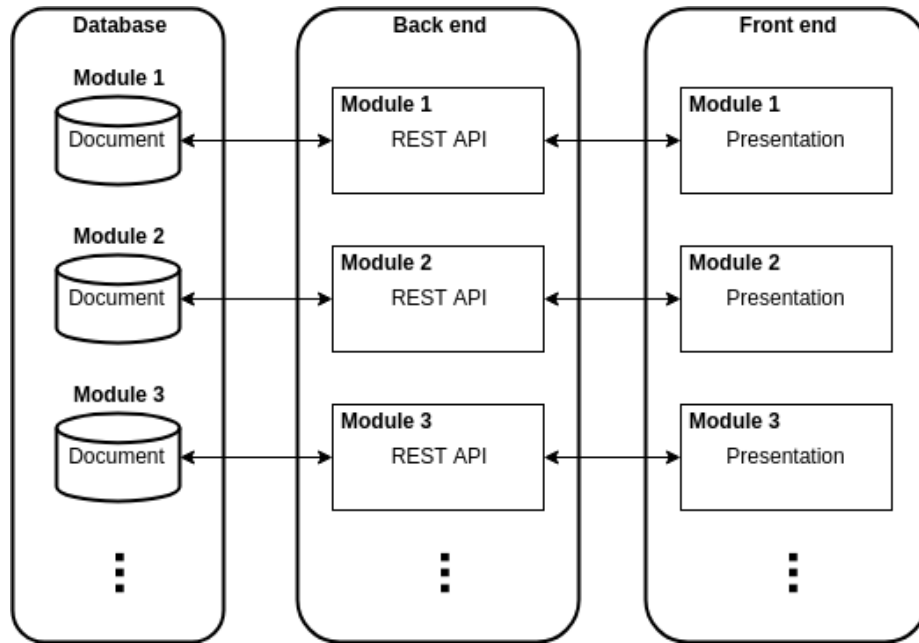
Figure 7: The communication flow by which every module communicates.

With this in mind, the choice to create a web application was evident. Users can view the dashboard regardless of the device they use, without sacrificing functionality. However, there are also disadvantages to web applications. For example, complex operations will not fit easily into a web application. The strength of web apps also leads to its major drawback: poor performance. A native application can draw much more computational power from the device it was made for. To transfer the computational burden to the server is also not a viable solution as this puts additional strain on the network. In case of real-time applications, latency becomes an issue due to continuous data transfer. However, the dashboard application should not experience any performance issues as the modules that were defined in section 3.5 do not require complex operations. Another drawback is that a web application requires a connection to a web server, limitting offline capabilities. However, retrieving medical records require a connection to a data repository anyway, for both web and native applications.

A typical web application consists of two parts: the back end and the front end. In software engineering principles, these refer to the separation of the data access layer and the presentation layer of the web application. For example, the back end fetches data requested by the front end. In turn, the front end presents the retrieved data towards the user. Due to the modular design of the dashboard, each module needs to have its own back and front end structures, visualized by figure 7. As this figure indicates, there is no direct interaction
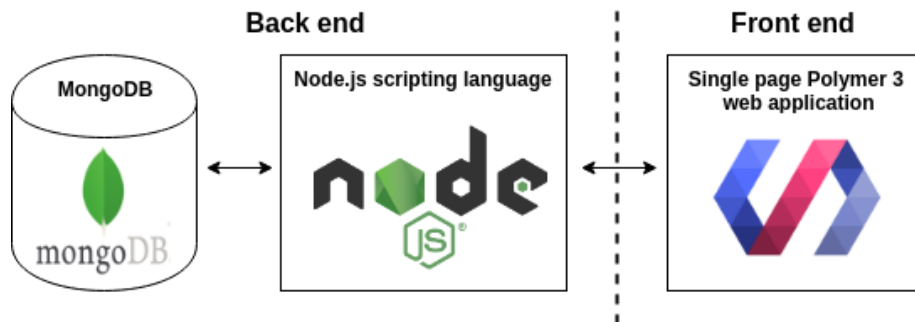
Figure 8: The three core technologies used to build the application.

between the modules, which facilitates low coupling. The next sections describe the back end and front end in detail. Changes made to the design from section 3 are explained whenever they occur.

4.2 Back end

The back end is responsible for everything related to the management of the data present in the dashboard application. It is here that the logic is defined to add, update, or remove records from the database based on the requests it received from the front end. The back end exposes a REST API which determines which requests the front end can send.

This section gives a detailed description of how the back end part of the dashboard was implemented. First, we go over the chosen technology stack after which we explain the back end structure. To close, each component present in the back end is briefly described.

4.2.1 Technology stack

Figure 8 shows the three core technologies used to develop the application. The back end was built using Node.js and MongoDB. We now give a brief explanation of what each back end component tries to achieve and why it was chosen.

4.2.1.1 Node.js

The back end server forms the heart of the dashboard application and Node.js was the preferred choice to implement it. Node.js (or simply Node) is a JavaScript runtime built on Google Chrome's V8 JavaScript engine [43]. Node avoids the classic thread-based approach to concurrency, which is relatively inefficient and can be very difficult to use. Instead, it provides concurrency via a single event loop that can support thousands of simultaneous connections, using non-blocking I/O calls. Node also has the added bonus of streamlining web development to the use of a single language.

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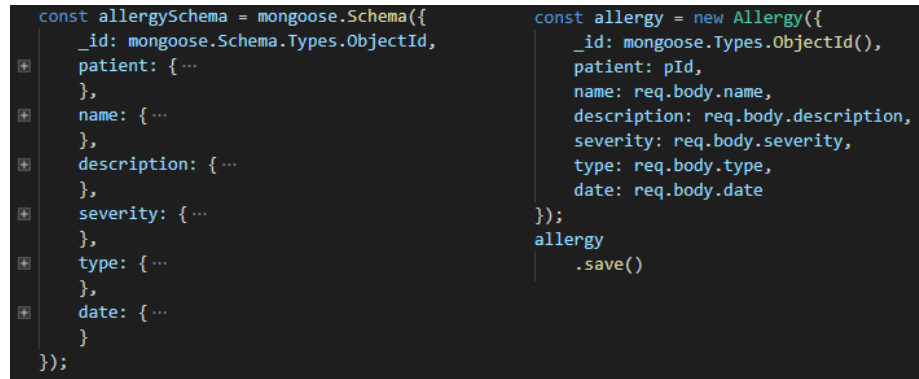The main reason Node was chosen, was due to the very large collection of packages that is available through the Node Package Manager (npm). For example, the Express package is only available via Node. This package was of significant help during the entire development process. Also, documentation is easily found thanks to the very large community that develops with Node.

4.2.1.2   MongoDB

A SQL database is table-based, whereas MongoDB is document-based [44]. This type of structure enables highly flexible data schemas, as new data fields can be added without affecting existing documents. This is especially useful when a new data structure from a 3rd party vendor needs to be added to the database. This supports the dashboard's goal of simple extensibility. Also, the developers of MongoDB officially support Node.

4.2.1.3   Node packages

Node allows developers to easily install a broad selection of packages. We now discuss the packages that were used for the development of the back end. These served many purposes, such as routing, encryption, logging, and request body parsing.

```
const allergySchema = mongoose.Schema({          const allergy = new Allergy({
    _id: mongoose.Schema.Types.ObjectId,              _id: mongoose.Types.ObjectId(),
    patient: { ⋯                                      patient: pId,
    },                                                name: req.body.name,
    name: { ⋯                                         description: req.body.description,
    },                                                severity: req.body.severity,
    description: { ⋯                                  type: req.body.type,
    },                                                date: req.body.date
    severity: { ⋯                                 });
    },                                            allergy
    type: { ⋯                                         .save()
    },
    date: { ⋯
    }
});
```

Figure 9: On the left is the schema of a model. On the right the controller creates a new allergy entry using the model.

Mongoose   Using Node without a library to communicate with MongoDB is very difficult, as data validation and casting must be written manually. By installing Mongoose, a MongoDB object modeling package, this will be taken care of [45]. Via this package we can define data schemas and its parameters. Hereafter, a data model is created by compiling the schema. It is now possible to create MongoDB documents in a very similar fashion to object-oriented programming, which encapsulates the more complex inner workings of MongoDB. Figure 9 shows an example. The entire database is constructed via these models.
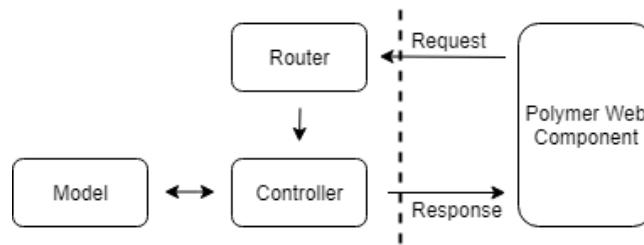
Figure 10: The architecture and interaction flow of a module.

Express   Express is a Node web application framework, which helps with the management of routing, connecting middleware, handling requests, and others [46]. It can also be of help with organizing a web application on the server side into a MVC architecture. Furthermore, Express makes the creation of a REST API server a much faster process compared to vanilla Node. Since we need to transfer data from MongoDB to our front end via a REST API, this framework is essential. Section 4.2.2 goes into detail how Express helped define the structure of the back end of the dashboard application.

Bcrypt & JSON Web Tokens   Basic encryption is provided by the bcrypt package [47]. Whenever a user registers, the password is hashed and then stored into MongoDB via Mongoose. In case the user successfully authenticates, the JSON Web Tokens package generates a token based on the login name, user id, clearance level, and a secret phrase [48]. This token is sent back to the front end and from now on, must be embed into every future request. After one hour, the token expires and the user must authenticate again.

Other   The body-parser package helps as its name implies with parsing request bodies. This package is connected to Express as middleware, since it captures the request and parses it before it lands into the developer's hands. For example, accessing parameters in the body of a POST request is done with this simple statement: `request.body.paramName`. Morgan is another helpful package which logs all requests made to the server. As such, it is a helpful debugging tool. Last, but certainly not least, is the nodemon package. Nodemon detects changes in a Node project. If changes are found, nodemon automatically restarts the server to apply these changes.

4.2.2   Structure

As mentioned before, the Express framework can help with organizing a web application into a MVC architecture. As such, the entire dashboard prototype is built around this architecture. A MVC architecture consists of three parts:

- Model: the part that manages the data and receives input from the controller. This is handled by Mongoose.

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- View: the view presents the model or in other words, the data. The front end is our view, which is a Polymer 3 server.

- Controller: the controller handles incoming requests from the view. Hereafter it calls the model to receive the desired data, which it then returns to the view. This is realized on the back end Node server with the help of Express.

Every module present in the back end has three files of the same name that are spread across the following three folders: controller, models, and routes. Figure 10 visualizes the architecture. The following example explains how the components are connected:

1. The front end sends a request to a certain route. Express checks this route and sees that the file `routes/patient.js` uses it.
2. `routes/patient.js` has every possible API endpoint mapped to a controller function which executes certain logic to retrieve data. All these controller functions are found in the `controller/patient.js` file.
3. Last, certain logic gets executed depending on which controller function is called. The controller calls the Mongoose model to perform certain actions on the database, which is defined in `models/patient.js`.
4. Depending on the operation, the controller can send data retrieved from the model back to the view. This transaction does not pass by the router.

In order to extend the dashboard application, these three files need to be created for each component.

Routing   The routes defined in the back end follow a simple structure. The application starts at the root endpoint: `/`. Suppose the server receives a request destined for the following endpoint: `/clinician/login`. At the root level, in `app.js`, the server forwards all routes starting with "clinician" to the routes defined in `routes/clinician.js`, due to the following line:

```
app.use('/clinician', clinicianRoutes);
```

All routes defined in `routes/clinician.js` are therefore called sub-routes, since they aren't defined at the root level.

The same counts for data associated with patients, but one step further. Suppose the server gets the following request: `/patient/id123/allergy`. The server will forward the `/id123/allergy` part to `routes/patient.js`. The patient module will now forward this route to `/routes/modules/allergy.js`, due to this statement:

```
router.use('/:pId/allergy', allergyRoutes);
```

4.2.3   Components and dashboard modules

We now briefly describe the purpose of every component within the back end of the prototype.

Clinician   This component allows users to sign up an log in to the system. The controller uses the previously mentioned bcrypt package to provide encryption. Also, the JSON Web Token package is used to return a authentication token should the authentication be successful. The model simply saves the username, encrypted password, and a clearance level. The last field was added to provide basic access control. However, this is not present in the prototype.

Layout   The layout component allows the front end to save the current configuration of a dashboard. The model stores the patient id, user id, size of the patient info module, a list of the small modules with their corresponding heights and locations, and a list of the main modules with their corresponding dimensions and locations. The existing layout is always deleted first before the new one is saved. This ensures that only one layout configuration exists for every user-patient combination.

Import   This module makes it possible to import a large set of patient data in a JSON format, which can be useful when migrating to this system. The component calls import functions from the patient component, which is described below. The data needs to be conform to the specification mentioned in appendix A.2.

Patient   The demographic data of a single patient or of all patients can be requested via this module. The router also receives requests that are meant for the dashboard modules, as explained in section 4.2.2 during the routing example. The controller also delegates parts of its import process to the relevant modules. For example, if the import information contains a key "prescriptions", then the patient controller passes this data on to the prescription controller.

Dashboard modules   The components related to the dashboard modules are straightforward in terms of functionality. These modules support the CRUD operations. However, the history module only allows the reading of data, since this is sensitive data that should never be deleted. Also, the history controller is called in the other controllers in order to log data changes. Additionally, the telemonitoring has sub-components for each parameter it supports. These are: blood pressure, blood sugar, heart rate, blood oxygen, and weight.

4.3   Front end

The front end serves as the face of the dashboard application and is more complex than its back end counterpart. Throughout the lengthy implementation phase several changes were made, which required some work to be redone, but in the end promotes better extensibility and usability.

A modular dashboard was built using the Polymer 3 framework in combination with several libraries. The topics web components and shadow DOM are very important in realizing loosely coupled and highly cohesive modules,

which is why it is important to understand them. After the used libraries are explained, the structure of the front end is described. To conclude, the end result is shown via various screenshots of the dashboard and its modules.

4.3.1 Polymer 3

Polymer is an open-source library that provides a set of feature for creating web components [49]. The library is developed by Google and contributors. Several Google services such as YouTube and Google Earth were developed with Polymer.

HTML provides us with standard elements such as `h1` and `img`. Web components allow the developer to create custom elements which are used in the same manner as the ones HTML provides. Suppose a calendar web component was created, a developer could add the element to any web page as follows: `<calendar></calendar>`. The actual definition of the calendar module resides in another file which is imported on the page where it will be used. This approach promotes the creation of reusable components. This also means that the dashboard application can be easily extended with these components. This is largely made possible by the shadow DOM.

Shadow DOM   The Document Object Model describes a tree of documents. The web browser builds such a tree for every web page it loads. The shadow DOM can be seen as a scoped subtree inside a custom element. The root of this subtree is called the shadow root. The structure, styling, and behavior of the children within the shadow DOM do not affect any elements outside of it. Therefore, the appearance and functionality of the custom element is encapsulated and hidden at the document level. Only events fired by elements in the shadow DOM can be caught outside the shadow DOM boundary. This idea of encapsulation is important for our approach towards the dashboard, as each module is responsible for its own appearance and functionality. Developers of custom modules should not need to worry about what happens outside of the shadow DOM.

4.3.2 Libraries

The dashboard must support resizing, and dragging and dropping of modules. To realize this, several libraries were compared with each other and the best fits were chosen. During this section the libraries used to create the front end functionality are described.

Packery & Draggabilly   Packery is a JavaScript library that makes gapless and draggable layouts [50]. As items are added and removed from the grid, Packery reorders the layout. The documentation of the library mentions that drag and dropping is supported via the Draggabilly library. This built-in support was the main reason Packery was chosen. There are two Packery grids in the prototype, one for the left panel and one for the main panel.

Interact.js This library implements JavaScript drag and drop, resizing, and multi-touch gestures for modern browsers [51]. However, Draggabilly already provides drag and drop functionality. Since Interact is not supported by Packery, we can't replace Draggabilly with it. Therefore, Interact serves as the library that implements the resizing functionality for the modules.

Other The handling of dates throughout the dashboard is done via the Moment library. This library provides very intuitive manipulation methods which are of great help when communicating dates back and forth to the back end. The charts of the telemonitoring are generated via the C3 library, which is a wrapper on top of the D3 library.

4.3.3   Structure

To start, the entire dashboard is packaged as web component. The application is loaded by placing `<main-element></main-element>` as the single child in the of the body found in the `index.html` file. This opens up the ability of having multiple instances of the application open side by side. However, this was not explored further.

All modules are placed in the `src` folder. This includes the `main-element`, but also the following web components: all modules that can be placed on the dashboard, the patient list (`patient-list-element`), and the patient information module (`patient-element`). Inside the `src/modules` folder each module is placed into its own folder. In case the module has both a small and a normal version, two files are found within this directory. Small variants of modules always end with the `-small` suffix. For example, the allergy module folder contains the files `allergy-element.js` and `allergy-element-small.js`.

The root of the `src/modules` folder contains the following two files: `base-element.js` and `base-element-small.js`. These are base web components which all other modules have to extend. This gives each module a streamlined look and design. Also, these base components provide templates which may or must be overridden for the module to work with the dashboard. We describe both base components now in detail.

4.3.3.1   Base components

Both base components provide the functions, interface elements, styling, and properties that all modules in the dashboard should have. They serve as a starting point for the developer when creating a new module. It saves the developer time as a basic layout along with utility functions are already defined. They also prevent code duplication. For example, the format of dates displayed in the modules is defined in the base component. Change this format in the base component and it will reflect to all other modules. The next paragraphs go into detail what both the normal and small base components provide.

Normal base component   The component provides a small block in which a header is defined. This header contains a placeholder title and dialog button. A button in the top right corner to remove the module is also present in the header, which can not be overridden or removed. Five templates exist which can be overridden:

1. `cssTemplate`: define the CSS styling here. Is empty in the base module.
2. `ironAjaxTemplate`: define ajax calls here using the `iron-ajax` web component. Is empty in the base module.
3. `dialogTemplate`: define dialogs that may be opened by the module in this template. Is empty in the base module.
4. `contentTemplate`: contains the actual content of the module. Contains a placeholder in the base module.
5. `dialogButtonTemplate`: specify the action to occur when this button is clicked, such as opening a settings dialog to configure the module. Contains a placeholder in the base module.

The title can be overridden by modifying the property in the extending module, which the following statement does: `this.title = 'Vaccinations';`

Finally, the base component provides several functions, some of which are placeholders that need to be overridden. These functions serve either as utilities for use within the module, such as getting a formatted date string, or as a function that is called from the `main-element`, such as getting the minimum size of the module. We now list these functions:

- `setDateFormats(datePicker)`: sets the format of the date picker if one is present in the module.
- `getDateString(date)`: converts a date to a string in the DD/MM/YYYY format.
- `getTimeString(date)`: gets the specific time from a date in the HH:mm format.
- `setPatientId()`: stores the id of the current loaded patient to a class variable.
- `update(e)`: called by the `main-element` to signal that the module should refresh its data. Needs to be overridden to send the data requests to the correct route.
- `sendUpdateSignal()`: should be overridden to fire a signal telling the `main-element` all instances of this module should refresh their data. The dashboard will do this by calling `update(e)` from those modules.
- `getMinSizes()`: called by the `main-element` when creating the module. Should be overridden by returning the minimum width and height of the module.
- `getSettings()`: called by the `main-element` when saving the module layout. Should be overridden to return the state of the module in case it needs to be saved.
- `loadSettings(settings)`: called by the `main-element` when loading the layout. Should be overridden in order to restore the state of the module.

Small base component The smaller component is similar to its normal counterpart. However, it is smaller in terms of what it provides. This module also contains a header with a placeholder title. The only other part of this header is the remove button. All templates except the `dialogButtonTemplate` from the normal base component are present and have the same purpose in the smaller version. The title of this module is also overridden in the same manner as the normal base component. The smaller module provides a subset of the functions of its counterpart:

- `getDateString(date)`: converts a date to a string in the DD/MM/YYYY format.
- `setPatientId()`: stores the id of the current loaded patient to a class variable.
- `update(e)`: called by the `main-element` to signal that the module should refresh its data. Needs to be overridden to send the data requests to the correct route.
- `sendUpdateSignal()`: should be overridden to fire a signal telling the `main-element` all instances of this module should update their data. The dashboard will do this by calling `update(e)` from those modules.
- `getMinHeight()`: called by the `main-element` when creating the module. Should be overridden by returning the minimum height of the module.
- `getSettings()`: called by the `main-element` when saving the module layout. Should be overridden to return the state of the module in case it needs to be saved.
- `loadSettings(settings)`: called by the `main-element` when loading the layout. Should be overridden in order to restore the state of the module.

4.3.4   Dashboard

Once the user opens the application, Packery will initialize the grids found in the two panels of the dashboard. Hereafter, the user must authenticate by providing his/her credentials. If the authentication succeeded, then the patient list will present itself. If the authentication failed, the user will have to try again. Once a patient is selected, the process of loading the layout starts, which we describe in the next section.

4.3.4.1   Layouting

Load configuration As soon as a patient is selected, Packery removes all modules that are present in the two grids. Hereafter, the patient information module is added to the left panel. Now the module configuration can be loaded, which consists of the following steps:

1. Call the API to receive the layout configuration of the current patient.
2. Load the small modules:
   (a) Create the module.
   (b) Set the configured height of the module.

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(c) Add the module to the grid of the left panel and tell Packery to place it at the location where it originally was.

(d) Restore the state of the module by loading its settings.

3. Load the other modules:

(a) Create the module.

(b) Set the configured width and height of the module.

(c) Add the module to the grid of the main panel and tell Packery to place it at the location where it originally was.

(d) Restore the state of the module by loading its settings.

This process only occurs when switching between patients. If there is no configuration, the dashboard will be empty.

Save configuration Whenever the user makes changes to the layout of the dashboard, the layout is automatically saved. The auto-save happens after one of the following events occur in either panel: adding or removing a module, moving a module, resizing a module, or changing the state of a module. The save process is as follows:

1. Retrieve all main modules from Packery and retrieve their settings, and calculate their sizes and locations.

2. Retrieve all small modules from Packery and retrieve their settings, and calculate their heights and locations.

3. Retrieve the current size of the patient information module.

4. Send all this information via the REST API to the back end.

4.3.4.2 Adding modules

The creation of the modules in itself was not difficult to do. However, an issue arose in an attempt to make these modules draggable. In order to make something draggable with Draggabilly, the library needs to have an identifier of an object such as a class name, that will serve as a drag handle. The original plan was to provide drag and drop by selecting the module title in the header of the module. This would serve as the drag handle. However, Draggabilly could not find the identifier, because it was encapsulated in the shadow DOM of the module.

The solution to this problem was to place the web component into a container which contains a thin bar at the top that serves as the drag handle. This is automatically done for all modules and does not require extra attention from the developers. Screenshots show the small grey bar at the top of the module. The following steps were taken to create the container:

1. Create the module and the container.

2. Set the resize event listeners on the container.

3. Set the minimum dimensions of the container.

4. Create the handle with its corresponding class name.

5. Append the handler to the container.

6. Append the new module to the container.
7. Set the remove and broadcast event listeners.
8. Add the container to the Packery grid.
9. Create a Draggabilly object for the container and bind it to Packery.

4.3.4.3 Resizing

As mentioned before, the Interact library was used to implement resizable components. For small modules, resizing is only possible by dragging the bottom edge. The normal modules can be resized by dragging the bottom and right edges. In order to provide a clean layout, the modules are resized in chunks of 20 pixels. This simplifies the process of arranging into a neat layout. This was done by subtracting the remainder of the division by 20 of both the width and height during the resize. In case the new width or height is different from the current one, then the resize occurs. While resizing, Packery wil move other modules out of the way. Interact also provides a listener to detect when the resizing has ended. After each resize end, the dashboard saves the layout changes.
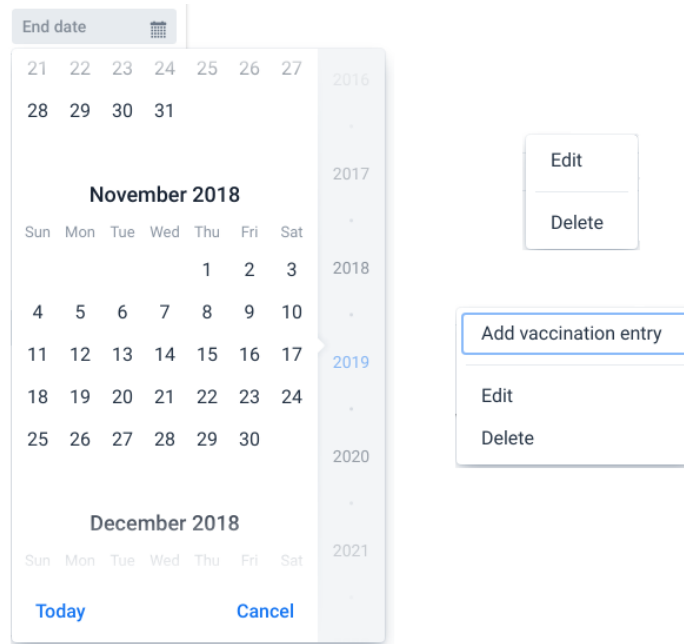
4.3.5 Modules

Figure 11: Left: the `vaadin-date-picker` component, right: two examples of the `vaadin-context-menu` component.

This section provides implementation details for each module. Some 3rd party
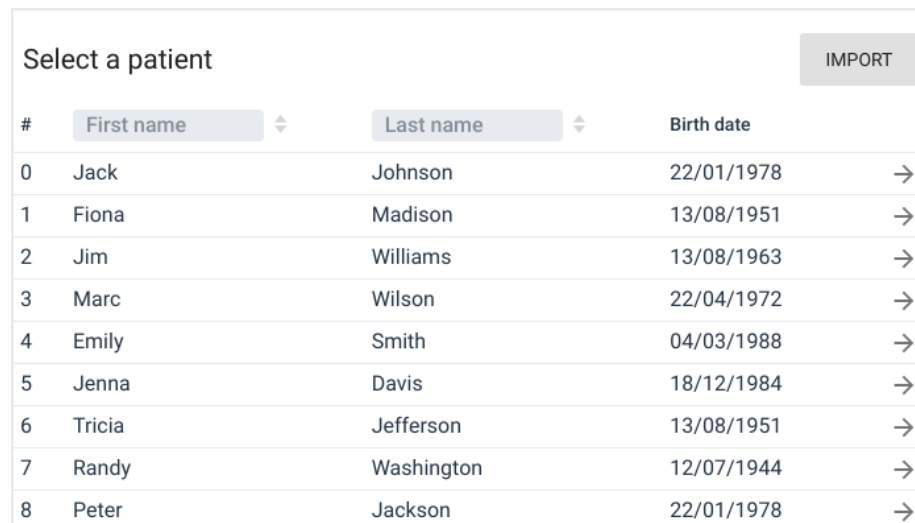
web components were used to provide features needed by several modules. These are the following: `vaadin-grid`, `vaadin-date-picker`, and `vaadin-context-menu` [52]. We briefly explain what role each Vaadin component has within the dashboard after which we describe the dashboard modules.

Vaadin grid   The `vaadin-grid` component creates data tables that have a clear interface and has support to show details of data rows. Throughout the dashboard, all data lists are made with this component.

Vaadin date picker   This component provides a date selection field. All dates are entered via this component. The user enters dates by either typing them in a correct format, or by selecting the date using the widget, which figure 11 shows shows on the left.

Vaadin context menu   The user can press the right mouse button on certain data to delete or update it. Otherwise, buttons would need to be displayed to provide these actions, which may clutter the screen. The data displayed in the Vaadin grid components can be edited this way. Two examples of such context menus are displayed on the right side of figure 11.

4.3.5.1   Patient list

#	First name	Last name	Birth date	
0	Jack	Johnson	22/01/1978	→
1	Fiona	Madison	13/08/1951	→
2	Jim	Williams	13/08/1963	→
3	Marc	Wilson	22/04/1972	→
4	Emily	Smith	04/03/1988	→
5	Jenna	Davis	18/12/1984	→
6	Tricia	Jefferson	13/08/1951	→
7	Randy	Washington	12/07/1944	→
8	Peter	Jackson	22/01/1978	→

Figure 12: The patient list component.

After successful authentication, the user sees the patient list. This list shows basic information concerning the patients that are in the system. Also, it is possible to sort and search by first or last name. As figure 12 shows, the user

can import patients by pressing the button in the top right corner. This opens a dialog box that accepts raw JSON data. The JSON data must follow the specification from appendix A.2. Also, this module does not extend the base component mentioned in section 4.3.3.1 because it will never be placed on the dashboard.

4.3.5.2 Patient information
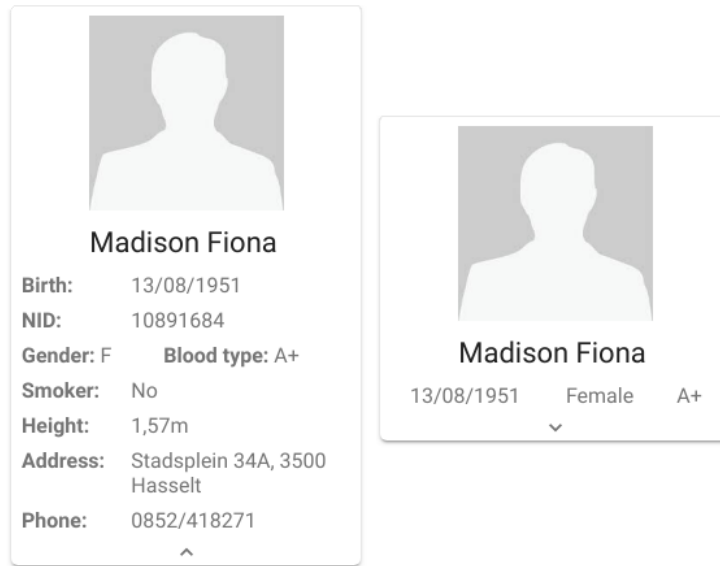
Figure 13: The two possible sizes of the patient information module.

The patient information module is always present on the left panel of the dashboard and it can not be removed. The reasoning behind this, is that clinicians should always be able to see which dashboard is open. It is possible that the name of the patient only appears in this particular module and if it is removed, confusion may arise. By pressing the arrow button on the bottom, the size of the module changes, which in turn triggers a layout save. Figure 13 shows the two possible sizes. This was implemented by swapping between two `div`'s every time the arrow button was pressed. There are no notable changes made to this module, compared to the design. The picture at the top of the module is a placeholder. This module also does not extend the base component, because it can't be freely placed on the dashboard.
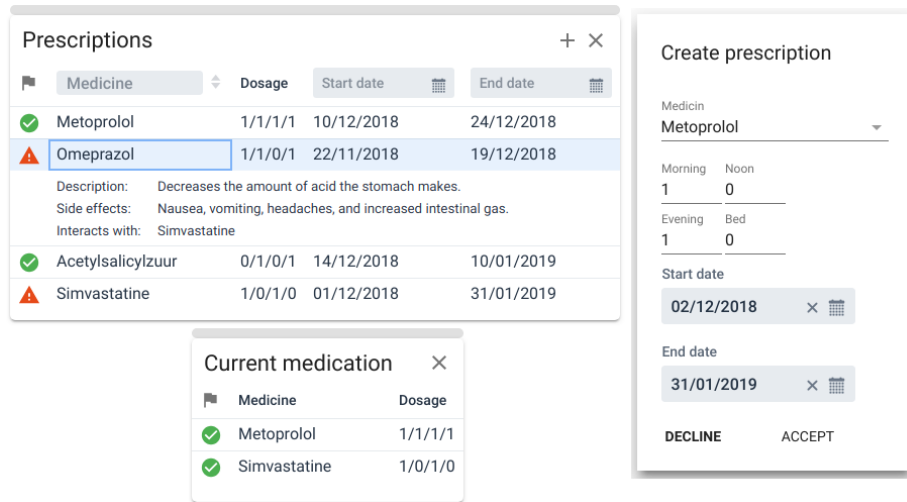
Figure 14: The normal and small version of the prescription module. Adding prescriptions is done via the dialog on the right.

4.3.5.3 Prescription

The prescription module is unchanged compared to the design. This module uses the Vaadin grid for both the small and normal versions to display the prescriptions, as figure 14 shows. Removing and editing the prescriptions is done via the Vaadin context menu. Also, note the gray drag handle on top of the modules. In case there are interactions, the icon in the leftmost column changes. Hovering over this icon indicates the interacting medicine.

When no dates are selected, all prescriptions that were ever assigned to the patient are shown. As soon as two dates are selected, the module checks if they are valid. These checks include that the start date must be before the end date. Every time the module receives prescriptions, it checks for prescriptions against interactions. Because this is a prototype, fictive interactions were created.

The small module always shows the medication the patient takes of today. This gives the user a way to quickly see the current medication scheme of the patient, without showing too much details. As such, from the small module no prescriptions may be added, edited, or removed.
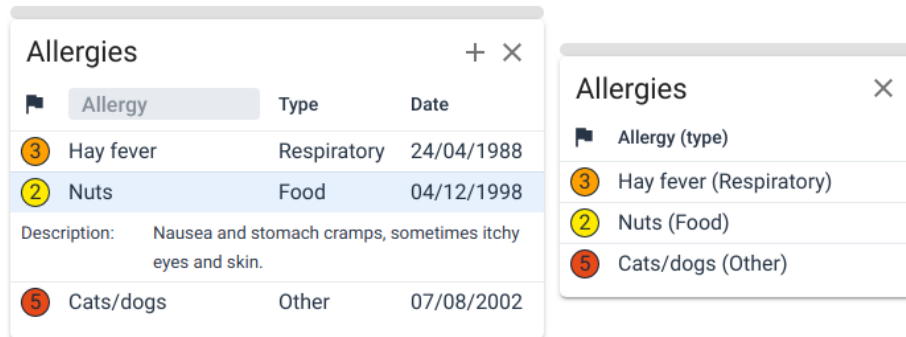
Figure 15: The normal and small version of the allergy module.
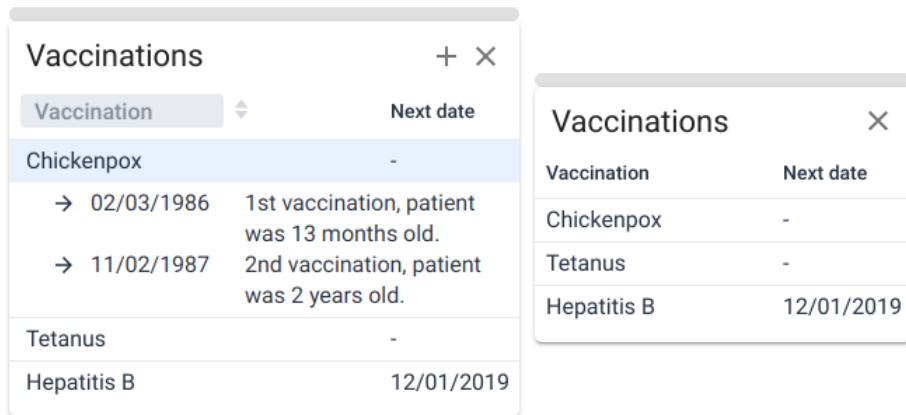
Figure 16: The normal and small version of the vaccination module.

4.3.5.4 Allergy

The allergy module may be the simplest one in terms of design and functionality, but it still is an important part of an EHR. No changes were made to the design of the module. Shown in figure 15, a more severe reaction to the allergy is indicated by a red icon. Again, the small module only serves as a reference and no changes to the allergies can be made from here.

4.3.5.5 Vaccination

This module is very similar to the allergy module. It shows a list of conditions for which the patient is vaccinated. In case a revaccination is scheduled, this date is also shown. For each condition, historical vaccinations can be added via the context menu (figure 11, right). These vaccination entries have a description and a date, as shown in figure 16.
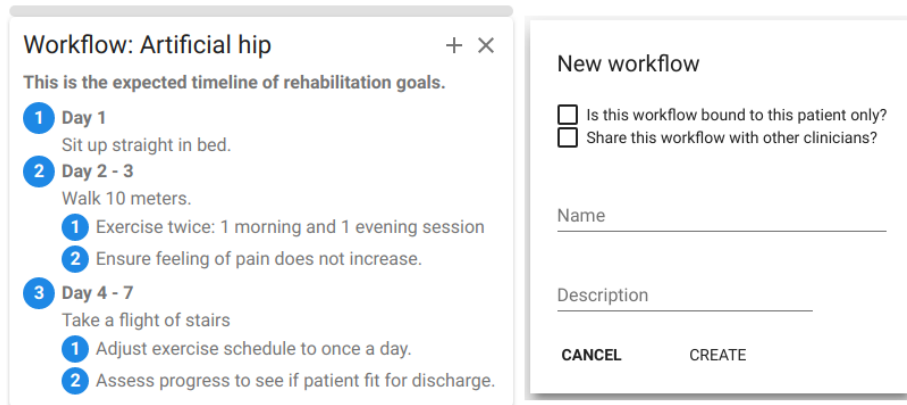
Figure 17: The workflow module on the left, showing a workflow for the example mentioned in section 3.5.2. The dialog on the right is used to create a new workflow.

4.3.5.6 Workflow

The workflow module was difficult to implement. However, there are no significant changes compared to the design. Figure 17 shows a workflow and also the dialog to create a new one. Whenever the user loads a workflow the layout is saved. The module overrides the `loadSettings(settings)` and `getSettings()` functions of the base component to save and load the identifier of the currently loaded workflow. It should be noted that multiple instances of this module may be added to the dashboard, with each showing a different procedure. They will not interfere with each other. Because these workflows can contain a lot of information, no small module was made. Providing a summary in this case is not useful, nor clarifying.
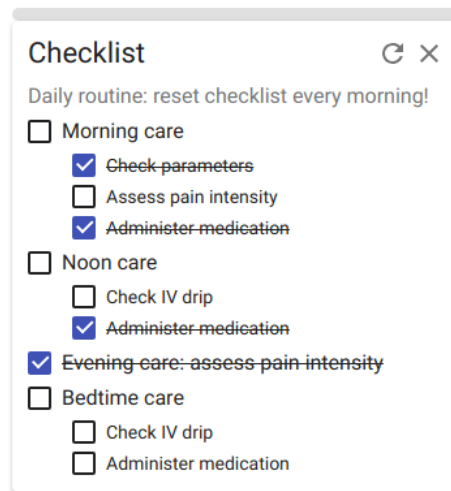
Figure 18: The checklist module.

4.3.5.7 Checklist

As a result of the workflow module, a new module not mentioned in the design was made. A checklist module was created which allows the user to add tasks and potential sub-tasks. This checklist is bound to the patient, so if one user checks off a task, it will also be checked for another user. The module was implemented by editing a copy of the workflow module, due to being similar in structure. The result is shown in figure 18. The button to the left of the remove button resets the entire checklist. A small module was not created for the same reasons one wasn't created for the workflow module.
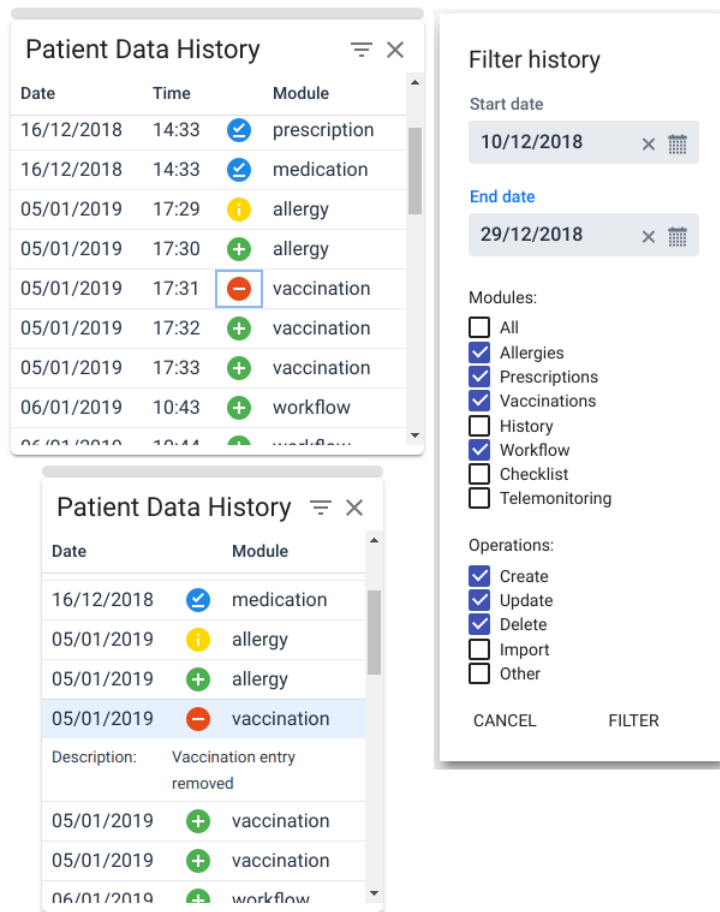
Figure 19: The history module where the wide module shows an extra column. Filters are set via the dialog on the right.

4.3.5.8 History

The history module was added late in development. No significant changes were made to the design. As figure 19 shows, the wider history module has an extra time column. This was an experiment regarding the resizing functionality to show and hide elements as the component grows or shrinks. Filters are set via the dialog on the right hand side of the figure. Historic entries can not be removed, only read, as they may be examined in an audit. No small module was added, as this can't be summarized in a clear manner.
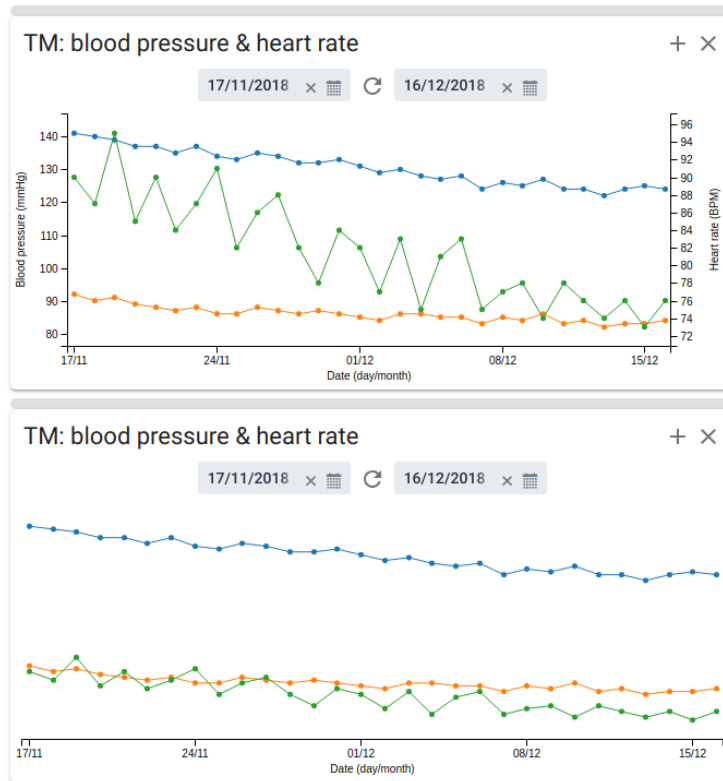
Figure 20: The top chart labels both parameters on the y-axis, while the bottom one doesn't.

4.3.5.9 Telemonitoring

The telemonitoring module was the last one to be added to the dashboard. As previously mentioned, C3 was used to plot the data onto a line chart. When the module is added to the dashboard, it will show no data until the user selects the parameters to plot on the chart. This is done by pressing the plus button in the top right corner, which opens a dialog to select the parameters. A maximum of two parameters can be shown on the same chart at a time. In case there are no values for a certain parameter, then the user can't select it. Once a parameter is selected, the user may choose to plot it according to the y-axis. To compare two parameters in relation to each other, it is suggested to plot both these data sets on the y-axis. This normalizes the data on the chart, which in turn makes it easier to compare the data. Figure 20 shows the difference. The differences of the green line are in the top chart much more noticeable. However, one can argue that the differences are exaggerated while there is not much difference, which the bottom chart implies.

Currently, the chart is completely redrawn every time the module changes
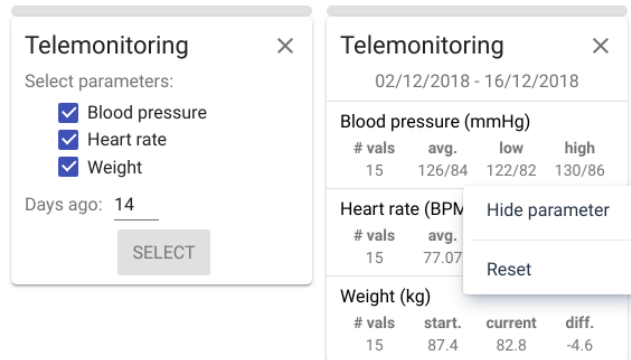
Figure 21: On the left, the user needs to configure the module. On the right, the summary is shown, together with its context menu.

size. Drawing the chart once and repeatedly resize that one resulted into unexpected behavior where the chart could only grow, but not shrink. Others have reported this on the GitHub page of the library and it is a known issue. As a result the chart is redrawn every time. Thankfully, we did not notice any slowdown. Also, changing the options of the chart will trigger a layout save.

The small module serves to give a brief summary of all the parameters the user selects for a certain time period. When the module is added, the user must select the parameters to summarize. Also, the user must select a starting date to generate the summary for, by providing the number of days to go back to from today. If the user selects 14, a summary is generated for the data from two weeks ago until today. Once the module is configured, the layout is saved. To reconfigure the module or hide a parameter, right clicking the parameter will open a context menu. Figure 21 shows the module. Left on the figure the parameters blood sugar and oxygen are hidden, because there are no data values of those parameters for the current patient. Also, this module can not be resized because the summaries are of fixed height.

5 Usability test

As the prototype neared completion, a usability test was designed. As the name implies, the purpose of such a test is to assess the usability of a prototype. While the prototype is being tested by a user, the researcher takes note of any usability issues that may arise. This evaluation method results in valuable feedback, as it shows directly how real users use a system [22, 53].

In this chapter we describe the design and results of a usability test to assess the user experience of the dashboard prototype. This test will focus on the usability aspect of the prototype, and not on the extensibility. However, in the future work section (6.2) we give suggestions to test this aspect. All the documents created for the test are found in appendix A.3.

5.1 Purpose

The goal of this test is to evaluate the usability of the dashboard prototype. The modules were designed with the usability principles mentioned in section 2.5 in mind. Customization was added by giving the user more freedom in defining the functionality present in the dashboard. However, the experience of the end-users will determine if this is of added value when used in a clinical setting. Therefore, we are interested in gathering the following information:

- Is the dashboard easy to use? Is there a low or high risk of errors?

- Is the dashboard easy to navigate? Are all functions easily found?

- Does the dashboard as a whole succeed in displaying information in a clear and concise manner? How about the individual modules?

- Is the layout customization practical? Is it fast, slow, error-prone...?

- How does the usability of the prototype compare to the system the tester uses?

Depending on the answers we receive to these questions, we can determine the next steps to take in future research, mentioned in section 6.2. While our primary concern is the evaluation of our prototype, we also want to gain insight on the EHR system(s) the tester uses. This way, we can identify potential improvements or additional features for our prototype going forward.

5.2 Participants

The prototype is designed for use in different medical settings, which are staffed by many different roles. To get the best possible results, we want our group of participants to cover as many different roles as possible. For example, an general care nurse has completely different expectations from an EHR system compared to a paramedic. This will yield feedback we would otherwise not have received if all participants had the same role.

Therefore, we need variety. Our participants should represent a wide spectrum of the health care industry in terms of the roles they fulfill. On top of that, having participants from different age groups is encouraged. Given the scope of this thesis, we chose the following sectors and roles to gather participants from:

- Laboratory unit: conducting tests and management of lab orders and results.

- Intensive care unit: requires close/real-time monitoring of several patients.

- General inpatient care: for example non-critical pediatric care within a hospital.

- Emergency response: for example a paramedic. Needs to respond fast, handle stressful situations, and needs to be mobile.

- A general practitioner: sees many patients daily with a large variety of conditions.

Now that we know who we want to test, the next question is how many. Nielsen determined that five participants find almost as much usability problems as for example a group of ten [54, 53]. In other words, five participants result in the optimal benefit-cost ratio associated with user testing. However, there are exceptions to this rule. A quantitative study for example should test a lot more individuals in order to get statistically significant results.

Our test is qualitative in nature, since we want to get a deeper understanding of what the needs of the end-user are. We are interested in *why* the user experiences certain things. Therefore, according to Nielsen, we don't need to gather many participants, but preferably still more than five. This is due to the fact that the end-users of the dashboard have different professions and work in different care settings. The needs of each participant vary greatly between these settings, which is why five participants may fall short in uncovering some important usability issues.

5.3   Test procedure

During the recruitment, willing participants may choose when and where the test will take place, given the location will not cause any disturbances. After meeting up, the following procedure takes place, with the estimated time for each step:

1. Pre-test, 5 to 10 minutes:
   (a) Greet and brief the participant.
   (b) Ask for informed consent.
   (c) The participant fills in a questionnaire which asks for demographic information and information concerning the EHR system he/she currently uses.
2. Test of the dashboard prototype, 20 to 25 minutes:

(a) Give the participant a brief tour of the prototype.

(b) The participant starts following the step-by-plan while being observed. No help or suggestions will be given unless necessary.

3. Post-test, 10 minutes:

   (a) The participant fills in a second brief questionnaire about the user experience.

   (b) The participant is interviewed. We go over suggestions, what was good/bad, future modules... Additional questions may be asked as the interview goes on.

   (c) Debrief the participant and hand out reward.

The informed consent form found in appendix A.3.1, is printed twice and filled in on the spot. The two questionnaires discussed in the next section, were created in Google Forms and are filled in using the laptop which has the prototype installed. Finally, the prototype is tested via the Google Chrome browser. A backup of the database is restored between each test to ensure that every participant will work with the exact same data.

5.4 Data gathering

The test results in quantitative data from two questionnaires. However, the qualitative information is more important, which is gathered from observing the participant during the test of the prototype and from the interview afterwards. Both questionnaires are found in appendix sections A.3.2 and A.3.3.

Quantitative data The first questionnaire asks at the start for demographic information of which the following can be qualified a quantitative data:

- Age.
- Technology experience (Likert scale, 1: not experienced, 5: experienced).

The second part asks for information regarding the current EHR system that the participant uses:

- Satisfaction (Likert scale, 1: very dissatisfied, 5: very satisfied).
- User friendliness (Likert scale, 1: strongly disagree, 5: strongly agree).
- Supports the participant's needs (Likert scale, 1: strongly disagree, 5: strongly agree).

The second questionnaire asks for ratings regarding the usability of the prototype:

- General experience (Likert scale, 1: very bad, 7: very good). Because this is the general opinion of the participant, more steps are defined for this scale.
- Easy to use (Likert scale, 1: strongly disagree, 5: strongly agree).
- Dashboard looks clean (Likert scale, 1: strongly disagree, 5: strongly agree).
- Modules look clean (Likert scale, 1: strongly disagree, 5: strongly agree).

- Modules served as a good example (Likert scale, 1: strongly disagree, 5: strongly agree).
- Enough customization options present (Likert scale, 1: strongly disagree, 5: strongly agree).

No other quantitative data is gathered. During the observation, errors are noted, but not counted.

Qualitative data The bulk of the qualitative data is gathered during the test of the prototype by observation and afterwards during the interview. When the participant is following the step-by-step plan, the following notes may be taken:

- The participant struggled finding UI element X.
- An error was made regarding X.
- The participant hesitated at step X.
- The participant asked question X regarding Y...

Questions related to the usability of the prototype and the current EHR system, current paper use in their care setting, module suggestions...are asked during the interview. Section 5.7.4 describes what qualitative data was retrieved.

5.5   Test scenario

During the step-by-step process, the participant works with the dashboard of three fictional patients. A short background is given for each patient and participant performs actions which relate to the situation of the patient. The participant has seen all aspects of the dashboard after the test of the prototype is complete. Appendix A.3.4 contains the step-by-step process. Also, the screenshots in appendix A.3.5 show the dashboard at the start of each scenario. We now describe each scenario.

Patient 1 Background: Kenny is an account manager of a large accounting firm. The combination of his stressful job, sedentary lifestyle, and smoking habit have lead to health issues. He has frequent palpitations and high blood pressure. At home, Kenny has to measure his weight, heart rate, and blood pressure on a regular basis with devices that send the values to his electronic patient record. In this scenario the participant does the following:

1. Apply a filter on the history module.
2. Add and configure a telemonitoring module to fill the empty space of the dashboard.
3. Reorder the modules on the summarizing panel, while adding and configuring a small telemonitoring module.

Patient 2 Background: Since Jozefien retired, she has been gaining weight at an alarming rate. As a countermeasure, she regularly visits her general practitioner. Each consultation, the practitioner updates her medication scheme

and tells her what she needs to pay attention to. In this scenario the participant does the following:

1. Remove and add a prescription, check for interactions.
2. Remove the allergy module to replace it with a workflow module.
3. Edit some steps of a workflow.
4. Reset the checklist and add some new tasks to it.
5. Hide a parameter in the small telemonitoring module found in the left panel.

Patient 3 Background: After a serious car accident, Bert is hospitalized in the intensive care unit. Bert has many allergies, an elaborate medication scheme, and misses some vaccinations. Currently he is being treated by several clinicians and being observed by nurses. It is important that everyone is aware of these allergies, the medication scheme, and missing vaccinations. However, the data in the EHR system is not up to date. The latest most up to date medical data is still stored in a paper dossier. In this scenario the participant does the following:

1. Change and add an allergy.
2. Remove and add a vaccination.
3. Apply a filter on the history module.

5.6 Recruiting participants

The search for participants began immediately after the usability test design was completed. A total of 9 people were contacted with the following backgrounds:

- 2 nursing students, both had internship experience in a hospital setting.
- 1 elderly care nurse.
- 2 intensive care unit nurses.
- 1 clinical laboratory department head.
- 1 paramedic.
- 2 home nurses, working for the same practice.

Five individuals immediately were scheduled to test the prototype. The two home nurses and one nursing student declined due to time constraints. The paramedic expressed interest and was scheduled several weeks later. Four general practitioners were contacted, but were unable to participate due to the short notice of the study. Six participants have tested the prototype.

5.7 Results

Before every test, the database of the application was reset and the log in functionality was tested to avoid any technical problems. As a result, every test ran smoothly without any issues. Every participant tested the prototype in a secluded and silent environment. Four tests were conducted at the homes of the participants and the other two in empty classrooms of Hasselt University. The test was estimated to take approximately 40 minutes to complete. In anticipation of lengthy interviews, a hard stop was put in place should the test

Age	Gender	Profession	Experience	Tech experience (1-5)
21	M	Nursing student	4 years internship	4
25	F	Elderly care nurse	1,5 years	4
23	F	Intensive care unit nurse	1 year 5 months	4
23	F	Intensive care unit nurse	5 months	4
49	F	Laboratory department head	28 years	3
22	M	Paramedic	1 year	5

Table 1: Pre-test results: general participant information

EHR system	Mobile	Satisfaction (1-5)	User friendliness (1-5)	Complete toolset (1-5)	Custom-izable	# other systems
Orbis	No	3	3	2	No	0
GEMS	No	3	3	3	No	6
Metavision & GEMS	No	5	4	4	No	2+
ICCA	No	5	5	4	Yes	4
HIX	No	4	4	3	Yes	1
KWS	Yes	4	3	3	No	0

Table 2: Pre-test results: EHR systems in use by participants. Note: same order is respected as table 1.

pass the 60 minute mark. This was the case for two tests. The durations of the other four were between 45 and 55 minutes. This caused no issues for any of the participants. When the test concluded, participants were rewarded with a bottle of wine. During the recruitment phase, each contacted individual was aware of a reward, but they did not know what it was beforehand.

5.7.1 Pre-test questionnaire

Table 1 shows some general information from the pre-test questionnaire regarding the participants. It should be noted that 5 out of 6 participants are between the ages 21 and 25. They also indicate a higher familiarity with technology, compared to the older participant. The younger participants also have limited work experience. The pre-test questionnaire also indicated that all participants use their smartphone and lap-/desktop daily. Four participants use their tablet a few times every month, of which one participant uses it daily. One participant uses a smartwatch daily, and is the only one to use a smartwatch at all.

Table 2 shows that all participants use a different EHR systems for their care setting and only one of them is used on a mobile device. The user satisfaction of the EHR systems scored an average of 4 out 5, with user friendliness scoring a bit less. The participants were more neutral towards the features the EHR system provides, scoring a 3,17 on average. Only two EHR systems provide customization. Lastly, one participant uses no less than 6 applications in combination with the EHR system, while two participants use none. During the interview, more questions were asked concerning their current EHR system.

5.7.2 Prototype test: observations

All participants were able to complete the test within the allotted time of 20 to 25 minutes. The two intensive care nurses were noticeably faster in completing all the steps, nearing the 15 minute mark. The elderly care nurse and the laboratory head were often unsure on where to click and often asked questions instead of trying. This may explain the fact that they took a bit longer to complete the test compared to the other participants. However, every participant received the same brief tour of the prototype, so no participant had more knowledge of the prototype compared to the others. We now go over the comments made by the participants during the test.

There were several comments regarding the prescription module. One participant noted that it would be useful if empty dosage fields were automatically filled with zeroes. Currently, the user needs to fill all fields manually. Another participant suggested something similar. Because today's date had to be filled in multiple times throughout the test, the participant would've liked a button that would automatically fill it in. This participant stressed that error checking was a very important component of the systems they currently use. Regarding the end date of prescriptions, one participant noted that they sometimes have to administer medication indefinitely, which the module does not support at the moment. In case there are interactions between medicines, one participant noted that it would be helpful to see the actual interaction effects in addition to the interacting medicine.

The test highlighted two issues. First, four participants struggled to add a new task to the checklist. This was done by opening the context menu on top of the checklist description. In this case, a button would be a better option. Second, three participants had difficulties finding the option to add a vaccination entry, which again was found in a context menu. More careful thought must be given on when to use these context menus. However, one participant had no issues with the context menu and thought it was really useful. This participant shared this thought also for the date picker.

Participants had a few more comments. Instead of clicking the arrow button to open the dashboard of a patient, the user can click anywhere in the row of the table to open it. Also, one participant liked both the normal and small telemonitoring modules in particular, describing them as very clean and simple. To conclude, a participant described the importance of access control and privacy surrounding the patient data history module.

5.7.3 Post-test questionnaire

Table 3 shows the results of the Likert scale questions concerning the usability of the prototype. The results are very positive, indicating a good overall experience with the dashboard. Furthermore, all participants indicated that they had no trouble finding their way around the dashboard. However, these results are not conclusive, due to the small sample size. Also, the fifth participant was the only older person in the sample group. The general experience of the dashboard

General experience (1-7)	Ease of use (1-5)	Dashboard clear UI (1-5)	Modules clear UI (1-5)	Modules good examples (1-5)	Enough Customization (1-5)
6	5	5	5	4	5
6	4	3	4	4	4
6	4	5	4	5	5
7	5	5	5	5	5
4	3	4	4	4	4
7	5	5	5	5	5
6	**4,33**	**4,5**	**4,5**	**4,5**	**4,67**

Table 3: Post-test results: questionnaire to assess usability of the dashboard. The bottom row indicates the average scores. Note: same order is respected as table 1.

and the experience with technology were both lower for this participant. But then again, a laboratory setting does not share many similarities with the other settings found in the sample group.

Maybe the most important result is that the modules served as good examples of what is possible with the dashboard. This allowed the participants to better relate the prototype to their work setting, which may lead to valuable feedback during the interview. Also, the questionnaire asked the participants to suggest some modules which would fit the dashboard, which we discuss in more detail in the next section.

5.7.4   Interview

Several topics were brought up during the interview, such as potential modules to add to the dashboard, use cases for the current modules, the current EHR system that is in use, the existence of paper in the work setting, what was good or bad, and other suggestions. For each topic, we discuss the feedback the participants gave us.

Module suggestions   Two participants suggested a drip management module. A drip, or intravenous therapy, is the administration of a fluid solution directly into a vein. This is often done via syringes. The module would help regulate and track the volume of the drip. Also, if the drip administers a medicine which affects blood pressure, then the module tracks this parameter as well. In case something is unusual is happening to this parameter, the module alerts the caregivers. This module is much more practical than managing the drips of multiple patients the manual way. A computer can easily track many ongoing drips.

Another module was suggested twice. Fluid balance is the balance between fluid that enters the body and fluid that leaves the body. This closely relates to drips, which serves as fluid input. A fluid balance module helps tracking the amount of fluid that enters and leaves a patient's body. In case any abnormalities

occur, then the module can notify the clinician. This again is an example how these systems can automate several steps of these processes.

Wound management is tedious process, as no wound is the same. A cut needs to be treated different than a stab from a needle. There exists a large variety of these wounds that each have their own step-by-step guide to treat them. A wound management module can provide the right guide at the right time. This way clinicians don't need to search through a thick file. Also, a participant suggested that if the module was used on a smartphone, the camera can be used to take pictures of the wound.

A participant also suggested an emergency contact module. For example, this module contains information of the family members of the patient. But it may also contain the contact information of the doctor on night duty. Since these doctors rotate their night shift periodically, it takes time look up the information manually via a paper calendar. If this again was used on a mobile phone, calls can be directly initiated from the module.

Other suggestions included body temperature monitoring, diabetes management, diet management, and pain status or relief modules. However, the previously mentioned ones were thoroughly explained by the participants on how they would see it being used in practice. One participant suggested a notification hub. This would be very beneficial for the dashboard, but also difficult to realize. A notification hub is not a module, but it is deeply rooted in the architecture of the application. From our approach, all integrated modules need to have a standardized way to implement the firing of notifications.

Use cases current modules   Every participant was asked if they could devise a scenario in which they would use the dashboard or a module from it. This resulted in several use cases, in particular to the workflow and checklist modules. Where one participant mentioned wound management as a potential module, another participant would use the workflow module to do this. In this case, every specific wound represents a workflow.

Another participant mentioned that every operation leads to a specific care path that needs to be followed. The participant saw this as an opportunity to model these paths in the workflow module. Furthermore, another workflow use case was to store patient specific requests in there. The participant gave following example: "An elderly lady wants to visit the chapel of the hospital every Sunday morning. However, she may not go alone and someone needs to accompany her." The workflow module serves as a reminder tool in this case.

If the workflow module allowed branching in the form of "if A happens, do B, else C", then a lot more possible use cases would arise, according to a participant. Another suggestion was to extend the patient information module by logging the "Do Not Resuscitate" order, or in other words, allow natural death to occur. To conclude, the checklist module also generated some use cases, such as: record the current administered medications, log the steps of the morning care routine, checking of parameters, and wound management.

Current EHR system Four out of six participants mentioned that their current system is not customizable. When the other two participants were asked to clarify the customization aspect in their EHR system, they both mentioned that "a doctor gets a very different layout compared to mine" and that the IT staff listens to their feedback. This is not what we meant by customization, which turned out to be limited in those two systems as well.

Some participants used a few software packages next to their EHR system. For one participant, the functions of these extra software packages were as follows: a consultation and transportation planner for patients, a diet planner which was connected to the catering service, and a support service for technical issues. One participant noted that next to their EHR system, they used a software package to retrieve lab results and send lab orders. When taking blood samples, these had to be recorded in both applications, which seemed useless to the participant.

Several other issues were highlighted regarding the current EHR systems. In one case, the system changes often, which causes it to break occasionally. Also, whenever an external digital document was received, the records it contained needed to be entered manually into the EHR system. Another participant highlighted that the system required a significant amount of training and that the application was not easy to use.

Lastly, a participant emphasized the fine-grained privacy rules and access control measures that were in place in their system. However, this resulted in some cases that there was no access to a medical record when there should be, hindering care delivery. The participant concluded that striking a balance between data availability and strict privacy rules is a difficult subject for such software. Another participant noted that the EHR system gave away too much information, thinking that they should not be able to see some pieces of information.

Paper usage Generally, paper usage was fairly limited for all participants. The intensive care nurses used no paper for internal care delivery. However, lab, prescription, and imaging orders were transferred on paper to other departments. The laboratory manager does not use any paper anymore since the latest upgrade of their EHR system. One participant mentioned that the administered medication for patients was still written down on paper, which seems troubling.

To conclude, one participant made the interesting comparison of paper usage with the use of laptop carts. These carts make it possible for clinicians to have more mobility in terms of computer access. However, the participant noted that these carts would get lost or get in the way, and wanted a truly mobile solution such as tablet computers. This participant noted as well that tablets may solve some other inefficiencies. When recording health parameters of patients, then the clinicians might be required out of protocol to immediately enter the data into the digital system. This results in a lot of walking from room to room which can be avoided by having a mobile device available to directly record the data with.

General One participant described that the customization aspect will be helpful to remind the clinician with what patient they are dealing with. Currently, the same layout is displayed for each patient, which may lead to confusion during a high workload. However, the same participant and another one, felt that the customization would be a lot of work for patients that wont stay long. A solution for this, suggested by three participants in total, was to provide default module configurations, either provided by the system or created by the clinician. One participant mentioned that it should be possible to prohibit the removal of some modules that are absolutely necessary in a given setting. The laboratory manager did not see the added benefit of customization in their work setting. Mainly, because their workflow does not frequently change, and because the software they currently use is very satisfactory.

6 Conclusion and future work

The results of the usability test led to valuable feedback. However, it also highlighted the shortcomings of this study. The last step of this work was to take a critical look at the end result of the entire thesis. From this we draw several conclusions, which lead to interesting topics for future work.

6.1 Conclusion

The literature study brought the following issues caused by EHR systems to light:

- An increase in the medical error rate after the installation of an EHR system, caused by poor usability and paper workarounds for missing functions.
- Heavy workflow disruption caused by the adoption or the update process of the system, resulting in productivity loss and negative motions.

The design of the dashboard put a heavy focus on both usability and interoperability to resolve these issues. The test indicated that the dashboard had good usability. This partly resolves the first issue. The dashboard application was also easy to learn. As a result, clinicians adapt quickly to the new system, limiting a loss in productivity. Also, the good usability of the dashboard facilitates a positive user experience. It seems this resolves the second issue, which is not the case.

The usability test featured a simple version of the dashboard, not suitable for deployment in a care setting. Therefore, the test can not measure whether these two issues are resolved. This requires a clinical trial wherein the prototype is tested in a real clinical setting. The issues arise only for these scenarios. However, clinical trials are complex studies and often require a prototype that closely resembles the final product. Also, real patient data is involved which requires security and privacy measurements to be in place. We discuss clinical trials later on.

Another test needs to be designed to assess the interoperability aspect of the prototype and how it solves the two problems. Such a test requires the IT staff of an institution to integrate and change several components that possibly interrupt the workflow of clinicians. This also evaluates the base components and the MVC architecture.

The last paragraphs indicate the shortcomings of the study. However, the prototype was received very well by the test participants. The feedback from the usability test, together with the insights gained during development, brought forth an extensive collection of future improvements and ideas. We conclude the thesis by providing a list of interesting topics for future research.

6.2 Future work

In this section, we present a list of topics that future research may focus on. We go into more detail on some of these by indicating, for example, the requirements, the goals, and the process. All the topics are related to each other are mentioned in no particular order.

6.2.1 Longitudinal study

The purpose of a longitudinal study is to gather data concerning the use of the prototype over a longer period of time. During this period users test the prototype continuously. The prototype does not require a clinical trial, which would determine the prototype's medical effects on patients [55]. However, the dashboard does not affect the treatment of patients. It is designed to be extensible and usable. It is challenging to conduct a longitudinal study in a clinical setting, as it requires an advanced prototype which allows the user to provide safe and efficient care. The advanced prototype should have some security and privacy measures in place, together with more advanced components suitable for the testing environment.

Assume the following example scenario where we have built an advanced prototype. At the first stage of the study, the prototype is tested by a small group of users. The gathered feedback is then implemented in the next version of the prototype. The new version is tested again, but by a larger sample group. This cycle repeats a few times. At a certain stage, the prototype is tested by hundreds of users. This indicates that such a study can be very costly. Due to this cost and the fact that an advanced prototype is required, a longitudinal study is not for the near future.

6.2.2 Evaluate effect of interoperability

The evaluation of the interoperability aspect requires two different tests. The benefits of the module-based approach mentioned in section 3.1 should minimize the loss in productivity due to workflow disruption. This requires a testing environment where such disruptions happen, which is difficult to control. Therefore, the prototype should repeatedly lead to positive results. Also, the test requires the prototype to be advanced enough to support the testing environment under normal conditions. The clinical trial of the dashboard prototype can include this test.

A second test involves the IT staff of a health care institution. The goal of this test is to evaluate the integration of new modules into the dashboard. The effect this has on workflow disruption needs to be thoroughly observed during the test. Again, this is a difficult environment to control. The feedback we receive from the IT staff will help to improve the base components and the back end structure.

6.2.3   Prototype improvement

The prototype can be improved on two levels: on a dashboard level, and on a module level. Dashboard improvements relate to changes that affect the entire dashboard, while module improvements only change the inner workings of a certain module.

Dashboard improvements   Currently, clinicians can create a custom dashboard for each patient. In the future, every clinician has one personal dashboard. This dashboard can contain other modules which are only of use to the caregiver. It may be filled with shortcuts to patients, an agenda, a personal routine, and more. Examples of modules for this type of dashboard were already uncovered during the brainstorm session in section 3.4.

One participant wished for a notification module in the prototype. This module gathers all the notifications that modules or the dashboard sends. To support this, the base components need to be updated so modules can override a function which creates the notification. Also, two participants suggested that the dashboard should provide default layouts which are also editable. It should also be possible to mark modules of layouts as necessary, to prevent them from being removed. Sometimes a module is absolutely necessary in a certain workflow.

Module improvements   The base components need to be updated to support notifications. It should help the modules define their own notifications according to the template the base component defines. Also, modules should be able to show or hide certain data according to its size. This removes the need for the small component definitions, because a small sized normal module will look the same.

Test participants suggested several modules. A wound management module would serve as a collection of steps to treat many different wounds. This removes the need for ring binders, which are difficult to search through. A drip management module was also suggested. This module helps the tracking of the drips of many patients. It may provide suggestions based on the vital signs of the patient and the currently configured drip. Finally, a fluid balance module helps tracking the fluid intake and output of a patient. The intake should include the same information of the drips managed with the previous module. During the clinical trial, many more useful modules may come to light.

A   Appendix

A.1   Nielsen's 10 usability heuristics

1. Visibility of system status: the system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

2. Match between system and the real world: the system should speak the user's language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

3. User control and freedom: users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

4. Consistency and standards: users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.

5. Error prevention: even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

6. Recognition rather than recall: minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

7. Flexibility and efficiency of use: accelerators unseen – by the novice user – may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

8. Aesthetic and minimalist design: dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

9. Help users recognize, diagnose, and recover from errors: error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

10. Help and documentation: even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

A.2 Patient JSON import specification

The dashboard allows to import the medical data of multiple patients in a JSON format. The application only accepts the structure that is defined in this section. The root structure is an array in which each object contains the info of a patient:

```
1  [
2      {
3          // patient 1 info
4      },
5      {
6          // patient 2 info
7      },
8      ...
9      {
10         // patient n info
11     }
12 ]
```

Each patient object contains key-value pairs in which the key indicates the type of information it value contains. For example, the key "info" contains as a value an object containing the demographic information of the patient. The following example imports a patient with an allergy:

```
1  {
2      "info": {
3          "firstName": "Michael",
4          "lastName": "Johnson",
5          "nid": "123454321",
6          "birth": "1983-02-09T11:23:00",
7          "gender": "M",
8          "bloodType": "O-",
9          "height": "173",
10         "address": "Largestreet 22, 12345 Bigtown",
11         "phone": "0123/9890777",
12         "smoker": "true"
13     },
14     "allergies": [
15         {
16             "name": "Nuts",
17             "description": "Nausea",
18             "severity": "2",
19             "type": "Food",
20             "date": "1998-12-04T00:00:00"
21         }
22     ]
```

```
23 }
```

We now define each key and describe the structure of its value. The structures are defined via examples. The comment after the key-value pair indicates the type of the value. The examples show all values within quotes. However, this does not mean they are all strings. All dates are entered as an ISO 8601 string value.

A.2.1 General patient information

The demographic information is imported by the controller of the patient information module (section 4.3.5.2). The "info" key is the only key that is mandatory to import a patient. All keys are mandatory. The structure of the JSON object is as follows:

```
1  "info": {
2      "firstName": "Michael", // String
3      "lastName": "Johnson", // String
4      "nid": "123454321", // String
5      "birth": "1983-02-09T11:23:00", // String
6      "gender": "M", // String, enum: ['M', 'F']
7      "bloodType": "O-", // String, enum: ['O+', 'O-', '
            A+', 'A-', 'B+', 'B-', 'AB+', 'AB-']
8      "height": "173", // integer
9      "address": "Largestreet 22, 12345 Bigtown", //
            String
10     "phone": "0123/9890777", // String
11     "smoker": "true" // boolean
12 }
```

A.2.2 Allergies

The allergy information is imported by the allergy module (section 4.3.5.4). The value of the key "allergies" is an array. Each object in this array defines an allergy. All keys are mandatory. The object has the following structure:

```
1  "allergies": [{
2      "name": "Nuts", // String
3      "description": "Nausea", // String
4      "severity": "2", // integer
5      "type": "Food", // String, enum: ['Food', 'Skin',
            'Respiratory', 'Drug', 'Other']
6      "date": "1998-12-04T00:00:00" // String
7  }]
```

A.2.3 Vaccinations

The vaccination information is imported by the vaccination module (section 4.3.5.5). The value of the key "vaccinations" is an array. Each object in this array defines a vaccination. Each vaccination can have multiple entries, which are defined in the array of the key "entries". All keys except "dateNext" are mandatory. The object has the following structure:

```
"vaccinations": [{
    "name": "Hepatitis B", // String
    "description": "Liver disease.", // String
    "dateNext": "2019-03-23T16:30:00", // String
    "entries": [ // array of objects
        {
            "description": "1ste vaccination, patient
                was 13 months old.", // String
            "date": "2014-11-14T13:45:00" // String
        }
    ]
}]
```

A.2.4 Prescriptions

The prescription information is imported by the prescription module (section 4.3.5.3) and the medication controller. The value of the key "prescriptions" contains two objects: "medicines" and "prescriptions". The medicines key defines the medicines that are used in the prescriptions of the patient. If the medicines are already defined in the database, the medicine is not imported. All keys except "interactsWith" are mandatory. The structure is as follows:

```
"prescriptions": {
    "medicines": [ // array of objects
        {
            "name": "Omeprazol", // String
            "description": "Decreases the amount of
                acid the stomach makes.", // String
            "sideEffects": "Nausea, headaches.", //
                String
            "interactsWith": [ // array of Strings
                "Simvastatine" // String
            ]
        }
    ],
    "prescriptions": [ // array of objects
        {
            "medName": "Omeprazol", // String
            "dosage": { // object
```

```
16              "morning": "0", // integer
17              "noon": "1", // integer
18              "evening": "0", // integer
19              "bed": "1" // integer
20          },
21          "startDate": "2018-11-22T07:20:00", //
                  String
22          "endDate": "2018-12-19T07:20:00" // String
23      }
24  ]
25 }
```

A.2.5 Workflows

The workflow information is imported by the workflow module (section 4.3.5.6). The value of the key "workflows" is an array. Each object in this array defines a workflow. Each workflow consists of multiple steps, which in turn can have substeps. All keys except "steps" and "substeps" are mandatory. The object has the following structure:

```
1 "workflows": [{
2     "name": "Consultation procedure", // String
3     "description": "This series of steps must be
          followed each time.", // String
4     "steps": [ // array of objects
5         {
6             "name": "Pre-consultation", // String
7             "description": "Check new data.", //
                  String
8             "substeps": [ // array of Strings
9                 {
10                    "description": "Blood pressure and
                          weight" // String
11                }
12            ]
13        }
14    ]
15 }]
```

A.2.6 Checklist

The checklist information is imported by the checklist module (section 4.3.5.7). The value of the key "checklist" is an object. The checklist consists of multiple steps, which in turn can have substeps. All keys except "steps" and "substeps" are mandatory. The object has the following structure:

```
1   "checklist": {
2       "description": "Consultation checklist", // String
3       "steps": [ // array of objects
4           {
5               "description": "Do measurements", //
                    String
6               "substeps": [ // array of Strings
7                   {
8                       "description": "Heart rate" //
                            String
9                   },
10                  {
11                      "description": "Blood sugar" //
                            String
12                  }
13              ]
14          }
15      ]
16  }
```

A.2.7   Telemonitoring

The telemonitoring information is imported by the controllers of each of the
following parameters: blood pressure, blood sugar, heart rate, oxygen, and
weight. Every value of each parameter is an array which contains the values.
All keys are mandatory of every parameter. The objects have the following
structures:

```
1   "bp": [{ // array of objects
2       "systolic": "138", // float
3       "diastolic": "87", // float
4       "date": "2018-12-13T09:40:00" // String
5   }],
6   "bs": [{ // array of objects
7       "value": "3.4", // float
8       "date": "2018-11-12T20:04:00" // String
9   }],
10  "hr": [{ // array of objects
11      "value": "72", // float
12      "date": "2018-12-22T23:29:00" // String
13  }],
14  "oxygen": [{ // array of objects
15      "value": "98", // float
16      "date": "2018-10-28T17:20:00" // String
17  }],
```

```
18  "weight": [{ // array of objects
19      "value": "74.8", // float
20      "date": "2018-12-02T12:30:00" // String
21  }]
```

A.3 Usability test documents

A.3.1 Informed consent: original (Dutch)

Note: the form was created in Microsoft Word and fit on exactly one page. The Hasselt University logo was located on the top right of the form.

Beste vrijwilliger,

Dit formulier dient om u informatie te geven over de studie waar u aan gaat deelnemen. Op het einde vragen we u dit formulier te ondertekenen om uw vrijwillige deelname te bevestigen. U kan te allen tijde uw deelname aan de studie intrekken. Een ondertekend kopie van dit document wordt aan u meegegeven.

De data verkregen van u en de observatie wordt geanonimiseerd en niet verder verspreid buiten de grenzen van deze studie.

Onderwerp: medisch dashboard met als focus per-patiënt personalisatie

Deze studie stelt een dashboard voor die een zorgverlener toelaat om per individuele patiënt de nodige functionaliteit samen te stellen. Door ons prototype van het dashboard te testen, kunnen we de sterktes en zwaktes ervan identificeren. We testen het prototype en niet u, de gebruiker. U kunt dus niets verkeerd doen tijdens deze test.

Het verloop van deze test bestaat uit drie delen:
1. Vragenlijst betreffende persoonlijke gegevens en gebruikte medische software (5 à 10 min).
2. Test van het prototype met behulp van een stappenplan (20 à 25 min).
3. Interview en een vragenlijst om de gebruikerservaring te toetsen (10 min).

Voordat de test van het prototype van start gaat, krijgt u een korte uitleg omtrent het gebruik van het dashboard. Zodra de test begonnen is, wordt u geobserveerd. Indien er problemen of onduidelijkheden ontstaan mag u altijd vragen stellen. Tenslotte wordt u aangeraden om luidop te denken.

Verklaring van toestemming

Handtekening testpersoon: Handtekening getuige:

Naam: _____   Naam: _____

Datum: _____

Contactgegevens: Naam: Dennis Cardinaels
                        Email: dennis.cardinaels@student.uhasselt.be
                        GSM: 0479 51 47 19

A.3.2 Pre-test questionnaire: original (Dutch)

Description: In de eerste sectie worden enkele demografische gegevens van u verzameld. Daarna vragen we informatie omtrent het EPD (elektronische patiëntendossier) dat momenteel in gebruik is.

Persoonlijke informatie

- Geslacht*[1]:   ○ Male   ○ Female
- Leeftijd*: _____
- Wat is uw huidige jobtitel?* _____
- Hoe lang werkt u al binnen de gezondheidszorgsector?* _____
- Hoe ervaren bent u met computers?*
  Onervaren   ○   ○   ○   ○   ○   Ervaren
- Welke apparaten gebruikt u dagelijks?*
  - ☐ Computer/laptop   ☐ Tablet
  - ☐ Smartphone   ☐ Andere: _____
- Welke apparaten gebruikt u enkele malen per week?*
  - ☐ Computer/laptop   ☐ Tablet
  - ☐ Smartphone   ☐ Andere: _____
- Welke apparaten gebruikt u enkele malen per maand?*
  - ☐ Computer/laptop   ☐ Tablet
  - ☐ Smartphone   ☐ Andere: _____

Elektronisch patiëntendossier (EPD)

- Wat is de naam van het huidige EPD?* _____
- Wordt het EPD op mobiele apparaten (smartphone/tablet) gebruikt?*
  ○ Ja   ○ Nee
- Hoe lang is dit EPD in gebruik? (indien u dit niet weet, laat open) _____
- Hoe tevreden bent u van het EPD?*
  Zeer ontevreden   ○   ○   ○   ○   ○   Zeer tevreden
- Het EPD is gebruiksvriendelijk.*
  Helemaal niet akkoord   ○   ○   ○   ○   ○   Helemaal akkoord
- Het EPD voldoet aan al mijn eisen.*
  Helemaal niet akkoord   ○   ○   ○   ○   ○   Helemaal akkoord

---

[1]A star indicates a mandatory question.

- Welke functies ontbreken in het EPD? _____

- Het EPD kan aangepast worden naar eigen wens.*   ○ Ja   ○ Nee

- Indien 'ja' op de vorige vraag, in welke mate? Is dit bijvoorbeeld per patiënt mogelijk? _____

- Worden andere programma's in combinatie gebruikt met het EPD?*
  ○ Ja   ○ Nee

- Indien 'ja' op de vorige vraag, welke programma's? _____

A.3.3   Post-test questionnaire: original (Dutch)

Description: De volgende vragen toetsen uw ervaring met het prototype. Indien u nog extra opmerkingen hebt die niet in de enquête genoteerd kunnen worden, mag u dit altijd melden.

Persoonlijke ervaring

- Algemene ervaring met het dashboard.*
  Zeer slecht   ○   ○   ○   ○   ○   ○   ○   Zeer goed

- Het dashboard is makkelijk om te gebruiken.*
  Helemaal niet akkoord   ○   ○   ○   ○   ○   Helemaal akkoord

- Het dashboard ziet er duidelijk uit.*
  Helemaal niet akkoord   ○   ○   ○   ○   ○   Helemaal akkoord

- De modules zien er duidelijk uit.*
  Helemaal niet akkoord   ○   ○   ○   ○   ○   Helemaal akkoord

- Alles is makkelijk terug te vinden in het dashboard.*   ○ Ja   ○ Nee

- Indien 'nee' op de vorige vraag, wat was moeilijk om terug te vinden? _____

- De modules dienden als een goed voorbeeld wat mogelijk is met het dashboard.*
  Helemaal niet akkoord   ○   ○   ○   ○   ○   Helemaal akkoord

- Heeft u suggesties voor potentiële modules? _____

- Er zijn voldoende personalisatie mogelijkheden aanwezig in het dashboard.*
  Helemaal niet akkoord   ○   ○   ○   ○   ○   Helemaal akkoord

- Wat vond u goed/niet goed aan de personalisatie? _____

A.3.4 Step-by-step plan: original (Dutch)

Note: the step-by-step plan was created in Google Docs and fit on exactly two pages.

Start

1. Log in als:

   (a) Username: "verpleger1".
   (b) Wachtwoord: "dashboard".

2. Selecteer patiënt "Kenny Martens".

Patiënt Kenny Martens

Achtergrond: Kenny is een account manager van een grote boekhouding firma. Zijn stressvolle job, sedentaire levensstijl en gewoonte om te roken hebben gezondheidsproblemen met zich meegebracht. Zo heeft hij regelmatig last van hartkloppingen en een hoge bloeddruk. Thuis moet Kenny regelmatig zijn gewicht, hartslag en bloeddruk meten met apparaten die de waardes doorsturen naar het elektronisch patiëntendossier.

Stappen:

1. Bekijk het dashboard en open en sluit het zijpaneel.
2. Pas een filter toe op de historiek van de patiëntendata:

   (a) Zet de startdatum op een week geleden en de einddatum op vandaag.
   (b) Selecteer enkel de voorschrijvingen en de telemonitoring modules.
   (c) Laat alle operaties geselecteerd staan.

3. Voeg een telemonitoring module toe dat de resterende breedte en hoogte van de pagina inneemt. Stel in:

   (a) Toon bloeddrukwaarden en plot ze op de y-as.
   (b) Selecteer data vanaf vandaag tot ongeveer een maand geleden.
   (c) Bekijk de waarden van enkele datapunten op de lijngrafieken.
   (d) Beschrijf de trend van de data op beide grafieken.

4. Open het zijpaneel en maak het patiënteninformatie moduletje kleiner.
5. Voeg een kleine telemonitoring module toe aan het zijpaneel:

   (a) Selecteer de bloeddruk, hartslag en gewicht als parameters.
   (b) Toon een samenvatting van de laatste 14 dagen.

6. Sleep de telemonitoring module zodat deze boven de huidige medicatie module staat.

7. Maak de webbrowser breder totdat het zijpaneel openklapt en ga naar de patiëntenlijst.
8. Selecteer patiënt "Jozefien Hendrix".

Patiënt Jozefien Hendrix

Achtergrond: Jozefien is een pas gepensioneerde dame die al heel haar leven

zwaarlijvig is. Nu ze pas op pensioen is gegaan, is ze alarmerend aan het bij-
komen. Om dit tegen te gaan, gaat ze regelmatig op controle bij de huisarts.
Bij elke raadpleging past de huisarts haar medicatieschema aan en daarbovenop
geeft hij suggesties voor waar ze op moet letten.

Stappen:

1. Bekijk de details van enkele voorschriften uit de lijst.

    (a) Verwijder het voorschrift voor "Furosemide".
    (b) Voeg een nieuw voorschrift toe:

        i. Selecteer medicijn "Simvastatine" en een dosering naar keuze.
        ii. Zet de periode van het voorschrift van begin december tot eind
            december.
        iii. Zijn er interacties? Zo ja, welke?

2. Verwijder de allergie module en voeg in de plaats een workflow module
   toe.

    (a) Laadt workflow "Consultatieprocedure" in.
    (b) Verwijder de eerste stap "Nieuwe patiënt".
    (c) Voeg een nieuwe substap "Medicatieschema controleren" toe aan de
        "Pre-consultatie" stap.

3. Reset de checklijst.

    (a) Voeg de taak "Medicatie voorschrijven" toe en vink deze aan.
    (b) Voeg aan de taak "Metingen uitvoeren" een subtaak "Gewicht" toe.

4. In het zijpaneel, verberg de zuurstof parameter in de telemonitoring mod-
   ule.

5. Ga naar de patiëntenlijst en selecteer patiënt "Bert Nieuwenhuize".

Patiënt Bert Nieuwenhuize
Achtergrond: Na een zwaar auto ongeluk, ligt Bert op de intensieve zorgafdel-
ing. Bert heeft een hele waslijst aan allergieën, medicatie dat hij inneemt en is
niet helemaal up-to-date met zijn vaccinaties. Momenteel wordt hij behandeld
door meerdere dokters en geobserveerd door verpleegkundigen. Het is dus be-
langrijk dat iedereen op de hoogte is van Bert zijn allergieën, huidige medicatie,
enzovoort. Echter zijn de gegevens in het EPD onvolledig, vergeleken met het
papieren dossier dat het ziekenhuis in handen heeft.

Stappen:

1. Bij de allergie module, doe het volgende:

    (a) Verander de reactiegraad van de "koeienmelk" allergie naar niveau
        1.
    (b) Voeg een "Latex" allergie (type "Other") toe met beschrijving "Jeuk,
        last van luchtwegen, niezen", reactiegraad 5 en de datum op vandaag.

2. Bekijk enkele inentingsdata van vaccinaties in de vaccinatiemodule.

    (a) Verwijder de "test" vaccinatie.

(b) Voeg een nieuwe vaccinatie "Hepatitis B" met beschrijving "Lever-ontsteking" toe.

    i. Kies 12 januari als volgende inentingsdatum.

    ii. Voeg een nieuwe historische vaccinatie toe met als beschrijving "1ste vaccinatie, patiënt was 12 jaar oud" en de datum 11 april 1990.

3. In de historiek van de patiëntendata, pas de volgende filter toe:

    (a) Zet de startdatum op 3 dagen geleden en de einddatum op vandaag.

    (b) Selecteer de allergie en vaccinatie module.

    (c) Selecteer alle operaties buiten "import".

    (d) Bekijk enkele details van de historiek.

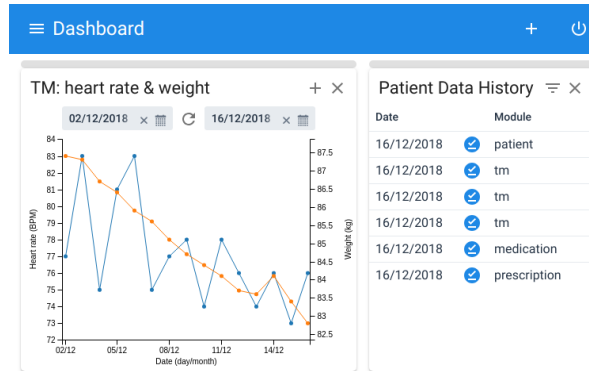### A.3.5 Screenshots taken at the start of each scenario

Figure 22: The dashboard of Kenny at the start of his scenario. There is still space left for other modules below.
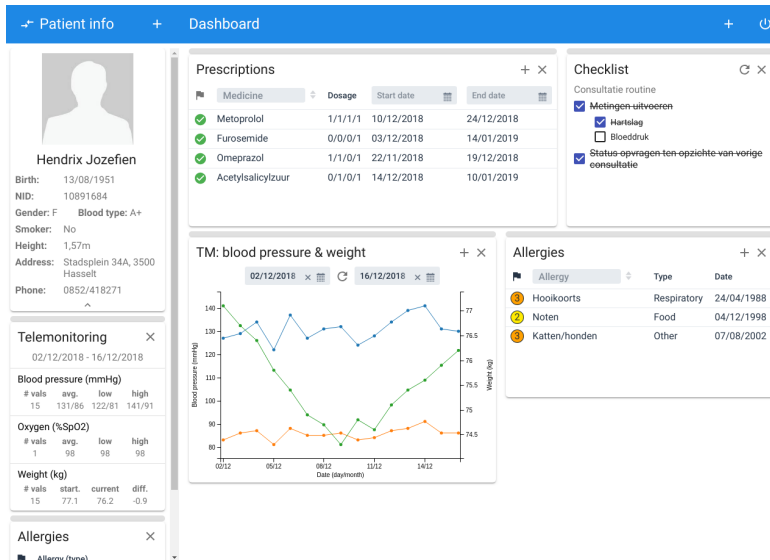

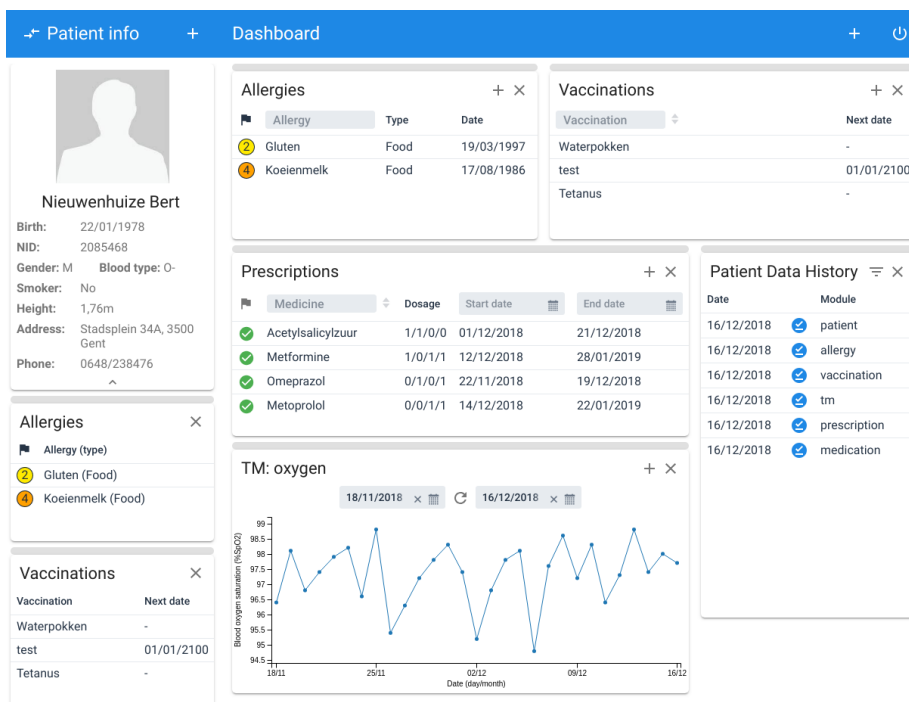Figure 23: The dashboard of Jozefien at the start of her scenario.

Figure 24: The dashboard of Bert at the start of his scenario.

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