

# Designing with Emerging Science

Developing an Alternative Frame for Self-Tracking

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The emerging science of the “gut-brain axis” has been used as the basis for self-tracking technologies assuming that this connection can be used productively for better regulating mood, supporting digestive health, and avoiding disease. Taking this emerging science as a source of design inspiration, this paper presents a design research process to uncover opportunities for novel interaction design and generate alternative approaches to self-tracking. We explored how this emerging scientific knowledge might be experienced and used and what these design spaces might look like through designing a self-tracking probe and asking science communicators working with the gut-brain axis to live with that probe. Their reactions led to a set of exploratory interaction design briefs and a more refined research product that collectively articulate how design can engage with emerging science to inspire a new perspective on self-tracking practices—one of cultivation rather than control.

**CCS CONCEPTS** • Human-centred computing~Interaction design process and methods

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## 1 INTRODUCTION

Self-tracking technologies facilitate the production of knowledge about the body through the collection of data. Self-tracking devices are used to document the data over time in relation to inner body processes, such as menstrual cycles, heart rate and pulse, and external behaviors such as diet and exercise habits, such as step counting [44,50]. HCI has been

increasingly attending to how design of self-tracking technologies influences the way that data is experienced and how the user's sense of self is constructed (e.g. [28,32,33,41]). This paper explores how emerging science can inspire interaction design for self-tracking systems. Rather than re-designing existing devices or building upon already-existing ways of tracking the body, we start with emerging knowledge about the body being brought into new design spaces, bringing with it new opportunities for design.

The relationship between the gut and the brain—or gut-brain axis—is an emerging domain of medical science that is beginning to receive popular attention [2,21]. The term “gut-brain axis” refers to biochemical signals sent between the gastrointestinal tract and the central nervous system. Recently, medical research has begun to link the composition and diversity and activity of gut bacteria to particular moods and emotions as well as mental diseases or disorders [16,35,65]. It proposes that our mental states are influenced by the types of bacteria we have in our gut, and that our mental states can, in turn, influence our microbiome. Signs that this is *emerging knowledge* are that the first large scale study with humans has only recently been published [65], that it is contested [34,57], and that it is closely followed by developers of self-tracking technologies to identify new opportunities for design.

One of the ways that interaction design research operates is to contribute to the shaping and development of emerging technical practices—it has a strong tradition in proposing alternative design directions that deliberately offer critical and speculative perspectives [3,18] to encourage a broader understanding of the possibilities for technology design. In this case, we engage with the emerging science on the gut-brain axis by imagining “what might a device that tracks the relationship between the gut and mental health look like?” In this imagining, we do not aim to design a device that implements this scientific knowledge. Instead, we see ourselves as in conversation with and inspired by issues that the science raises, but not as doing this science ourselves. As researchers interested in how the self is constructed phenomenologically through technology—and particularly through self-tracking technologies—our interest is not with designing technologies for the gut-brain axis *per se*. Rather, by exploring how this science can be materialized in self-tracking technologies, we seek to also explore whether this new knowledge about the body is useful or desirable, how might this knowledge be used, and how “self-tracking” might be productively reframed.

This project uses a self-tracking probe, design concepts, and a refined prototype as research artefacts to design with emerging science as a source of inspiration. The self-tracking probe was designed for domain experts to be lived with over a period of time and to initiate reflections on the relationship between the gut and the brain in order to gain both objective and subjective accounts of tracking the possible relationship between the gut and mental state. As described below, the probe is used to examine and interrogate aspects of potential design, rather than the gut brain axis itself. This probe study led to a collaborative articulation of a set of self-tracking device design briefs, as well as three design concepts. These briefs formed the foundation of a more refined prototype, *Loupe* and *Lightbox*, that offer a way to reflect on longer-term relationships between the gut and the brain. This process led to the idea of self-tracking gut health as a kind of cultivation, and this cultivation as fostering a different approach to self-tracking.

## 2 BACKGROUND: THE GUT-BRAIN AXIS

In order to use the gut-brain axis as an inspiration for design, we needed to understand what the emerging science was. The gastrointestinal system and the large intestine in particular contain a complex and dynamic microbial ecosystem. The gut microbiota contains 100 trillion bacteria, more than any other area of the body [2], and represents between 300 and 1000 different species in various distributions [29,72]. Populations of microbes vary widely across different individuals [64], and are influenced by age [26], diet, nutrient intake [74], and geography [75]. Gut flora is said to defend against infectious agents, develop and maintain the lining of the colon, and metabolize otherwise indigestible compounds

in food. However, the presence or overabundance of particular bacteria in the digestive tract can contribute to diseases or disorders such as inflammatory bowel disease, obesity, colon cancer, or sepsis [29]. Signals from the gut can reach different parts of the brain: the insular lobe, the limbic system, the prefrontal cortex, the amygdala, the hippocampus, and the anterior cingulate cortex [2]. This signalling also occurs via neurotransmitters such as gamma-aminobutyric acid, serotonin or dopamine, impacting the brain through the vagus nerve [62]. These neurotransmitters have been linked to regulating moods and emotion [38] as well as diverse mental health issues such as depression [15,65], Parkinson's [16], Alzheimer's [69], or autism [35].

## 2.1 An Emerging and Unsettled Science

The possibility that microbes in the intestinal tract can produce compounds that include neurochemicals that influence the brain is compelling and promising for future treatments and diagnostic methods. However, this excitement may need to be tempered. Alongside the potential upsides from these findings, there has been a call for more rigor when it comes to how these emerging findings are being translated to possible applications [47]. Firstly, microbiome studies that report on the gut-brain relationship base their findings on rodent experiments [51]—as mentioned above, a large-scale study on humans was only published recently [65]; secondly, studies do not include other sites in the body that host their own microbiomes and also connect to the vagus nerve [34], meaning that the gut may not affect the brain alone; and thirdly, the studies risk being distorted or oversold [34,57]. Further, environmental pollutants and socio-economic confounders need to be considered, particularly for studies that link gut flora to depression and anxiety [57].

## 2.2 Current self-tracking devices on the Gut-Brain Axis

Despite the call for more rigor when it comes to emerging findings and their translation into possible applications, the excitement towards gut-health and its potential relation to the brain is starting to gain commercial interest from existing self-tracking applications for gut-health. The mobile applications *Cara: Food, Mood, Poop tracker* [12]; IBS tracker *Bowelle* [9] (Figure 1, right); and *Symple Symptom tracker* [63] act as diaries to help uncover the relationships between the food a person consumes, the characteristics of their faeces, digestion-related pains, and their mood and stress. Other than diaries, some applications come with self-testing or tracking equipment. *AtlasHealth* [5] and *Viome* [67] are applications that include a stool sample test that can be sent back to the lab for analysis, returning a report that describes the diversity and composition of gut bacteria. *Viome* in particular links the microbiota analysis specifically to ailments such as obesity, diabetes, anxiety, depression, and auto-immune diseases. The application *FoodMarble* [22] tracks digestive symptoms, sleep quality and stress levels, and comes with a breath analyser called AIRE to track gut fermentation levels throughout the day on a 0-10 scale (Figure 1, left). Some self-tracking applications for mental health also take possible relations to gut health into consideration, although less explicitly. *Moodfit* [48], for example, not only offers mood tracking, but also allows a user to create experiments to test how particular food might affect mood. Notably, these systems and devices are not based on broad clinical trials but are doing their own kind of speculation on how this emerging science should be applied. They make assumptions about how the body should be imagined, what tracking the body is for, and how the data from self-tracking should be utilized.

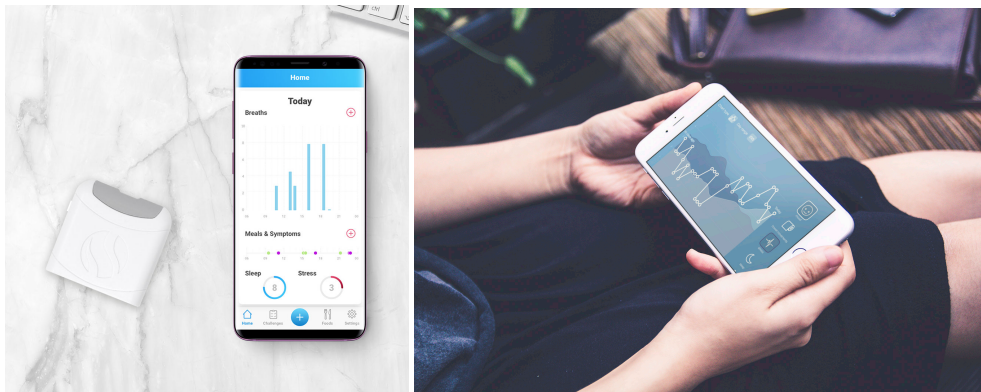


Figure 1: FoodMarble's AIRE, left, registers digestion quality via gut fermentation. Right, Bowelle's IBS-oriented food tracking interface. (Images from press kits)

### 3 SELF-TRACKING PROBES FOR DOMAIN EXPERTS

The previous section discussed the tensions between an unsettled area of emerging science, commercial enthusiasm, and popular imaginations of the potential for harnessing the relationship between mental health and the gut. This complexity leads to a diverse set of methods to access how the science operates in practice and in application, and where design researchers can get a hold of what is happening there. To engage with the science at play in this domain has led us to use design research approaches that are commensurately open-ended and exploratory while being rooted in personal experience as well as relevant domain expertise.

#### 3.1 Probes in Design Research

Since their introduction two decades ago, there has been an explosion of probes as an established activity in design research [6,27,45,46]. Probes have been described as devices to provoke reactions [24]; as self-reporting tools to elicit inspirational responses from people [25]; as instruments to be deployed to find out about the unknown [37]; and as ways to make the 'ordinary' visible, supporting an ongoing dialogue between participants and designers [27]. Our interest in probes is motivated in particular by their potential for fostering an explicitly critical character—especially in the way that their self-reporting qualities can both unravel and articulate the experience of living with technological artefacts over longer periods (see also [20]). Within the self-tracking domain in particular, probes have been used to track household products [23], experiences of chronic illness [4,55], or as a documentary activity [19].

Fundamentally, probes aim to elicit responses from study participants. Provocation has been employed as a tactic to evoke reflections on issues addressed through the probe, for example by using techniques from conceptual art [25:26]. Explicit critical stances that are manifested in artefacts with the character of a probe tend to link to critical design practices, for example, with the critical artefact methodology [10] or provotypes [7] that aim towards developing novel technologies. To that end, technology probes are pieces of simple, flexible and adaptable technologies that aim to collect information about their use and users, inspire users and design researchers to think about how technology could support needs and desires, and to field-test a technology [36].

#### 3.2 Involving Experts in Collaborative Speculation

The involvement of domain experts in processes of design has been widely practiced and studied. Having domain expertise implies knowledge of essential aspects of a specific field of inquiry. In the evaluation of software interfaces,

for example, heuristic evaluations typically involve design and domain experts [52]; design-driven innovation [66] argues for the involvement of domain experts to create new technological applications with radical new meaning; and methods have been explored to bridge the gap between design team knowledge and domain expertise [59]. In the development and evaluation of self-tracking devices in mental health for example, designers commonly work with health perspectives to propose design considerations (e.g. [40,54]).

In the context of design research, Wakkary et al have used the expertise of philosophers to help understand the relations between people and technologies in a technique they call *co-speculation* [70]. We seek to adapt this method by involving domain experts not just for their knowledge of a specific field of inquiry, but also to bring this knowledge together with an account of their experiencing their particular expertise.

Employing probes to get first-hand accounting that inspires the design of self-tracking devices brings together a vast amount of work from research related to design probes as well as self-tracking. Novelty here is not necessarily in the combination of these two research areas, however. Rather, it is in employing this combination in an emerging domain of medical science, engaging domain experts as primary participants in that inquiry through co-speculation.

## 4 THE GUT FEELING PROJECT

The Gut Feeling project set out to explore a breadth of possible applications for self-tracking the gut-brain axis. In this section, we first describe the considerations that went into the design of the probe, and then describe how we used the probe to find out what it might be like to live with a technology that tracks a relationship between the gut and the brain.

### 4.1 *GutFeeling3000*: A Self-Tracking Probe

The background section above shows that the medical science is only at the early stages of understanding the gut-brain connection and that its complexity is not close to being fully understood. Contemporary commercial designs of self-tracking devices tend to subscribe to a reductionist approach to representing the body [14,71]. This notion of commensuration—the process by which different qualities are transformed into a common numerical metric—tends to be prioritized over other ways of assessing the status of the body, because of their association with rationality and their support of the notion that “value” can be standardized and compared across people [38:97]. Our own interest in this topic comes from unravelling these assumptions about how information about the body can be made valuable or understood as having worth, and instead approach these practices from other points of view [31,39]. Curiosity about how the relationship between the brain and mind has entered popular culture—while being rooted in some as-yet unsettled scientific fact—motivated this design application in particular.

As a self-tracking probe, the design of *GutFeeling3000* (Figure 2) came deliberately from a critical perspective responding to that reductionist, data-driven approach to self-tracking. In *Speculative Everything*, Dunne and Raby [18] describe different kinds of thought experiments for doing speculation. Alongside *what-if scenarios* and *counter-factuals*, they present *reductio ad absurdum* as a critical device. *Reductio ad absurdum* is a logical move that demonstrates the ridiculousness of an argument by taking it to its extreme, revealing its absurdity. In critical design, this translates into designs that take a prevailing belief as true, push it to an extreme, and reveal that there are indeed contradictions at its core. By committing to absurdity in a design object, the dissonance it creates opens a space for reflection, letting a user articulate issues they come across regarding self-tracking in their everyday life. The absurdity of a simple count for such a complex system as the gut-brain axis led us to design the probe *GutFeeling3000*.

*GutFeeling3000* is a cardboard cube containing a gas sensor (detecting either ethanol or CO<sub>2</sub>), a small display, and a reset button. It uses the gas sensor to speculatively assess gastroenterological conditions, inspired by the gut-fermentation-based applications above. For example, the gas sensor emulates the commercial AIRE device that uses a

hydrogen-based breath test to track gut fermentation levels, and evokes the breath test performed in clinical settings to diagnose common gastroenterological conditions such as small intestinal bacterial overgrowth (SIBO) and irritable bowel syndrome (IBS) [58]. Existing breath tests measure various gases produced in the intestine that diffuse into the systemic circulation and are exhaled through the lungs, helping clinicians draw conclusions about how readily the gut digests particular substances. By using real gas sensors to sense chemical changes in a users' breath, GutFeeling3000 as a technology probe offers an example of a real-world interaction around breath sensing to help set the scene to imagine future devices for tracking the gut-brain axis.



Figure 2: The GutFeeling3000 probe device.

The device describes its functionality on the side of the box:

*By sensing the gases you have on your breath, this device can determine which bacteria you have in your gut. New research shows that the type of bacteria you have living inside your stomach dictates your mental state. Some bacteria release hormones that make you feel happy, and some send signals to your brain that encourage anxious and depressed feelings and behaviour. By analysing your breath, this device can determine how your gut health is influencing how you feel.*

GutFeeling3000 takes the breath reading from the gas sensor and presents it as data, a single number between 0 and 254—the default range for expressing analogue input in our microcontroller. Using this somewhat arbitrary and certainly oversimplified numerical representation instead of some other mapping of the data was a *reductio ad absurdum*-based design decision meant to prompt reflections on how the breadth of the lived experience of the gut-brain axis and the felt relation between mental state and gastrointestinal state could be expressed through a single data point. A small notebook was included with the device to participants so they could capture the responses and experiences evoked by using GutFeeling3000, enabling the comparison of readings over time. The tracking part of the probe was therefore not part of the device itself but rather built from the juxtaposition of the various diary entries. Instructions for taking a reading were included on the other side of the device:

1. Press the top button and release.
2. Wait until calibrating is complete (approximately 5 minutes).

3. Breathe into the orange sensor.
4. Record your reflections on the result.
5. Use the device at least once a day for two weeks.

The name “GutFeeling3000” positions the probe as a kind of ‘pseudo-product,’ evoking the naming schemes of retro-futuristic consumer devices. The positioning of the small digital screen, orange breath sensor, and instructions for use together created a functional appearance and interaction. The cardboard material and lightweight nature of the object was chosen to communicate to users that this is a preliminary version of a self-tracking concept—one that is open to being iterated upon. In total, we produced 5 probe devices that were used in our study.

#### 4.2 Deploying GutFeeling3000 with Domain Experts

We approached domain experts to live with the probes. This allowed us to access both their objective, abstract understanding of the gut-brain axis, as well as their subjective experiences of using the probe artefact. Rather than just interviewing them to access a more reflective and abstract expertise, we hoped to use the probe to collect their situated, direct personal reflections of experiencing this topic in a different way than they would normally. We wanted them to live with and use GutFeeling3000 in order to engage with the science that they are already cognitively and objectively familiar with, but from an embodied, subjective perspective. Their reactions helped us consider whether this knowledge about the body could be useful or desirable and how it might be used in future design concepts.

To find experts on the gut-brain axis, we reached out to a research group from a medical museum connected to a local university. Since 2017, this group has been involved in the design and curation of an exhibition on the gut-brain axis and had just embarked on a multi-disciplinary research project exploring the topic further. This meant that this group of researchers had an understanding of the variety of research and current work that has been taking place in this domain. This was not a group of clinical or experimental scientists, but rather researchers skilled and interested in understanding how science about the body is communicated as well as how it correspondingly shapes society. The group of expert researchers comprised of five people, each approaching the gut-brain axis from the perspective of their own academic background (Table 1).

Table 1: Backgrounds of expert participants.

	Position	Background
P1	Senior Researcher	Medical Humanities
P2	Senior Researcher	Medical Science Communication
P3	Junior Researcher	Sociology of Science
P4	Junior Researcher	Zoology
P5	Junior Researcher	Psychology and Well-being

Our collaboration consisted of four meetings over a period of six months. In the first meeting, we were introduced to one another’s work. During that conversation, the experts expressed an interest in the self-tracking probe, agreeing to live with it for two weeks. The probes were given to them in a brief second meeting, where we deliberately did not provide a detailed explanation of the GutFeeling3000 in order to avoid giving direction to how they understood the probe. The third meeting took place two weeks after the hand-over. In that meeting, we discussed the experts’ experiences with the box, and speculated what a self-tracking device might be like if it was built with these experiences in mind. The fourth and final meeting discussed possible avenues for future design possibilities for gut-brain self-tracking devices. In the next section, we present our expert participants’ experiences of the GutFeeling3000 probe. We

then unpack how the probe was conceptualized by the experts in that meeting. Then, we discuss three design ideas that have resulted from this collaboration, and finally, a refined prototype based on these design ideas.

The following accounts are drawn from both the diaries that our participants kept over the two-week study whilst using GutFeeling3000, as well as transcriptions of the interviews from the meeting where our participants presented their experiences to us. This first set of subheadings come from summaries of the experiences of use from our five participants.

#### 4.2.1 *Self-Reflective and Philosophical Questions.*

For P1 *“the box did a lot of things outside the measurements.”* He reflected on the way that using GutFeeling3000 *“made me think a lot of things about myself.”* One of these aspects was how *“one of the other times I got a lower number, 169... I was super tired, but my head was still kind of racing, so it really made me think about that kind of dissonance, the way how your body feels something and your mind is going in a different speed, and that felt like being stuck in two settings at once.”* P1 also reflected on the more philosophical questions that this experience prompted, e.g. the *“power and illusion of numbers”* to change how the body is understood.

#### 4.2.2 *“Knowing Too Much” and Resisting Quantification.*

P2 had trouble playing the game of imagining that the number given by GutFeeling3000 had anything to do with her gut health. While there is a real-world link between the gut and the gases that it produces that could possibly reflect its internal state [58], she described knowing *“a bit too much about this”* to feel comfortable fully entering into speculation towards the probe’s efficacy. Part of this might have been related to the daily measuring. GutFeeling3000 did not work for P2 in terms of temporality *“because I felt like a lot of the things that I was talking about in terms of the feeling part have a much slower timescale than the multiday measurement (of the microbiome).”* P2 instead enjoyed using the experience as a prompt to keep a diary of her thoughts and feelings and wider reflections on how this phenomenon is too complex to reduce into quantified data.

#### 4.2.3 *Resisting Self-Surveillance and Responsibility.*

P3 used the device unwillingly. She wrote *“I am not sure it is good or healthy for me to inquire so much about my own body. It is as if a new space of possible governing or conquering has just opened.”* This led to reflections on how P3 would not want these devices to exist at all: *“it gives me the sense of tremendous internal change, somehow giving a sense of being even more an individual with responsibility. Now also for my intestines, and frankly I don’t need more responsibility or knowledge.”* For P3, any designing for self-tracking was intrinsically a problem. For them the idea of tracking anything brought along issues of becoming newly responsible for that part of themselves, of being beholden to yet another part of themselves that they need to optimize and structure their behaviour around.

#### 4.2.4 *Intuiting Changes over Time.*

P4, whose background was in the sciences, said *“I think I approached this like an experiment.”* Over time, the study gained momentum for P4: *“the initial one meant nothing, and then following one only meant something by the comparison to the previous one.”* P4 did not record much beyond the number, and very little about her mental state, but told us how *“most of mine were quite similar, so I was like, is this working? Or am I just really steady? And then it happened that I did a reading after a difficult phone call, and the reading was much higher than all the other ones.”*

#### 4.2.5 *Hyper-awareness and Health Concerns.*

P5 had some concerns about what the information produced by GutFeeling3000: *“I felt a bit nervous about measuring my microbiome, what if it turns out to be unbalanced or unhealthy?”* P5 also forgot to use the device and described feeling



embarrassed, she reflected on the fact that this might create a feedback loop where, *“if my mind affects my microbiome—does that mean that the number of today measures embarrassment in some weird way?”* The device had created a situation that changed how P5 experienced herself, even if she forgot to do the self-tracking daily: *“I think I have been more aware of how my stomach and my mind have been doing during these days.”* For P5, the purpose of a device attending to the gut-brain relation at all was questioned: *“why am I relating to a box, why am I not meditating instead? Could I have engaged in other kinds of practices to consider this thing?”*

The sub-headings above indicate different values and goals that could lead to a different kind of self-tracking for the gut-brain axis. They reflect the experiences that these experts had bringing their knowledge to the study through using the probes.

### 4.3 Reflecting on Self-Tracking from the Probe

In addition to the summarized experiences of use for the participants, we used bottom-up thematic analysis [11] to generate codes from each participant’s transcripts and logbooks. These particularly related to design aspects of GutFeeling3000. When designing GutFeeling3000, our intention was to be deliberately provocative in order to evoke responses by reducing a complex biochemical process of theirs to a numerical digit. This design decision proved to be a successful mechanism in raising reflections on reductions like these in general: on the one hand, there is a rationalizing power that comes from using numbers, while on the other hand, it is obviously absurd that this number could be meaningful to a person. While 5 participants are not very many for thematic analysis, the expertise with the topic and the level of engagement with the probe led to rich data and commentary on design aspects of GutFeeling3000. The codes from this process of analysis are expressed as subheadings below.

#### 4.3.1 Making Meaning Through Finding Patterns.

The readings that the probe produced were both opaque as well as provocative to our participants. (e.g. P5 *“I have absolutely no idea about how I can relate to this number”* or P3 who wrote in her diary: *“why are the numbers so high today? Because I just ate a banana? Because I feel slightly nauseous?”*) P4 and P1 found their numbers to be relatively similar over time, and questioned how the distinction between readings might be interpreted (P1 *“maybe the difference between 199 and 200 is really significant, though to me it looks like it is not because it is all on the high end”*), and expressed uncertainty about the functioning of the box. P3 experienced a larger variation across different readings yet articulated in her diary that it was still hard to interpret: *“perhaps the difference between 125 and 142 is equivalent to nothing”*. This not-knowing invited experimentation and manipulation among some of the experts (e.g. P1: *“it felt like it got a baseline reading.... If I kept blowing, then it just reached a certain point that was the peak point and then it couldn’t get any higher”*).

#### 4.3.2 Criticisms of Reduction.

P2 speculated that the number could possibly relate to factors such as diversity in her gut microbiota and its composition, but *how* exactly was unclear. In trying to interpret their experience with the probe, both P2 and P1 drew parallels to the calorie as a way of reducing complexity into one number: *“the logic of the calorie... it took all the complexity of the body and reduced it to this number which could be generalized across food, across bodies, it is like the perfect dream, you take whatever it was and you could crush it through that logic and you get a number that would be the same for you and the same for me, it is so powerful. But now it turns out to be not quite the case that with a lot of science that says a calorie is not just a calorie. That logic does not hold up anymore.”* P3 even referred to the box as ‘calorie machine’. Even though reducing factors to numbers is questionable, it could still be desirable. This was phrased eloquently by P1, who said *[the box] runs into our desire for patterns and real knowledge*. P2 recognized the challenge of meaningfully capturing complexity and pointed out that the presentation dictates the response: *numbers are for taking action, prompting feelings could be a more*

*complex representation of sorts*. Attempting to capture the complexity in a number was considered absurd by P1 as well, because of the perceived goal of that number to capture and express both the diversity of the gut microbiome as well as a user’s feelings.

## 5 GENERATING DESIGN IDEAS

The broad themes above served as a basis to imagine speculative gut-brain tracking devices. By giving ourselves and participants a deliberately provocative and reductive probe, we invited speculation on what kinds of devices would have been preferable in its place. Rather than adapting one device to fit the diverse ways in which we had each imagined using knowledge about the gut, we wanted to design from the subjective experience outwards. We aimed to produce idiosyncratic concepts reflecting each person’s desires and experience. These devices represent the broad design space possible for implementing new scientific knowledge about the body, as well as to raise practical reflections for self-tracking devices like these.

Our third meeting with the experts was the first where all of the design researchers and experts were present. It consisted of an initial introduction and overall debriefing conversation. Afterwards, we broke into pairs of one design researcher and one expert. In these paired design sessions, we discussed what a device that reflected their experiences with, expertise in, and desires for the gut-brain axis would be like. These initial sketching meetings, the conversations with experts, and further explorative sessions in our studio were refined into five design briefs representing a broad range of possible self-tracking directions that reflected very different perspectives in how they implement the emerging science on the gut-brain axis (Table 2). These ideas point to a different approach to self-tracking than the commercial devices discussed above. These five briefs were distilled to three interaction design concepts to explore design opportunities for the gut-brain axis. For all of these, the ethical concerns of doing design in this space that P3 rose remained a contributing factor in our process—we sought to avoid self-surveillance, feeling overcontrolled, and forcing responsibility in our ideating and concept refinement.

Table 2: Design briefs from the expert study.

P1	Design a ‘machine’ for philosophical inquiry around the interaction between the environment, mind, and gut, to stimulate rational reflection on their complexities, interrelatedness, and scale.
P2	Design a ‘moment’ to enable being more present with yourself to support introspection on the connections between body and mind.
P3	<i>Do not design</i> —any design in this space creates new responsibilities and forces self-surveillance.
P4	Design an ‘accessory’ that prompts reflection on the more-than-human and your relationship with your microbiota in the moment.
P5	Design an ‘externalization’ of the self that prompts wonderment and promotes appreciation about internal processes, specifically by displaying complex biochemical transformations and signals.

### 5.1 Concept A: The Philosopher’s Machine

Concept A derives from P1’s use of GutFeeling3000 to wonder on the philosophical implications of how the environment influences his mental state. For him, the complexity of this relationship should be revealed and made explicit. This led us to imagine a mechanical, unpredictable tool that takes the breath of the user, while “speaking back” to them in ways that are manipulated by the device and world in combination.

We used his design brief to imagine a self-tracking device modelled on a water pipe (Figure 3). P1 blows into a pipe attached to a cylinder with three unmarked dials on it. As he turns the dials, they influence the respective weighting of

the microbial data points taken from both the environment and his breath. P1 wanted the output of the sensor readings to take the form of words that the device speaks. He would be able to puzzle over what aspect of the data being processed produces which word. This reflects the many factors that played into how he experienced the world as an individual; particularly the influence of the environment he is in on the constitution of his gut bacteria. Ultimately, P1 wanted a device that would help him think philosophically through the complexities of his gut-brain relation and how he understood and constructed his sense of self.

This design idea frames self-tracking that helps the user consider their relationship with their environment and broader contexts of life. In line with his critique of the calorie as a reductive and inaccurate metric, the game of working out the un-solvable puzzle of which data points produce what words reflects P1's critique of science's tendency to reduce the complexity of the world to simple, straightforward truths.



Figure 3: A [mechanical calculator](#)<sup>1</sup>, [water pipe](#)<sup>2</sup>, and [overstuffed armchair](#)<sup>1</sup> illustrate the philosopher's machine. Images from [Flickr](#) via Creative Commons licenses <sup>1</sup>[CC BY-NC-ND 2.0](#) and <sup>2</sup>[CC BY-ND 2.0](#).

## 5.2 Concept B: A Reflective Fiddling Moment

Concept B was designed in response to P2's interest in how information about gut bacteria can augment one's sense of self. In her one-on-one session, P2 said how she wanted a device for conscious fiddling as a form of introspection—of being with her body in a different way. What P2 had found valuable when using GutFeeling3000 was that the interaction with it provided her a moment of introspection. She wanted the information about her gut and brain to be experienced through her body, rather than visually or through sound. Concept B could be a fiddling toy joined together with resistance bands (Figure 4). The different segments of the toy respond to the breath of the user through tightening or loosening their connection to one another. When the user has a higher level of mental-health-influencing gut bacteria, then the segments become harder to manipulate. P2 wanted a device that reflected her emotional state. When feeling more tense or excited, her emotions are reflected by the embodied experience of more tightly joined segments. Conversely, as P2's internal state is more relaxed, the segments become looser and become easier to manipulate. Concept B employs a user's embodied experience to communicate gut-brain data by reflecting the user's emotional state in the tension felt when fiddling with the individual segments. This device frames self-tracking as being inherently embodied, and deliberately addresses that embodied state in the tracking process.



Figure 4: A sinuous [fidget toy](#) and [variable resistance bands](#) combine to form a reflective fiddling moment. Images from [Flickr](#) via Creative Commons license [CC BY-SA 2.0](#).

### 5.3 Concept C: An External Microbiome Accessory

Concept C responds to both P4 and P5's design briefs as they had many overlapping factors. The concept derived from conversations during the one-on-one sketching sessions. For both expert participants, their experiences of using GutFeeling3000 led to them wanting a device that externalized their microbiome, providing a way of carrying it with them, encountering it throughout their day. This concept imagines a microbial accessory that is carried with them (Figure 5). They breathe on the device and the bacteria on their breath is then incubated in a petri dish. This dish can then be displayed on a pendant and reflected on as it changes over time. This concept fits with P4's understanding of the self-tracking act as a scientific experiment, as well as with P5's desire to address the taboo around gut health by presenting the microbiome in a public way. This concept frames self-tracking as tracking not only our self, but also the others within us.



Figure 5: a [compact](#)<sup>1</sup>, a [locket](#)<sup>2</sup>, and a [petri dish](#)<sup>1</sup> imagine an external microbiome accessory. Images from [Flickr](#) via Creative Commons licenses <sup>1</sup>[CC BY-SA 2.0](#) and <sup>2</sup>[CC BY-ND 2.0](#).

## 6 MATERIALIZING EMERGING SCIENCE

These three briefs influenced us to produce a more refined concept that builds on aspects of each. From Concept A, we incorporated the idea of environmentally dependent data about the self and how that information operates in the world. From Concept B, we extracted the idea of a reflective encounter with the self, on the connection between inside and outside, and contemplating the relation between those parts. Last but not least, Concept C was the main inspiration for this prototype, as it is meant to externalize the microbiome, enable one to carry it with them, and establish a care relationship with it over time. The refined concept is based on the idea that there may be important interactions between the saliva microbiota and the microbiome of the gastrointestinal tract—streaking a saliva swab over an agar plate

therefore might allow the culturing of gut microbiomes directly [42,49]. We chose to design a viewer that stages the complex structures of that microbiome for close examination and aesthetic appreciation.



Figure 6: *Loupe*, the viewer, and *Lightbox*, a platform for storing petri dishes and swabs.

### 6.1 Loupe and Lightbox

As an alternative avenue for self-tracking that considers the gut microbiome and mental well-being at the same time, we present *Loupe* and *Lightbox* [8]. *Loupe*, named for the jeweller’s tool that offers close appraisals of gemstones, is a viewer that allows us to closely examine and aesthetically appreciate the complex structures of cultured gut biota. We imagine that the user takes a daily swab from their mouth and inoculates an agar plate with it. These samples grow over the course of a week or longer, becoming a lasting record and marking of that day’s microbiome. By incubating a previously internal microbiota into an external collection, the collected samples become a visualization of gut health over time. The externalization, though, means that the structures that grow in the dish have a shared history at their starting point alone: after the swab, how they progress is a collaboration between the sample, the climate of the petri dish, and the environment at large. When inserted in the viewer, a petri dish can be rotated to look closely from various angles at details of the structural complexities of the cultured forms (Figure 7, right). The transparency of the bottom of the device allows viewing the bacteria in backlight. *Loupe* can either be worn as a pendant (Figure 7, left), or stored on its companion object *Lightbox* (Figure 6, left). *Lightbox*, after the medical tool for examining X-ray radiographs, offers a venue to appreciate the growing structural complexity in petri dishes, as well as a space to store and tend to the dishes over time. It is where the agar petri dishes can be nurtured, and provides dedicated room for the cotton buds used as a saliva swab (Figure 6). By paying attention to details and craft of objects, we wanted to emphasize the importance of the cultured microbiome as something beautiful and precious, as well as something to be respected and handled with care.

Together, *Loupe* and *Lightbox* offer a way for a user to reflect on and engage with their gut over time from a new perspective. Creating, monitoring, and disposing of the petri dishes creates for the user an ongoing, reflective interaction with their gut over time. By entering into this material relationship with their externalized microbiota, a user is afforded a vantage point to reflect on issues of food, mood, digestion, and other issues of gut wellness and mental health—the gut-brain axis. In the next section, we discuss how the notion of *cultivation* in self-tracking, fundamentally allows us to frame self-tracking technology as a kind of slow technology [30,53], and opens up avenues for both future design research and different approaches to self-tracking technologies.



Figure 7: Loupe being worn around the neck, and in use.

## 6.2 Gut-tracking as Cultivation

Culturing agar plates from swabs and breath samples is intended to prompt reflections on the experiential qualities of this culturing as a self-tracking practice. Taking a saliva swab and streaking it over an agar plate is more careful and intentional than simply breathing onto or into a device. The slow timeline of the culturing process inspires experiences of daily curiosity about the evolution of the microorganisms and appreciation of the process of their growth. The emergence of complex bacterial structures (Figure 8) becomes a record of a microbiome over time. In using the *Loupe*, perceiving the structural complexity of bacterial forms is strengthened by viewing the petri dishes against sunlight or backlight from *Lightbox*. *Loupe* and *Lightbox* reconceptualize self-tracking of the gut as a kind of *cultivation*. By this, we mean that the relationship between the self and the microbiome can, by being externalized, become one of tending to and caring for the self and the other. These petri dishes offer a means to grow a different relationship to an underexamined part of yourself over time, raising questions about where “you” end.

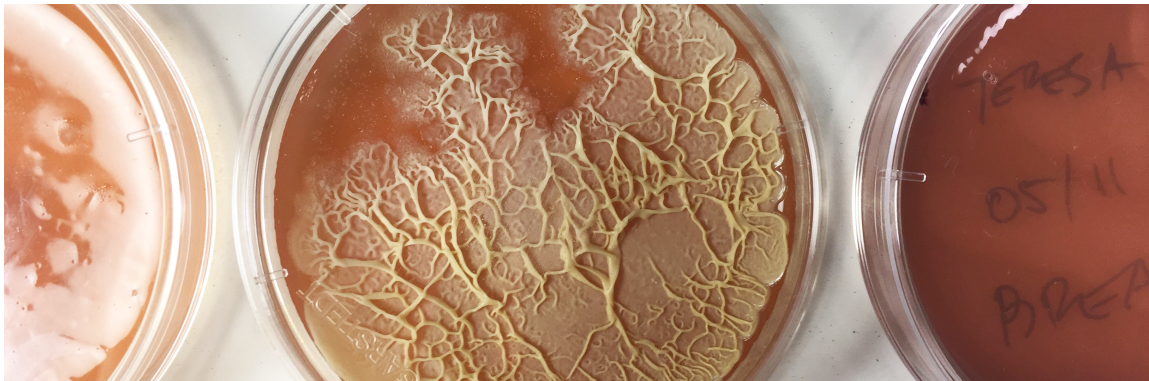


Figure 8: Detail of bacterial and fungal growth on agar plates cultured from mouth swabs.

### 6.2.1 A Vantage for Reflection.

We imagine this cultivation as an intentional culturing of bacteria in order to reflect on what grows. Gut bacteria is affected by factors such as gases in the atmosphere and ambient temperature, and like Concept A, demands attending

to the context and conditions of growth, disputing the idea that it is the constitution of the gut bacteria alone that dictates a person's mental state. We are always situated within an environment. Rather than declaring concrete truths about the body as an entity unto itself, the petri dishes invite for a co-constructive form of self-tracking—the meaning behind the data that the growing bacterial forms produce must be deciphered by the user. This links back to themes from the probe study suggesting that self-tracking should offer ways to connect the past to the future and find patterns over time. The petri dishes on *Lightbox* become a physical archive of internal states that have each taken their own course.

Working with our design concepts led us to ask the question “what happens when the state of one's gut becomes visible for others to see?” *Loupe* is worn as a necklace representing the gut's condition as well as the influence that it has on our mental lives to the people around us, making them visible and public. The design of contemporary self-tracking devices are shaped by societal and cultural norms [17,73] that encourage this tracking to be hidden and private. As P5 indicated, conditions related to gut-health are at risk for stigmatization, in part because the nature of the symptoms focus around the bowel and rectum. By designing to draw attention to the material of the gut, making public and even celebrating the processes that affect digestion, we hope to make this material familiar and normal.

### 6.2.2 *Encountering a part of yourself*

The ongoing relationship and interaction with the petri dishes externalizes the gut microbiome, creating a microcosm of our inner workings, a terrarium for our biota to live within. Cultivation is not only about growing, but also caring about what we grow. This reflects the concept that the gut microbiome is part of a multiple self, as well as an other that cannot be controlled. This perspective on self-tracking raises questions about who we really are, and to what extent we can think of ourselves as a singular being. If the gut microbiome is composed of independent living organisms, with their own desires (e.g. for sugary foods), and our moods are influenced by these alien forms, then how much can we really say that we are monolithic beings? These questions reflect a more-than-human definition of the “self” being tracked [56]. As a different style of self-tracking gut health and reflecting, the concept eschewed and subverted reductivism, as described by P1 and P2, and hopes to avoid the self-surveillance described by P3, instead postulating a way to build meaning into a system and through growing familiarity with the other in us over time. This links to the themes from the probe about encountering the self differently. Drawing from scientific ideas that gut bacteria influences mental state, *Loupe* and *Lightbox* propose that our lived experience of the world is not only shaped by external events, but also our inner states. This design emphasizes that our mental lives are rooted in the body as well as emerging as a collaboration with other biological entities [47].

### 6.2.3 *Cultivating the self*

As an interaction that takes care and engagement over time, we see the *Loupe* and *Lightbox* as an example of a slow technology. After Hallnäs and Redström [30], and drawing from Concept B and the timescales mentioned by P2, the *Loupe* creates a “moment of reflection” on a part of the self that can only be experienced over time. Using *Loupe* is not designed to be as directly informative or as effective as contemporary self-tracking systems. By eschewing representational logics, such as a numerical interpretation, the design of this viewer and the platform invite a more complex and emergent understanding of the gut to provoke reflection in use [60,61]. Instead of presenting data *about* the material, we present the material *itself*. After P3's concerns, this helps to allay fears around self-tracking that creates hyper-awareness of health in favour of building a relation—cultivating a part of the self in the world and drawing insights from that back into everyday life. Producing an ongoing relationship with a heretofore taken-for-granted part of the self might seem like a strange idea. Sampling, culturing, and keeping microbiome specimens over time is not a normal or natural thing to do. We argue that this relationship offers something that is missing from current self-tracking

technologies in creating a familiarity with the materials that produce the sensation of wellness or illness directly, and over time could create a more intuitive, tangible assessment of health.

## 7 DISCUSSION

Our overall aim with this project was to design with emerging science to uncover opportunities for novel interaction design and generate alternative approaches to self-tracking. From this perspective, new and emerging science can lead directly to new design spaces and in so doing, create new opportunities for design. We explored how this emerging scientific knowledge might be experienced and used and what these design spaces might look like through firstly designing a probe, and then using reactions to this probe to develop idiosyncratic designs that represent how our participants imagined uses of this scientific knowledge. This process led to the idea of gut health as a kind of cultivation, and this cultivation as fostering a different approach to self-tracking. This was an exploratory process that denotes an attitude of wondering and speculation towards what is possible when new knowledge about our bodies emerges.

As interaction design researchers, we use this knowledge to imagine different kinds of self-tracking technologies through materializing speculation. For us, the most important aspects of this speculation are how people will react to new knowledge, and the ways that it might be implemented and automated through the design of digital technologies. By designing self-tracking devices, we facilitate conversations about what we might want to do with these new understandings, framings, and concepts of ourselves, as well as what aspects of these insights need to be considered when designing devices that put this scientific knowledge to work. Beyond new framings for self-tracking, this work contributes self-tracking probes as a means to engage experts in an emerging domain and provides an example of how speculative approaches to design invite interaction design researchers to design with emerging science.

### 7.1 Using Probes to Reflect on Emerging Science

This project is not about monitoring digestion nor mental health as such. Rather, the goal of the project is to consider how the inner state of the body can be reflected upon using self-tracking technologies in an emerging domain of medical science. The self-tracking probe helped to cohere an experiential understanding of a design space among participants in the project. As a means of accessing this emerging domain, the experiences and desires of expert researchers as co-speculators using the probe emphasize opportunities for a different kind of accounting than seen in commercially available tracking devices. As self-tracking technologies become increasingly ubiquitous, other approaches to tracking will be increasingly important. While self-tracking technologies might appear on the surface to belong to a quantified world of measurement and optimization, in fact they participate in broader and more situated ways, influencing how people feel, sense, and behave in everyday life [1,13,43].

Based on this, the probe study pointed us to a very different account of both the “self” and “tracking” that cast the self as “self & environment” and tracking as beyond solely numerical representation. The design of the self-tracking probe was deliberately provocative in this respect, following a critical or speculative design tactic, *reductio ad absurdum*. This move meant that our probe also implicitly questioned whether or not the gut-brain axis could be measured and quantified at all. *Reductio ad absurdum* in this context set an autobiographical, reflexive agenda among the experts that deliberately stirred critical reflection, resulting in design concepts and briefs that tended to move away from quantification and abstraction, instead staying close to individual experience. Inviting this scepticism into the process of designing for emerging science breaks down the dominance of scientific knowledge that otherwise dominates design discussions in this space—that of the rationalizing agendas that lead to products for optimizing and making more efficient and effective selves.



## 7.2 Speculating Together with Domain Experts

Having domain experts approach the medical science both objectively and subjectively proved to be a productive platform for the collaborative articulation of a set of alternative design briefs. These design briefs consider the experiential phenomena of a topic, and not solely the rationalization of that topic in service of a product, which the enthusiasm towards this emerging science might otherwise lead to. By enlisting domain experts to use that expertise in the knowledge of the condition coupled to their knowledge of their own lived experiences, the probe created a constellation of situated speculative concepts that pushed away from understanding the gut-brain relation as being a simple avenue to understand the gut as representing and indicating either being simply healthy or, if outside of those bounds, being cast as ill.

Moving away from this simple binary, we have a range of concepts that engage with other representations of how the mind and the gut are related and intertwined. The diversity of the resulting concepts is tied to the particular experts that we engaged with. As science communicators rather than clinicians, their work embraces the possible and not just the provable, thinking through the broader cultural and social implications of these technologies rather than what kinds of implementations might currently be available. The variety of design ideas that resulted from this process is important, as each of them articulate new agendas for designing within emerging medical science, as well as possible technological implementations of the gut-brain relationship. By including co-speculators as part of this design research project, the outcome of this speculation is a set of design briefs that are rooted in their subjective experience and objective expertise.

## 7.3 Cultivation: An Alternative Frame for Self-Tracking

By proposing a different kind of self-tracking, cultivation establishes a relation with the self that is not adversarial, about self-surveillance, or meant to foster discipline. Based on emerging science, it proposes a kind of self-tracking that is meant to create a collaborative relationship with a part of your body over time. In conversation with the concerns of P3, who felt that designing self-tracking technologies was intrinsically problematic, framing self-tracking as cultivation moves away from constraining the self-tracking agenda as being fundamentally about responsibility and managing the self. Rather than rely on redesigning existing categories of instruments and devices, interaction design can be used to question and trouble the goals and assumptions that paradigms like self-tracking have established, especially in emerging domains such as the gut-brain axis. The fundamental reason to consider the gut-brain axis as a domain for interaction design is because the science itself is not yet settled. The assumptions built into most self-tracking systems that is based on science of this sort—including the new technologies that are rushing to use preliminary scientific data to help us reflect on our gut health—assume that that life experience is quantifiable into data, that this data can lead to more perfect knowledge, and that this knowledge can lead to action towards better health practices [68]. In contrast, this project generated a number of new and different considerations of how this emerging science might operate moving away from straightforward representations of health. The promise of measuring the gut-brain axis is not that it *represents* the self, but rather that it is a *part* of the self. This microbiome is an active, more-than-human actor that partially composes who we are—our cognition does not come from the brain alone, but instead can be considered as an ongoing collaboration between the self and the other, that is partially and perhaps permanently influenced by environmental factors. We believe that further developing a perspective on self-tracking that takes nuances like these into account is a promising perspective for future interaction design research.

## 8 CONCLUSION

This paper outlines how design can engage with scientific issues—here tracking or measuring the relation between gut and brain—as a prompt for reflection for designers and developers in emerging scientific domains. Here, we present a conceptual framework, a methodological approach, and an example of a design process. In particular, we developed a probe study with expert researchers that resulted in a number of design briefs representing an expanded field for design. By engaging with these domain experts as co-speculators, we produced alternative approaches to self-tracking the gut-brain relation that incorporates their situated expert knowledge as part of a design inquiry leading to a refined prototype, *Loupe* and its *Lightbox*. These postulate a different frame for self-tracking technologies and new relationships that users could develop with their body over time—that of cultivation with the body rather than controlling it. In exploring designing for the emerging science of the gut-brain axis, we illustrate how speculative interaction design can be used to reframe assumptions in an application domain as well as the applications that are built on that knowledge. This process helps bring new perspectives to the domain that could support a broader range of human needs and experiences.

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