Abstract
Historically, blood glucose monitoring (BGM) device design has focused on the physiological aspects of diabetes, with less consideration for the psychological aspects of relating the measurement to one’s experienced symptoms. In this pictorial, we explore how the subjective experience of blood glucose monitoring can be supported. We developed the BGM diary, a training system for existing BGM devices. The BGM diary involves a practice of guessing and measuring of blood glucose, followed by an annotation of felt symptoms to facilitate learning about experiences and symptoms. We unpack how blood glucose work could involve persons with diabetes in other ways in their care program through an elaboration on the design aspects of the BGM diary and reflections with a diabetes nurse.

Authors Keywords
Diabetes; self-management technology; blood glucose monitoring; subjective experiences.

CCS Concepts
• Human-centered computing~ Interaction design
**Introduction**
During most of the twentieth century, the biomedical model has been the preferred model among healthcare professionals. This model constitutes health through freedom from disease, pain, or defect. George Engel has critiqued this biomedical view on health [13, 15] and strived for a more holistic approach by recognizing that the development of illness in each patient is a consequence of their own complex interactions between biological, psychological, and social factors. The move from a biomedical model to a bio-psycho-social model aligns with contemporary design research on devices for self-management and self-tracking [3, 7, 31], including devices on for example Multiple Sclerosis [4] or fertility [19]. These research products first and foremost consider the lived experience of the person who uses the devices, opposed to the abstracted medical knowledge of a health practitioner [22].

For many years, persons with diabetes have been at the forefront of electronic medical devices entering their home. From the introduction of blood glucose self-monitoring devices in the early 1980’s; to insulin pumps in the early 1990’s; to continuous blood glucose monitoring [2, 8] and applications for dieting and pedometers for tracking activity [29, 30] over the last two decades. In this pictorial, we expand this design space and explore how the practice of blood glucose monitoring can support subjective experience, and go beyond the biomedical purpose of informing the person with diabetes on their blood glucose.

**The Bio-Psycho-Social Model of Health**

**BIOLOGICAL**
(e.g. physical health, genetics, disability)

**SOCIAL**
(e.g. education, social support, peer relationships, socio-economic background)

**PSYCHOLOGICAL**
(e.g. self-esteem, emotions, coping skills, attitudes & beliefs)

**WELL-BEING**

Blood Glucose Monitoring devices in themselves address the biological.
Blood Glucose Monitoring practices as part of a treatment program address the social.
How can Blood Glucose Monitoring devices and practices also address the psychological?

**DESIGN INSIGHT**

Smartphone applications exist that aim to support the person with diabetes in noting down glucose levels, behavior and mood levels: MySugr [25], OneDrop, [27], Diabetes:M [12], or Glucose Buddy [18].

However, these applications primarily are a logbook for quantitative physiological data. Functionality related to psychological aspects such as reflective note-taking are supplementary, and not a core part of the experience.
**About Diabetes**

A stable blood sugar level is generally between 4 and 7 mmol/L before a meal, and below 10 mmol/L two hours after the meal. When blood sugar is high, the body’s insulin will turn it into glycogen and store it in the body. Diabetes (Mellitus) is a group of metabolic diseases that is characterized by lacking this capability of turning blood sugar into glycogen [1]. The vast majority of diabetes fall into three broad categories: Type 1, Type 2 and Gestational diabetes. For Type 1, the cause of high blood sugar is an absolute deficiency of insulin secretion. For Type 2 and Gestational diabetes, the cause of high blood sugar is a combination of resistance to insulin action and an inadequate insulin secretory response.

High blood sugar (hyperglycemia) can cause dry mouth, weakness, headache, frequent urination, blurred vision and increased thirst. Low blood sugar (hypoglycemia) can cause sweating, hunger, sleepiness, lack of coordination, pallor and irritability [15, 24]. Chronic high blood sugar is associated with long term damage, dysfunction and failure of eyes, kidneys, nerves, heart and blood vessels. In addition, depression, anxiety and diabetes distress is prevalent in persons with diabetes.

**Diabetes Management**

Symptoms of both high and low blood sugar are highly individual and dependent on the severity of either hyper- or hypoglycemia. Low blood sugar is treated by ingesting food and beverage. High blood sugar requires insulin. Management of diabetes in daily life focuses on controlling blood glucose through exercise and diet, and with the assistance of blood glucose monitors and injection of insulin. As design researchers we are particularly concerned with the role of these blood glucose monitoring (BGM) devices in diabetes management.
Deconstructing BGM Devices: How do they Work and How Accurate are They?

BGM devices are used by persons with diabetes to measure blood sugar. In terms of their working mechanisms, the first BGM devices from the 1960’s used urinary glucose measurement, while devices from the 1980’s onwards used biosensors. Continuous glucose monitoring (CGM) devices use an implanted sensor under the skin that transmits glucose readings every 5 minutes [17, 33]. The design of BGM devices generally subscribed to a biomedical view on health, and the development of the newer CGM devices does not deviate strongly from the trajectory that health is something that primarily needs to be measured.

BGM devices contain a biosensor that can read test strips to which blood can be applied. These disposable strips are chemically treated, and contain a dehydrated enzyme (glucose oxidase) and an iron-based conductor. The enzyme reacts with the glucose in the blood sample to create gluconic acid. This acid then reacts with the iron-based conductor to create ferrocyanide. The BGM device runs an electrical current through the iron-based conductor to display the glucose value in mmol/L (or mg/dL) [6][28]. This electrochemical process makes all blood glucose meters susceptible to heat, cold, and humidity.

The American Diabetes Association recommends that glucose meters fall within ±15% of the laboratory method at all concentrations [32]. For example, the commonly used Contour XT BGM device has a variance of 0,85 mmol/L between 0 and 5,5 mmol/L, and a 15% variance for measurements from 5,5 and above. Further, approximately 91-97% of overall inaccuracies are operator dependent [32], making it essential that the user (often the person with diabetes) is proficient in its use and understand its capabilities and limits.

DESIGN INSIGHT

BGM devices do not provide the true value of blood glucose; do not provide the same value over multiple tests from the same finger; nor will show the same value as other glucose measuring devices [6, 28]. People with diabetes usually are informed by nurses that the BGM comes with these inaccuracies. However, the device communicates an accuracy (one digit after the decimal point) that is often interpreted as a precise outcome to act on in the patients self-management. This can result in an experience in which the device prescribes how the patient should feel.
BGM Devices in Use
The type of diabetes determines to a large extent the use and experience of BGM devices. For Type 1, the device can enter a person’s life during childhood, is interacted with multiple times a day to calculate insulin need, or is used in emergency situations; for Type 2, the device can enter a person’s life in adulthood, is interacted with a few times a week or month or in emergency situations; and for gestational diabetes, the device enters a person’s life during pregnancy, and is interacted with multiple times per day or for emergencies [10]. However, the BGM device’s design and presentation does not reflect these different roles, interactions, and intentions of using the device in the life of a person with diabetes.

<table>
<thead>
<tr>
<th>TYPE 1</th>
<th>GESTATIONAL</th>
<th>TYPE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0+</td>
<td>40+</td>
</tr>
<tr>
<td>Occurrence</td>
<td>12%</td>
<td>10%</td>
</tr>
<tr>
<td>Frequency of use</td>
<td>4-5 x / day</td>
<td>4-5 x / day</td>
</tr>
<tr>
<td>Used for learning</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Used for emergencies</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Used for diagnosis</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>

Focus: Type 2 Diabetes
Type 2 diabetes is most often related to lifestyle (i.e. diet and exercise), and typically introduced later in life. Following a Type 2 diagnosis, people usually enrol in a treatment program that runs for a year. In this treatment program, nurses and clinicians screen for comorbidities, optimize treatment plans and provide education on diabetes, diet, exercise, and motivation. This education includes learning how to use the BGM device that a nurse introduces.

To learn how to use the BGM device, diabetes associations offer a ‘guess-measure’ sheet to recently diagnosed patients. On the sheet, the person with diabetes can write down a guess, before doing their measurement. Following the measurement, the patient can compare the outcome to their guess. Repeating this process several times a day, over several days, provides the person with diabetes with a sense of how to relate their subjective experience to the actual measurement.

This method aims to aid the person with diabetes in anticipating what their blood glucose measurement will be. However, it also underplays the act of reflecting and understanding one’s own experience. It, still, reduces the experience to a single digit, and even though this estimate might be in a range, it does not invite the patient to keep a qualitative record of one’s subjective experience over time. Instead, it predominantly provides a quantitative account of these experiences.

DESIGN INSIGHT
Persons with Type 2 diabetes who have to learn how to connect their subjective experience to a measured blood glucose value do so by guessing their blood glucose level and compare it to a blood glucose level measurement. However, this leads to a single quantitative number encapsulating a qualitative account of felt experiences [cf. 23].
**Towards a Design Brief**

The Type 2 diabetes treatment program offers a social infrastructure that can support reflections on the BGM device and related experienced symptoms. The quality of these reflections could be increased by enabling the newly diagnosed person with diabetes to better understand the impreciseness of the BGM device and their experiences of symptoms over time. Therefore, we decided that instead of redesigning a BGM device, we would design a training system for existing BGM devices. This training system would re-frame the existing guess-measure procedure to explicitly address the experience of diabetes symptoms. It should support conversations with nurses and doctors in the treatment program, and stimulate reflections on attitudes and emotions while learning to live with diabetes.

**System Map**

The system map depicts how the training system is handed over together with a BGM device at the start of a treatment program (1). At the end of the program, the training system is handed back, while the BGM device is kept by the person with diabetes (3).

In use (2), the training system is envisioned to support reflections on both experienced symptoms and device accuracy, through a more qualitative way of guessing (a) and measuring (b) blood glucose levels, and offering dedicated moment of reflection on each of these (c). These reflections can alter the discussions with nurses to more directly address psychological aspects related to the disease.

The italic text to the right indicates where current practices in the treatment program would be altered.

**1. Initiation of the training program**

In a consultation, the nurse introduces the person with diabetes to a regular BGM device and the training system.

**2. Use of the training system**

a) The person with diabetes guesses the blood glucose level with consideration of how certain they are.

b) The person with diabetes measures the blood glucose level, and the system shows the accuracy of the measurement.

c) The person with diabetes reflects on their experienced symptoms in light of their guess and the measurement.

**3. Discussion with nurse**

The person with diabetes meets with the nurse to discuss their measurements and the variety of experienced symptoms.

The person with diabetes keeps the BGM device and returns the training system to the nurse.
**Design Inspiration**

To initiate the design and form giving process we found inspiration in associations, interactional qualities and form factors.

These images are organized from A-G, roughly moving from inspiration in terms of experience (e.g. dedicated, careful) to inspiration in form and interaction as seen in existing consumer products (e.g. step by step engagement, mobile).

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**A/ Ritualistic, dedicated and careful.**

**B/ Construction through de-construction.**

**C/ Product - notation combination.**

**D/ Tuning in with analogue feel.**

**E/ Transparent functionality**

**F/ Storable and mobile form factors.**

**G/ Step-by-step engagement.**
Design Proposal: BGM Diary

The BGM Diary is a training system for BGM devices. It follows a step-wise logic of guess*-measure*-annotate. The system repeats a similar terminology from existing training programs, yet the asterisks intend to denote that these procedures are adjusted to recognize the patients’ subjective experience. Guess* recognizes that one number can not encapsulate a qualitative account of felt experiences, while measure* recognizes that the BGM device comes with inaccuracies.

‘Annotate’ is added to allow the patient to write date-stamped entries based on the combination of experienced symptoms, the guess, and the measure. The BGM device stores the measure data. The nurse can access this data, and together with the annotations, support discussions in the treatment program.

The BGM Diary appears as a notebook. In the guess and measure side, the patient can plug a BGM device into it. Its name, form factors, and separation from the BGM device deliberately signal that BGM Diary is an artefact dedicated to reflective documentation of subjective experiences. This intents to equally pay attention to experiences as well as the BGM device in the training program.

### GUESS*

1. Use the slider to guess the expected blood glucose value.
   A corresponding red line appears on the left display.
2. Use the certainty wheel to indicate the certainty of the guess.
   A gradient appears around the red line to indicate the level of certainty.

### MEASURE*

3. Plug the BGM device into the BGM Diary and do a blood glucose measurement.
   A red line appears on the right display that corresponds to the number on the BGM device. This line, together with a gradient around the red line, indicate its variance.

### ANNOTATE

4. Write the date and time in the paper notepad, together with reflections on experienced symptoms.
   Accumulated annotations support a better understanding of the kinds of experienced symptoms during the training program.
Guess* and Measure*: Considerations of Form and Function

Opposed to guessing the expected blood glucose value through a single digit, the slider and certainty wheel combined invite the person with diabetes to indicate a range of values for the expected measurement. This action captures the uncertainties and complexities that are part of starting to do blood work.

The BGM device itself presents a blood glucose measurement with a precision of one digit after the decimal point. By including the variance in this number, the BGM Diary aims to counter this apparent precision, leaving more room for interpretation and more room for reflection on symptoms.

The displays that are used to indicate the guess and the measure each use a combination of a red line and a red gradient. This graphical form represents the existing medical practices (the red line) and complements it with a more nuanced presentation of what it means to engage with them (the gradient).

The numbers to indicate the measurement in mmol/L are positioned between the displays and range from 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 19, 24. The device includes low and high numbers to allow for a guess in that range, e.g. for experienced symptoms that push towards the extremes - even though blood sugar levels below three mmol/L (extreme hypoglycemia) require immediate treatment and cause blackouts for the person with diabetes.

3-color E-ink displays were considered to give a print-like aesthetic; a slow refresh rate to signal an element of thinking; to support a sense of inaccuracy; and keep the latest guess and measure results permanently visible.
Thomas, a 62-year-old person with newly diagnosed Type 2 diabetes, finished dinner an hour ago. He feels heat throughout his body and is thirsty. Thomas has tried unsuccessfully to drench his thirst in water. He uses the BGM Diary and guesses that his blood sugar is probably high, but probably not excessively high - something in the range of 8-10 mmol/L. Thomas sets the slider around nine and rotates the certainty wheel to show his uncertainty. He measures his blood glucose and sees that his blood sugar is much higher, at around 13.

It is 11:30, and Tomas got up early this morning. Since breakfast, he did not eat and has started to feel really tired and is very annoyed with everything. Thomas uses the BGM Diary. He remembers from conversations with nurses that many people get cranky at a low blood sugar. He is relatively sure that it must be between 3 and 4 mmol/L. He takes a blood measurement and sees the blurred lines around 4.5 mmol/L - not as low as he expected.

Annotations are used to articulate experienced symptoms. During the training period, these annotations invite for reflection and connect experienced symptoms to the range of possible measurement outcomes, such as feeling tired or experiencing stiff joints at respectively low and high blood glucose levels. Annotations can also be used to express aspects of subjective experience linked to the disease, complimentary to the measurements.

The annotations are made in a hand-written notebook-style, rather than digital annotations, to signal the individual character of the BGM-diary. The paper notepad is divided into a clean white page and a part with striped lines, to invite both for writing and rapid doodling experiences. The hand-written entries intend to create meaningful personal reference points over time.

Upon return of the BGM Diary, the patient can rip out the pages from the diary as a document of the training period. The BGM device itself stores the blood glucose value measurements, that together with the annotations could be discussed with a health practitioner in more detail if needed.
Reflections with a Diabetes Nurse

The BGM Diary is a conceptual proposal that was developed based on a deconstruction of the BGM device and the ‘guess-measure’ material from existing treatment programs. Upon completion of the design proposal, we conducted an evaluative interview with a trained diabetes nurse, to learn more about how the inclusion of subjective experience could influence treatment practices. The interview took approximately one hour, and included an explanation of existing treatment practices by the diabetes nurse, an explanation of the proposal based on the product renderings and scenarios, and a discussion of the potential value of the BGM Diary. The interview was transcribed and analyzed, and resulted in three main findings: firstly, that a qualitative component such as a diary could enable nurses to see what patients focus on during their treatment program; secondly, that the BGM Diary could allow patients to externalize disease management aspects that can be difficult and taxing in the early parts of their diagnosis, and thirdly, that the BGM Diary assumes that experienced symptoms are relatively stable over time, while they in fact are dynamic and changing for the patient.

Involving Patients Differently

The initial impression of the BGM Diary was that it could be of practical use: a tool to support the treatment program and various other treatment interventions that are important in improving wellbeing and health in diabetes patients.

“As a learning tool I find this practical and interesting (...). Surely, persons with newly discovered diabetes could benefit from it to control their diabetes. But also in other learning periods such as diet changes, new kinds of exercise and other times where you are making changes to your life as a person with diabetes. We have, e.g., at the moment, an intervention running to have persons with diabetes exercise more. You could imagine that in such an intervention, some could benefit from a tool like this.”

Being and feeling healthy, and connecting to one’s disease(s), is highly individual. Following this, the nurse indicated that a treatment that addresses subjective experience could cause conflicting interactions, where the patients understanding of their disease and their self-identified symptoms clash with the health professionals understanding and the symptoms they are familiar with from their practice. However, a device like the BGM diary could bring in something else to the consultations between patient and health professional, by facilitating a conversation between a patient and a health professional about experienced symptoms beyond the common symptoms.

“As a patient, you can be met with ‘that is not a normal symptom’, but that is not really useful for you as a patient. (The BGM Diary) would most likely bring things to the clinicians that they will find difficult to understand. In that way, it is interesting to see what the patients focus on and how it can be activated in clinical praxis. Will it show something new?”

Although there has been a move away from viewing health only as freedom from disease, pain or defect [13, 15], this standpoint shows that patients and health professionals understanding of health can differ, and that the design of treatment devices can play a role therein. Even if the health professional sees health as constituted of elements shared across a population, patients themselves will bring their subjective experience.

“We (as clinicians) can objectively collect things; also based on what has been written down. But it will give another result if we asked the patients directly: ‘what did you learn about your symptoms?’ Maybe there is one symptom that is more important to the patient than others or one that to them has been at the forefront during the treatment.”

It is also clear that, as new devices are given form and put into treatment, they push to the responsibilities and approaches that clinicians and nurses have to treatment.
Devices alike the BGM diary can support and facilitate a movement towards patient involvement, where the patient’s perspectives on their illness come to the forefront of treatment, with shared decision-making playing a large part of the treatment.

Externalizing the Disease
Persons with Type 2 diabetes can have an excellent stable long-term blood sugar, but high fluctuations in their daily blood sugar. When these high fluctuations stay unregulated, there is a risk of comorbidities. CGM is a recommended solution to monitor this. However, the BGM Diary was regarded as an alternative to support patients in recognizing their symptoms and gain a more stable blood glucose.

“This (BGM Diary) would definitely help as an assistive tool to those that do not have CGM. It would create some kind of certainty or safety to newly discovered (persons with diabetes). I find that, when you are newly discovered, you are more focused on your disease. This can help in noting down things and put it to the side. That you have something you can bring to your nurses in consultation, can help them.”

The BGM Diary is asserted to be useful, not only in it being a learning tool, but also for patients to externalize aspects of disease management that can be difficult and taxing in early parts of one’s diagnosis.

Symptoms are not Static
The BGM Diary was designed with newly diagnosed in mind, from a motivation that the experienced world is subjective and complex [7]. However, experienced symptoms and how they are interpreted are always affected by the patient’s changing lives:

“If you have a device like the BGM Diary, how often would you need to use it? Our body is not stable, our organs change. A 40 year old body is as when you were 20. Especially with diabetes, we know that it affects your blood vessels and emotions. How does this affect your capability to understand your symptoms?”

With symptoms not being static, regaining one’s attention to one’s own bodily experience and symptoms must be done regularly and at key moments, especially when there are larger changes in symptoms. The nurse regarded the BGM Diary as something that could facilitate this, not just during treatment, but also for the years following treatment. This insight opens up the design space for devices like the BGM Diary.

“How long would I have the same feeling with symptoms? That ‘bodily’ feel, how long will it last? (...) Purely logical, I would say this is not going to be a one-use method. I would say that you should do this once a year, work with your symptoms, or maybe a week every year.”

Symptom fluctuation shows the complexity of experience over time: the patient’s physical health, genetics and disability prescribe how their body deteriorates; their education level, social support and socio-economic background point to their capability to search for information; and their self-esteem, emotions, and attitudes and beliefs, affects to what degree they trust their experience, and what they consider important to inform clinicians about. This insight calls for more design research that brings these areas together in the design of electronic medical devices.

Discussion
The reflections on the BGM Diary with a diabetes nurse showed how addressing psychosocial practices could support persons with diabetes in better reflecting and understanding their experienced symptoms. It also showed that this could involve them differently in their care programs by nudging the conversation with the health practitioner. A such, it could help avoid bias by bringing in subjective experience into a more general treatment rationale of the health practitioner. Nonetheless, the evaluation also addressed how living with diabetes requires ongoing attunement to experienced symptoms, beyond the training program, calling for further design research. Naturally, this would need to include evaluations of the BGM Diary with persons with diabetes.

Beyond this call for future work, it must be taken into consideration that the BGM Diary is designed within the frame of a Northern European care system, where rules and regulations are in place to protect the patients data rights. The data owner is the person with diabetes themselves and the data is accessible through governmentally developed health platforms. In other healthcare and insurance systems this might be different, and consequently, the BGM diary might need to be evaluated taking this into consideration.

In summary, how patients, health practitioners and designers model health and related self-care devices affects how a treatment is seen. The design of interactive systems that primarily focus on physiological issues only partially address what it means to live with the disease. Psychological and social aspects should be equally considered in the design of self-care medical devices, and designers can do so by working from existing practices, procedures, and technologies. With the BGM Diary, we offer a design research exemplar that addresses the psychosocial practices surrounding blood glucose measurement, and particularly how symptoms are experienced individually. As such, this design research contributes to addressing the gap between a person’s lived experience with diabetes and the abstracted medical knowledge of a health practitioner and the respective medical treatment devices. We hope that this work inspires future work into patients’ perception and understanding of devices’ metrology that engineers and designers have constructed.

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