People’s growing desire to better track and manage their health is leading the global market for self-monitoring technologies to reach an estimated $72 billion by 2022. This boom has contributed to a new potential to support people in collecting and interpreting data about their own health and well-being. However, there is a mismatch between what technology currently delivers (e.g., step counts and sleep scores) and what people expect from it (i.e., personalized health insights and recommendations). Current technologies fall short of their personalization potential due to complex and interrelated challenges (e.g., in meeting personal needs, in data quality, in their integration into clinical practice). A holistic approach is therefore necessary, focusing on end-to-end design that understands the individual, their environments, and their contexts. My research focuses on human-centered approaches to collecting, interacting with, and using novel health data toward improving human well-being through personalized insights and recommendations. I explore this in two major thrusts of research:

**End-to-end design and development of practical tools to enable collection of actionable health data in-the-wild.**

I have conceived, designed, built, and validated two personal health technologies:

- **TummyTrials,** an app that assists people with irritable bowel syndrome in identifying their individualized food triggers by scaffolding the design, execution, and analysis of self-experiments in the context of their daily life.
- **Beacon,** a novel device that supports people with chronic liver diseases in self-monitoring their liver function.

In developing these technologies, I adopt an approach that emphasizes understanding the needs and context of an individual and associated stakeholders; holistic design and development of technologies to address identified needs and context; and iteratively evaluating and refining technologies using quantitative and qualitative field data. In developing these technologies, I contribute new techniques for collecting and representing health data. Through studying their use, I contribute new understanding of people’s interactions around health data in the context of their day-to-day life.

**Conceptualizing domain-agnostic frameworks and instruments to support researchers and designers.**

In the end-to-end design and development of personal health technologies, I also navigate more general challenges that other researchers and designers will encounter. I leverage my experience to identify these challenges and propose solutions to support better research and design in this space. I have systematized approaches and design recommendations through developing a framework for self-experimentation, through design recommendations for building targeted personal health technologies, and through a survey instrument to inform design of health tools.

My research draws upon expertise from multiple domains, and I have developed collaborations across computer science, human-centered design, and medicine. My research has led to several successful grants, including a UW Innovation Award (~$500k), NIH #R01LM012810 (~$1.5m, one of three projects), NIH #R21DK117431 (~$400k), and a patent application. My research has received two Best Paper Honorable Mention awards (CHI 2017, DIS 2018) and garnered strong interest from clinicians, researchers, and startups seeking to incorporate my research in their work.

1. **End-to-End Design and Development of Personal Health Technologies**

Novel health data has potential for a large impact in chronic health conditions. Chronic conditions account for 90% of health spending in the US, with 60% of US adults managing at least one condition [1]. Chronic conditions lead to greater difficulties with day-to-day activities and with social and cognitive functions that impact personal independence. Much of the existing understanding of these conditions is based on population averages, leaving individuals struggling to understand and manage their own condition. However, individualized diagnosis and management of chronic conditions requires new forms of data which are not yet supported by existing tools. **In this research thrust, I aim to empower and support individuals with chronic conditions through building end-to-end personal health technologies that assist in collecting and interpreting appropriate data toward meeting their individualized needs.** I pursue this through two major themes of research:

- **Enabling people to answer their own health questions through self-experimentation (an n-of-1 approach).** I have explored opportunities for individualized interventions to assist people with irritable bowel syndrome in identifying their food-based triggers using self-experimentation [3].
- **Improving self-management of chronic conditions by transitioning from one-off clinical screening to at-home self-tracking.** I have explored supporting individualized understanding in people with chronic liver disease by developing a new self-tracking device to monitor the stability of their cognitive functioning [4].

In designing these technologies, I emphasize scaffolding to reduce burdens, improve data quality, reduce required expertise, and create a non-stigmatizing experience.

1.1 **TummyTrials: Diagnosing Food-Based Triggers for IBS using Self-Experimentation**

Irritable bowel syndrome (IBS) is a chronic functional disorder characterized by episodic abdominal pain with diarrhea and/or constipation. It affects 20% of US adults and is one of the top 10 reasons people seek primary care. IBS symptom flare-ups are triggered by a variety of factors that vary by individual (e.g., certain foods, eating behaviors, stress, sleep disturbances, menstruation). Clinical tests (e.g., blood tests, X-rays, colonoscopies) are generally inconclusive in determining an individual’s specific triggers. Current care practices often employ food diaries and elimination diets, but these techniques are burdensome and clinician interpretation is both difficult and error-prone. In the absence of an alternative, people
often resort to trial-and-error by adding or removing trigger factors and observing their immediate impact on symptoms. This often leads to dubious findings due to unreliable data, a lack of structure, or a lack of necessary expertise.

To assist people with IBS in their identification of their individualized triggers, I adopted a self-experimentation approach. Self-experimentation, also referred to as an n-of-1 trial, is where an individual serves as their own control, highlighting their response to an intervention (i.e., in contrast to population-level understanding in clinical trials). I created TummyTrials, an app that supports people in the design, execution, and analysis of scientifically valid self-experiments in context of their daily life. In designing TummyTrials, I drew upon existing medical research and findings from my formative surveys and focus groups with IBS patients. TummyTrials reduces tracking burden by only asking for minimum viable data – symptom level and compliance with experiment condition; provides structure and rigor through customized notifications and prompts; scaffolds domain expertise in designing the self-experiment by using a wizard that includes common symptoms, trigger foods, and meal plans created by a dietician; and scaffolds interpretation by performing statistical analysis and providing textual and visual summaries of the result.

I investigated the feasibility of TummyTrials for supporting people in collecting and interpreting data through in-the-wild self-experiments. I recruited 15 IBS patients, asking them to create, schedule, and undergo a 12-day self-experiment to determine if a specific food triggered their IBS symptoms. 12 of 15 participants completed the study with 100% compliance, much higher than 11–55% seen with traditional food diaries. Participants also reported that TummyTrials reduced the overall burden of remembering and tracking, provided structure to a process that can otherwise be trial and error, and provided accountability. These findings provide support for a holistic approach to scaffolding barriers in collecting and interpreting self-experimentation data, thereby supporting people in understanding the personalized nature of their condition. I presented these findings at CHI 2017; the work was awarded a Best Paper Honorable Mention (top 5%) [3]. I am supporting a colleague in extending this work to explore personalized Bayesian graphical models examining impact of different foods on IBS symptoms. This model will explain trigger-symptom relationships and facilitate better understanding of individual differences among the population.

I built TummyTrials using an open-source technology stack and mentored a design student in creating a non-stigmatizing visual language for the app. Our team received a UW Innovation Award (~$500k) to develop and evaluate TummyTrials and recently an NIH grant (~$1.5m) to improve upon and expand our self-experimentation approach to other chronic conditions.
1.2 Beacon: Supporting Self-Monitoring among Patients with Chronic Liver Diseases (Cirrhosis)

Cirrhosis affects 4.5 million US adults and is currently the 11th most common cause of death. Up to 80% of people with cirrhosis at some point will experience hepatic encephalopathy (HE), a spectrum of neurocognitive impairments. HE ranges from no visible symptoms to mild confusion in its early stages, but can be fatal in later stages if left untreated. Early detection of HE is therefore desirable, but it currently is only diagnosed in clinical visits when symptoms have progressed to visible personality disorders. Data sparsity due to infrequent clinical visits and a lack of objective measure can make it difficult for people at risk of or currently experiencing HE to discern changes in their cognitive abilities in a timely manner to receive treatment. Critical Flicker Frequency (CFF), the minimum frequency at which a flickering light source appears fused to an observer, is a neurophysiological test that has proven capable of detecting HE in early stages in research trials, but the equipment is highly specialized, costly, and not available in majority of clinics. CFF provides a potential approach for data-driven, objective self-monitoring among HE patients.

![Figure 2: I propose using the CFF test to enable a data-driven approach toward patient self-monitoring of hepatic encephalopathy. Lafayette FFS (top row) is the current gold standard for measuring CFF. It is bulky, expensive, and requires specialized training. Beacon (right) provides a portable, inexpensive, and self-administrable alternative. Beacon enables at-home self-monitoring, which no current CFF device is capable of, for early detection and intervention.](image)

To assist in early diagnosis of HE, I created Beacon, a portable, inexpensive device that enables people to measure their own CFF. Beacon enables cirrhotic patients to self-measure their CFF without requiring any specialized training. Beacon is designed to address two key barriers to adoption of existing devices like the Lafayette Flicker Fusion System (FFS): (1) limited access to testing devices due to cost constraints (~$3000 just for hardware) and inconvenient form factor; and (2) the need for specialized training to use the device. In contrast, Beacon costs ~$50, has a compact form factor, and provides step-by-step guidance through text and audio instructions to measure CFF.

Moving from a closed chamber design (e.g., Lafayette FFS) to a portable design resurfaces three key factors that impact CFF measurement — viewing angle, ambient light intensity, and device’s light intensity. To ensure a near 0° viewing angle, Beacon has four surrounding red lights which assist an individual in aligning themselves with the device. I ran multiple studies to characterize the impact of ambient light intensity and device’s light intensity on the measured CFF and to choose appropriate values for later studies. Finally, I conducted a study with 41 healthy adults ranging from 18 to 99 years of age, finding that Beacon performs on par with Lafayette FFS in measuring CFF, achieving a Pearson’s correlation coefficient of 0.88. Next, I conducted a focus group with hepatologists to understand current standard of care for HE and potential barriers in adopting CFF in early screening for HE. I presented these findings at UbiComp 2018 [4].

![Figure 3: Working alongside industrial and mechanical engineering students, I have iteratively updated the form factor and assembly process of Beacon. (#4 from left) is the version I used for the pilot studies presented at UbiComp 2018. (#8) is the current version being used in the clinical evaluation and for future at-home deployments.](image)

I am currently working to make Beacon a viable at-home self-monitoring tool, by running a comparative study with cirrhotic patients at the UW Medical Center to evaluate Beacon’s performance in a patient population. In parallel, I am iterating on Beacon’s design to prepare for a longitudinal home deployment study. Toward my vision of adopting a data driven approach to monitoring HE, Beacon provides an alternative to current occasional clinical screenings (i.e., every three to six months), instead enabling daily at-home self-monitoring. Similar to how technology has enabled better monitoring and standard of
care for conditions like diabetes and hypertension, I envision Beacon empowering and supporting patients by providing new data for use in their self-management and clinical care.

I built Beacon using off-the-shelf components paired with a custom mobile app. I also mentored students in industrial and mechanical engineering to iteratively refine Beacon’s design and production process. Based on our formative research, our team recently received an NIH grant (~$400k) to evaluate Beacon among a cohort of cirrhotic patients. In addition, we have a patent application in submission and are actively working toward commercializing our technology.

2. Conceptualizing Novel Approaches and Methods for Building Personal Health Technologies

Designers encounter many challenges in the end-to-end design and development of personal health technologies. Observing the shortcomings of current tools and leveraging my own experience in building new tools, I also work to systematize broader underpinnings of my research to create generalizable approaches and recommendations for researchers and designers.

2.1 Framework for Self-Experimentation in Personalized Health

For complex chronic conditions where triggers vary from individual to individual, it is vital to understand and account for individual differences. The personal informatics research community across HCI and medicine has explored self-tracking as a potential approach to understanding individual variations. I proposed self-experimentation as a more rigorous form of self-tracking that motivates tools to assist in discovering individual variations. As a part of an interdisciplinary team of researchers I developed a framework for self-experimentation which provides common terminology for developing tools. The framework consists of three steps: formulating a hypothesis to test (e.g., caffeine worsens my abdominal pain); testing the hypothesis through a self-experiment (e.g., by systematically adding and removing caffeine); and analyzing the results to inform a decision for next steps (e.g., reducing caffeine to one cup a day). I also identified absolute and desired requirements for the application of this framework (e.g., characteristics of independent and dependent variables). The aim of the framework is to assist people in (1) narrowing down the question to determine the minimum data needed; (2) using effective study design to maintain rigor while reducing burden; and (3) providing analyses to support effective decision making. I conducted three focus groups and an online survey (60 respondents) to evaluate the feasibility and understandability of the framework. This research is one of the pioneering works within HCI proposing the use of an n-of-1 approach toward building and evaluating health and wellness tools. This research was published in JAMIA in 2016 [2].

![Figure 4: My framework for self-experimentation in personalized health aims to provide structure to current trial-and-error processes. It does so by determining the reason for data collection upfront, by being low burden, only collecting the bare minimum data; and by being contextual, running the experiment in day-to-day life.](image)

2.2 Design Recommendations for Building Targeted Personal Health Technologies

To design effective self-experimentation tools, designers need to be mindful of the range of questions people want to answer using such technologies. Using prior IBS interview data (from 25 patients and 10 providers) and a survey (78 respondents), we distilled the questions into nine templates based on the hypothesized relationship between dependent and independent variables (e.g., whether there is any effect, whether an effect is noticeable, a threshold before an effect is noticeable, a temporal relationship in an effect). We also demonstrated that Bayesian methods can better answer the questions that people have about their self-experimentation data and can do so in a way that we believe is easier to understand than p-values and confidence intervals. Our findings aligned with recommendations from the Agency for Healthcare Research and Quality on analyzing n-of-1 data and endorse adoption of Bayesian analysis to better support a variety of question templates. The Bayesian analysis and nine template questions we formulated can serve as a starting point for future tool designers in explicitly deciding what kind of questions they can support or in expanding support for multiple question types. These findings were published in JHIR in 2018 [7].

2.3 A Survey Instrument for Evaluating Design of Health Tools

Developers, designers, and researchers are encouraged to employ rapid prototyping methods to project the adoption and acceptability of their health intervention technology (HIT) before the technology becomes mature enough to be deployed. Although these methods can inform designers about which features affect use, they do not provide causal explanations that can better guide design refinement and transfer to other applications. In collaboration with a colleague, I developed a survey instrument for disentangling the causal relationships in the mental models that people develop around conceptual HITs. As a researcher manipulates characteristics related to their HIT, the survey instrument measures user-intrinsic factors through questions based on the Health Belief Model – an established framework for explaining and predicting health-related behaviors. Responses to the survey instrument are analyzed using structural equation modeling to disentangle the causal
effects of these factors on outcome variables, producing both actionable feedback on an HIT design and usable evidence for the broader community. The instrument has the potential to aid in building generalizable knowledge of how to design better health technologies by providing common terminology grounded in theory [5].

3. Future Directions & Opportunities
I am driven to empower and support individuals through building new technology and reducing barriers to collecting, understanding, and acting upon personal health data. Building on my track record of working as a part of multi-disciplinary teams, I plan to collaborate across engineering, design, and medicine to solve complex problems that researchers in this space will encounter in building the next generation of personal health technologies. My research agenda will continue to focus on using a human-centered approach to design, deploy, and evaluate novel health data experiences.

3.1 Evolving Personal Health Technologies
In my research with IBS and migraine populations, we identified the goals and needs of people using these technologies evolve over time [2, 3, 6, 7, 8]. To address the ever increasing complexity of designing such dynamic technologies, my colleagues and I propose exploration of templates. These templates will be collections of relationships around (1) what questions people want to answer; (2) what data are necessary to answer those questions; (3) when and how to track such data; and (4) what analyses and visualizations are appropriate to answer a question with the data. Recognizing the changing goals of an individual, a platform can adapt to suit the person’s current needs. For example, once caffeine is determined to be a likely trigger for abdominal pain, a next goal can be to check if there is a specific threshold of caffeine below which abdominal pain is manageable. Developing such templates necessitates a holistic approach requiring input from different stakeholders, balancing the trade-off between burden and value received, and evaluating for scientific rigor and practicality.

3.2 Interweaving N-of-1 and Population Data
Much of modern medicine is based on large-scale randomized controlled trials (RCTs), which provide population-level evidence regarding the effectiveness of an intervention. This top-down approach works well when the focus is on assisting a majority of a population, but RCTs have critical limitations in that they are not always feasible due to challenges of scale and associated economics, and individuals and providers who are unable to find the evidence they seek in existing trials are then left to fend for themselves. My work with n-of-1 experimental design aims to fill this gap by adopting a bottom-up approach and focusing on the individual. Such studies provide outcomes that are actionable for an individual, and I believe they also can help build population-level knowledge, which can in turn inform future n-of-1 studies. I plan to bridge these two approaches to study design by collating n-of-1 data to form new population-level understanding and to use existing population-level understanding to guide better targeted n-of-1 interventions. Opportunities for research themes within this question can include better explainable machine learning models (owing to the rich data collected at an individual level) and actionable diagnostic experiments which can be run in a matter of days or weeks as opposed to months or years.

3.3 Translating Technology from Lab to Clinic and Home
Many health innovations created in research do not make it into the hands of the individuals who need them, be that practitioners in clinics or individuals at home. In my experiences with commercializing TummyTrials and Beacon, I encountered systemic barriers that impede any effort to bridge these gaps. I aim to support other researchers and designers in bringing their tools to the market by identifying and scaffolding barriers pertaining to such translational efforts. As I continue to work on these translations and as I learn more through my interactions with various communities (e.g., HCI, global development, medicine, non-profits, investors), I will work to synthesize and disseminate recommendations for future researchers to follow and build upon in their own journeys. As one step toward building this community and these practices, I plan to organize a workshop at CHI and AMIA where HCI and medical researchers can share their experiences and findings from their translational efforts toward creating a best-practices guide.

References