“The Internet of *What*?” Understanding Differences in Perceptions and Adoption for the Internet of Things

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This study explores people’s perceptions of and attitudes towards Internet of Things (IoT) devices and their resulting (non)adoption behaviors. Based on 38 interviews (19 pairs each consisting of a Millennial and their parent), we found that few had a clear understanding of IoT, even among those who had already adopted it. Rather, they relied on two distinct conceptual models of IoT that shaped their beliefs, concerns, and adoption decisions: Many approached IoT with an “user-centric” technology mentality, viewing IoT devices as tools to be controlled by the end-user, and focusing on their tangible aspects (e.g. breakability). Others drew on an “agentic” technology perspective, where IoT behaviors were device-driven and, at times, negotiated between the user, other people, and/or the IoT devices. Our study revealed that consumer-oriented IoT currently cater towards the agentic view and raise concerns for those coming from a user-centric perspective. We also found that generational differences in attitudes towards IoT were rather explained by these differing perspectives. Instead of following the trend towards greater automation and agentic modes of interaction, we advocate for a hybrid and personalized approach that supports a spectrum of agentic and user-centric perspectives and provide design recommendations to work towards this end.

CCS Concepts: • **Human-centered computing→ Empirical studies in HCI** • **Human-centered computing→ Empirical studies in ubiquitous and mobile computing** • Security and Privacy → Human and societal aspects of security and privacy

Additional Key Words and Phrases: Internet of Things, Technology Adoption, User-Centric, Agentic

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1 INTRODUCTION

The availability of high performance, low-powered processors has enabled a new category of devices referred to as the Internet of Things (IoT). IoT introduces the novel idea of connecting any device (e.g., a sensor) or

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appliance (e.g., refrigerator) to a larger network of devices or to transmit and store data via the Internet. Gartner [33] has forecasted that the number of IoT devices on the market will reach nearly 21 billion by 2020, while others have projected upwards of 30 billion [5]. Consumer-based IoT devices include fitness and health trackers, such as the Fitbit and Apple Watch, as well as smart home devices, such the Nest thermostat [34] and Amazon's Alexa [13]. IoT devices are already expected to dethrone smartphones as the largest category of connected devices in 2018 [35], as tech giants such as Apple, Amazon, Google, and Microsoft are all positioning themselves to take advantage of bringing IoT to consumer markets [36]. However, a 2016 survey by Accenture tells a different story; consumer demand for IoT devices is much lower than expected, with only 13% of consumers intending to purchase a smartwatch and up to 11% intending to buy a smart home system [37]. Similarly, in 2016, another market survey found that just under 16% of adults in the U.S. regularly used a wearable device [15]. While the market is still projected to grow, forecasting firms have cut the growth outlook going forward [15,28], raising important questions about the low uptake of this widely heralded technology.

Our study examined the adoption (or non-adoption) of two types of consumer-based IoT—wearable and in-home IoT devices—from the differing perspectives of Millennials and their parents. These are two of the most popular and widely available consumer IoT devices [24,27,38], but demand for them is lower than expected [37]. Additionally, we investigated whether generational differences may lead to different perceptions and adoption patterns for these IoT. Research suggests that consumer-based IoT devices are often targeted toward older adults (e.g., homeowners and individuals with health and fitness concerns) [39]. These individuals also tend to have more concerns regarding usability and privacy than their younger counterparts [20]. However, there is a lack of nuanced data on usage, privacy, and other perceptions for different age groups and across different types of IoT devices. Hence, our study considers these important perspectives by exploring the following questions:

RQ1: How do individuals conceptualize IoT and how does this influence their adoption decisions?
RQ2: What are the motivations for and barriers against the adoption of consumer-based IoT from the perspectives of adopters and non-adopters?
RQ3: Do these trends differ based on IoT type (i.e., wearable vs. environmental) or generational differences (i.e., Millennials vs. their parents)?

To answer these questions, we conducted 38 semi-structured interviews and explored people's attitudes, understanding, and use of commercially available wearable (e.g., fitness tracker) and environmental (e.g., in-home) IoT devices. To examine generational differences, our sample included Millennials (ages 18-26) and one of their parents. To contrast users with non-users, we interviewed both those who had adopted various types of IoT, as well as those who had not. Our analysis revealed that very few participants had a full or clear understanding of IoT, even among those who owned IoT devices. Moreover, those who understood IoT were not necessarily the ones who adopted. Rather, we found that individuals drew from two distinct conceptual models that emphasized different aspects of IoT technology. These conceptual models shaped their attitudes, beliefs, and behaviors around IoT, which we refer to as the "user-centric" and the "agentic" technology perspectives. Individuals drew from these models to inform their opinions about IoT, as well as their adoption decisions. We were surprised to find few generational differences between Millennials and their parents that were not explained by their differing technology perspectives, as opposed to their differing ages. The insights from this study help us to not only understand how IoT is perceived by different groups of people, but why they hold their different beliefs. Specifically, we found that currently available consumer-oriented IoT are more amenable for individuals coming from an "agentic" technology perspective, but that they are problematic for those drawing on an "user-centric" point of view. We contribute to the existing understanding of IoT by discussing how the distinction between user-centric and agentic technology perspectives can inform the design and marketing of consumer-based IoT. Our research highlights the opportunity for consumer-oriented IoT products to embrace the entire IoT value spectrum, covering both "user-centric" and "agentic" approaches to IoT, thereby alleviating many of the concerns identified in this paper.

2 BACKGROUND

We study two types of consumer-based IoT: 1) **Wearable IoT devices** and 2) **In-home IoT devices**. We chose these two IoT domains due to their popularity among everyday consumers [24,27,38,40], and because they represent the two primary types of "person-centric" and "home-centric" IoT products that are commercially available for use [23]. Based on Atzori et al.'s [3] survey of the IoT literature, these consumer-based IoT devices would be broadly classified within the domains of healthcare and smart environments (i.e., home), respectively. Health-related IoT technologies are used for the purpose of tracking, identification and authentication, automatic data collection, and sensing [3]. Wearable IoT devices are often used for personal health and fitness tracking and, as the name suggests, are worn on the body [19]. Examples of wearable IoT include "smart watches," the Fitbit, and some fitness tracker apps that are installed on mobile smartphones [31]. In-home IoT devices are often used for remote control, automation, and surveillance of one's home [3,26]. Examples include "smart home" systems, such as Nest [34], which has extended its offerings from thermostats to include cameras, smoke detectors, and carbon monoxide alarms.

A number of researchers have delved into understanding users' perceptions, attitudes, and adoption of consumer-based IoT devices [8,9,12]. For instance, Brush et al. [8] interviewed smart home users to find that there are a number of barriers to use, such as cost of ownership and poor manageability, that need to be addressed before in-home IoT becomes more prevalent. Carrington et al. [9] highlighted the accessibility problems associated with wearable fitness trackers by interviewing athletes confined to wheelchairs, showing how designers made faulty assumptions about who their users were and their capability and need for tracking steps. In 2011, Jia et al.[22] interviewed nine tech-savvy individuals, who were quite familiar with IoT, about how they felt about these more agentic devices; they found their participants perceived themselves as still in control (i.e., personal agency) of the agentic IoT devices (i.e., proxy agency), as long as the devices met their needs. In 2017, Cila et al. [12] created a taxonomy to help designers re-conceptualize IoT product design by framing IoT devices as agents that collect, intervene, and create. As device autonomy increases, designers must consider how to artfully delegate control away from the user to these IoT devices in a way that does not break from social norms held by human agents. We noticed that these studies either focused on the empirical insights gained from *users* or they designed IoT systems for meeting *user* needs. In contrast to the existing HCI literature, we broadened our empirical lens to examine the perspectives of *non-users*, who are often overlooked in technology-focused research [6], but are key to understanding barriers to adoption [30]. We also compared the unique perceptions of Millennials with their parents with regards to the adoption, use, and non-use of consumer-based wearable and in-home IoT devices.

3 METHODS

3.1 Study Overview

This study was conducted during the summer of 2016 as part of a Research Experience for Undergraduates (REU) on the Internet of Things, which emphasized the cybersecurity and privacy aspects of IoT. Ten undergraduate students from engineering and computer science disciplines across the United States were trained as researchers and involved in the data collection process after being voluntary participants of this study. A faculty mentor (last author) interviewed the 10 REU students as participants for the study, but also as a means of training the students on how to conduct interviews. The REU students then completed Internal Review Board human subjects training prior to interviewing one of their parents as well as another student-parent pair where the student did not come from a Science Technology Engineering or Math (STEM) major. REU students were given the option to recruit a second student-parent pair if they chose not to participate in the study themselves. Data collection involved semi-structured interviews, followed by a web-based survey. See appendix A for full interview schedule and appendix B for survey questions that were used in this study.

3.2 Semi-Structured Interview Design

REU students were then given a semi-structured interview script and were asked to read the script verbatim to participants to ensure consistency between interviews. However, they were also encouraged to ask follow up questions to solicit deeper feedback from participants throughout the interview. The high-level structure of the interview script is summarized in Table 1**.** First, participants were asked to provide their own definition of the "Internet of Things" and examples of IoT devices to help us understand their familiarity with the topic. Next, the researchers gave a general definition of IoT reflective of the predominant sensors and data collection paradigm of commercially-available IoT (as shown in Table 1) [5,21,27,38]. Given that there is a lack of consensus around the definition of IoT and that many definition are overly technical [23], we chose to use a simple definition of "sensors that are connected to the Internet that can collect, store, and transmit information, as well as remotely control physical devices." Then, participants were asked specific questions about their use (or non-use) of wearable and in-home smart devices, as well as their perceptions regarding the potential (or real) benefits and drawbacks of these IoT consumer-based technologies.

Interviews were audio-recorded and later transcribed by a research assistant. Prior to audio-recording the interviews, participants were given a copy of the informed consent and verbally consented to participate in the study. After completing the interview, participants were asked to take the web-based survey. The survey included questions on demographics, as well as additional measures on adoption and usefulness. For this paper, we only included the survey data for reporting demographics (see appendix B).

Table1. Overview of Semi-Structured Interview Questions

Question Categories	High-Level Summary of Questions Asked
Background	Participants were asked to define the Internet of Things in their own words and to provide examples of what they considered as IoT devices.
IoT Definitions	To help orient participants who were unfamiliar with the concept of IoT, the interviewer provided a general definition of IoT reflective of the predominant sensors and data collection paradigm of commercially-available IoT [2,14,18,30]: "*IoT are sensors connected to the Internet that can collect, store, and transmit information, as well as remotely control physical devices.*" Then, the interviewer delineated two of the most popular categories of consumer-oriented IoT [16,18,30,32] for the study focus: 1) wearable smart devices "*used for body or location tracking*," and 2) environmental smart devices "*used to sense, provide remote access, or to automate aspects of one's physical environment.*" These definitions were used to help frame the remaining interview questions.
Wearable Smart Devices	Participants were asked about whether they used any wearable smart devices, the actual or perceived benefits and drawbacks of these devices, and more detailed questions regarding norms around the IoT technology usage.
In-Home Smart Devices	Participants were asked the same questions as above but in the context of environmental or in-home smart devices.
Concluding Remarks	Participants were asked their overall impression of the benefits versus drawbacks of consumer-based IoT smart devices and given the opportunity to ask questions about the study.

Table 2. Descriptive Statistics for Student-Parent Participant Pairs

Dyad	REU	Gender		Wearable IoT		In-Home IoT		Perspective	
ID	Y/N	Y	P	Y	P	Y	P	Y	P
1	Y	M	F	Smartphone (Runtracker)	-	-	-	User-centric	User-centric
2	N	M	M	-	Smartphone (Step counter)	-	-	User-centric	User-centric
3	Y	M	F	-	-	-	-	Hybrid	User-centric
4	N	F	M	Smartphone (Location)	-	-	-	Agentic	User-centric
5	Y	M	F	-	Smartphone (General)	-	-	Hybrid	Agentic
6	N	F	F	-	-	-	-	User-centric	Hybrid
7	Y	F	F	Fitbit	-	-	-	Hybrid	User-centric
8	N	F	F	Fitbit	Fitbit	-	Light Control	Hybrid	Agentic
9	Y	F	F	-	-	-	-	Agentic	User-centric
11	Y	M	F	-	-	-	-	User-centric	Hybrid
12	N	M	M	Fitbit	Fitbit	Smartphone (Weather)	Gas/Air Sensors	Hybrid	Hybrid
13	Y	F	M	Smartphone (Runtracker)	-	Nest Thermostat	Nest Thermostat and Security Camera	Agentic	Agentic
14	N	M	F	-	-	-	Nest Thermostat	Agentic	User centric
15	Y	F	F	-	Fitbit	-	-	Hybrid	User-centric
16	N	M	M	-	Smartphone (General)	-	Thermostat & Garage Door Alarm	Hybrid	User-centric
17	Y	F	F	-	-	-	-	Hybrid	User-centric
18	N	M	F	Nike Fitband	Fitbit	Chromecast	-	Hybrid	Agentic
19	Y	M	F	Smartphone (Location)	-	-	Security Camera	Hybrid	User-centric
20	N	M	F	-	-	-	Garage Door Opener	Hybrid	Agentic

3.3 Qualitative Analysis Approach

To avoid biasing our results, the REU students who participated in the study directly and as interviewers, were not involved in the data analysis process. Instead, three faculty mentors led two Ph.D. students in conducting an iterative thematic content analysis [7]. The Ph.D. students first copied the interview data into an Excel spreadsheet for initial coding. Data were structured as one row of data for each participant with multiple columns representing each interview question asked. Each participant was assigned a Dyad ID (linking students with their parents), and we noted whether the participant was one of the REU students, a non-STEM student, or a parent. The faculty mentors created an initial codebook for the Ph.D. students to code the interview data. The students split up the coding process based on the different questions asked in the interview and were asked to discuss any new codes that emerged with the faculty mentors and one another. After data coding was complete, the group of researchers met multiple times to form a consensus on the key themes that emerged from the analysis. These themes are presented in this paper.

3.4 Participant Profiles

A total of 19 student-parent dyads (38 participants) completed the interview portion of the study, which included 10 REU students, 9 non-STEM students, and 19 parents (of the respective students). Eleven students were male and eight were female. In contrast, 14 of the parents were female and five were male. All of the students were Millennials between the ages of 18-26-years-old. All parents were from Generation X (born between 1965-1980), except one Baby Boomer (born between 1946-1964) [29]. The majority of the participants classified themselves as Caucasian or white (7 students, 10 parents), followed by Hispanic (4 students, 2 parents), Asian (3 students, 3 parents), African-American (1 student, 2 parents), and Pacific-islander (1 student, 0 parents). Three students and 2 parents chose not to disclose their ethnicity. Household income of parents was distributed as follows: more than \$80K (8 parents), between \$25K and \$54K (2 parents), below \$25K (1 parent), and the rest did not disclose income. Descriptive statistics for each participant pair is shown in Table 2. In the presentation of our results, we accompany quotations with Dyad IDs and denote whether participants were parents ("P") or youth ("Y"). In Table 2, wearable and in-home IoT device adoption and use is reported based on participants' conceptualization of IoT, which is discussed in more detail within our results. Dyad ID 10 was not included in Table 2 as they did not complete the interview process.

4 RESULTS

4.1 What is IoT?

Prior to providing a definition of IoT, we asked participants to define IoT in their own words. Very few participants were able to provide a clear definition. However, while half of the parents admitted to complete ignorance, only a fraction of the students did not know what IoT was, including an REU student, who began by guessing, "cellphones, computers," but then laughingly confessed, "I don't really know." (7Y)

Almost half of the participants described IoT either too broadly or inaccurately by creating a tautology, combining some forms of the words "internet" and "things." For example, many participants described IoT as any internet-enabled technology or device: "Things that require internet." (6P) Other participants equated IoT to everything having to do with the internet, computers, and how technology has been integrated in our everyday lives: "How do I define internet of things? I would say, how you use the internet in our daily lives." (2P) One student explained IoT is how "you can shop on the internet; you could connect with other people on the internet like social media wise." (8Y)

Given this type of broad framing, these participants often gave examples of IoT devices that included everyday end-user technologies, such as desktop computers, laptops, tablets, email, end-user applications, and internet-connected or "smart" devices (e.g., phones, watches, and TVs).

Additionally, a few students gave examples of IoT that were not IoT, such as programmable devices that are not internet-connected: "Anything that can be programmed to do something on its own so even like setting a machine to turn on sprinklers to start itself in the morning.” (6Y) Another REU student defined IoT too broadly as “very cutting edge technology,” correctly including Google Glass and wearable devices, but then also including “virtual reality and augmented reality devices,” explaining that it’s more about interacting with the internet rather than being an observer of it. (9Y)

Participants who were not previously familiar with the term IoT tended to equate IoT to end-user technologies for engaging online. They seldom understood that IoT included devices (e.g., sensors or appliances) that could passively connect to the internet and transmit data without user intervention. Even the ones who did were not always sure how this data was being used:

> “I would define it as the interconnected space of things that we wouldn’t normally associate with computer technology. The fridges they have with the embedded computers that tell you what to get at the grocery store, those NEST thermometers that apparently track your... I’m not sure exactly what they track but they track something.” (2Y)

Only a quarter of the participants provided a relatively complete and accurate definition of IoT. This included one parent (of an REU student) and one non-STEM student who (hesitantly) provided a solid definition with examples of IoT: “The IoT or the Internet of Things...devices that connect with each other over the internet. I think smart phones, blood pressure monitoring, heart rate sensors.” (11P)

As somewhat expected, two-thirds of the REU students (who were participating in the summer research experience on IoT) provided accurate and complete definitions of IoT. These definitions included both internet-enabled end-user technologies (e.g., smart phones, watches, wearable devices, GPS systems), and more specifically, sensor-based networks and internet-connected appliances (e.g., traffic sensors, supermarket sensors, surveillance cameras, coffee pots, thermostats). These students were also more likely to articulate purposes for these internet-enabled devices, such as allowing for remote control or access, location tracking, health monitoring, as well as information collection, storage, and retrieval. 1Y explains:

> “I mean it’s generally just sort of like a sensor network. For example, if you just have a very literal definition of things, like your coffee maker is connected to the internet, and you can manipulate it to make a cup of coffee off you phone, so you’re just interconnecting things that aren’t typically intuitively connected.” (1Y)

In Table 2, we included any wearable or in-home IoT devices participants self-reported actually using in the past during their interviews. Given that many participants framed IoT quite broadly, this often included the use of smartphones (in general) or for specific purposes (e.g., location tracking, step counting, checking the weather). Even with this broad definition of IoT, adoption rates among participants were fairly low with 42% of students and 37% parents using wearable devices. In contrast, 16% of students and 37% of parents reported using in-home IoT smart devices, with one student who reported using her parents’ Nest Thermostat. We did not consider the self-reported general use of laptops, computers, or the internet as forms of IoT usage when coding the interviews and summarizing participants’ responses in Table 2.

Overall, our findings illustrate that the term “Internet of Things” may not be as pervasive to those outside of the technology field as technologists may assume. Ironically, we discovered that a large number of participants were already using IoT without classifying it as such. 1Y admitted, “I’ve had it for probably two years before I even knew what IoT was.”

In order to better understand the factors influencing people’s adoption attitudes towards currently available IoT, we next provided our participants with a general definition of IoT (see Table 1) that reflects the predominant paradigm of commercially-available devices, a sensors and tracking view of consumer IoT [5,21,27,38]. This allowed us to gently redirect some participants who gave too broad (e.g., “going online”) or inaccurate (e.g., virtual reality) definitions of IoT prior to probing them on their attitudes and conceptualizations of IoT in order to understand how these influence their adoption decisions for existing commercially available IoT (**RQ1**).

4.2 Two Emergent Conceptual Models of Consumer-based IoT

Our study uncovered two distinct conceptual models of consumer-based IoT that emerged from our interviews and shaped our participants' perceptions and behaviors around the use and non-use of both wearable and in-home IoT. We label these models as the "user-centric" technology and the "agentic" technology perspectives and discuss each in more depth in the sections that follow.

Even with the same baseline definition of IoT, these two perspectives guided participants towards different preferences for interacting with IoT devices, and ultimately, how they used these technologies. The *user-centric* technology perspective emphasized the self and the idea that the user should be the one to initiate actions and control what happens when using IoT. For example, using remote control to turn off their lights at home. Participants who drew from this perspective often focused on the more tangible aspects of IoT, such as breakability and real-world consequences when the IoT device malfunctioned.

In contrast, participants who drew from the *agentic* technology perspective treated IoT devices as the facilitator of actions, at times coordinating between users, devices, and the environment. For example, participants used wearable devices to track where and how far they ran, as well as to build a community to help them achieve their health and fitness goals. Their focus was more on the intangible and communication-oriented concerns and benefits of IoT, such as feeling watched or being able to connect with others.

These conceptual models also shaped participants' perceptions of whether IoT would afford convenience and make their life easier, versus just add additional complexity to their daily routines. This, in turn, led participants to evaluate IoT devices in different ways, emphasizing different value propositions. Importantly, we found that most participants drew from both conceptual models, not a single viewpoint, and given the particular model they were drawing from, this influenced their perceptions about the benefits and drawbacks of a given IoT technology. Table 2 details whether participants drew predominantly from one perspective (at least three-quarters of their responses aligned with a single perspective) or not (designated as "hybrid" perspectives).

4.3 User Centric Technology Conceptual Model

The *user-centric* conceptual model draws on a frame of mind where the end-user plays a key role in the functioning of the technology. It also approaches IoT devices as tangible consumer products. Interestingly, none of the Millennials relied exclusively on a user-centric point of view, although the vast majority drew from this view at least a few times, albeit to a lesser extent than their parents, during their interview. In contrast, half of the parents solely drew from this perspective, even though many parents drew from both conceptual models. The fact that most participants drew to some degree from a user-centric technology perspective, is likely due to the material nature of IoT, and the commonly held perception of IoT devices being susceptible to physical constraints. In the following section, we describe the themes that emerged from the user-centric technology perspective and how this perspective guided participants' perceptions of IoT.

4.2.1 The User has Control (User Driven). Individuals who drew from a conceptual model of user-centric technology focused on IoT as an end-user driven technology. In other words, they perceived that end-users initiate actions and use the internet as a way to connect to IoT devices and use them, or vice versa, that IoT devices are a tool that allows users to access the internet. The idea of IoT as facilitating remote control aligned well with this view. Participants who drew from a user-centric perspective often talked about the benefit of being able to turn something on or off from another location: "You know the proverbial: did you leave the iron on and burn the house down? Then those would be things that would be definitely beneficial." (4P)

Although IoT devices can take a more proactive role in sensing and automating behaviors, those taking the user-centric perspective envisioned a much more user-initiated interaction. Even after the interviewer provided a definition of IoT that included sensors that could track, sense, and automate aspects of one's life, few of the participants who primarily used the user-centric model picked up on this definition. For instance, 20P described the value he saw in using IoT as the following: "In terms of energy savings and stuff like that, energy conservation: If you are not at home and you could somehow remotely decrease the heat and even, you know, kind of on-the-fly, at the moment." He still envisioned the user having a central, instigating role in regulating the temperature. Similarly, many other user-centric participants often focused on what “I” or “you” could do with IoT devices, not what IoT devices can do for “me.”

This idea of active user-involvement is further reinforced by several interviewees emphasizing the user’s central role in making sure the IoT functions smoothly. Some voiced concern about people spending too much time and getting sucked into their phones to manage these interactions, which could even pose a safety hazard. 4P compared this to how people are on their “phone looking up things on the internet when they should be driving.” (4P)

These individuals used an “end-user-centric” way to conceptualize this new technology, which may not be completely accurate. Even when discussing sensor-based and automated IoT, which are inherently device-driven, interviewees would anticipate user-centric problems:

> “If it’s sensing a pattern but then you’re not really following that pattern, then it’s [not] really going to be meeting your needs. And it might be, for example, making it cool when you’re not even home when you need it to be [cool] and wasting energy. So yeah, that’s the biggest thing if you have an irregular, unpredictable pattern.” (8P)

Although this parent understood that the IoT thermostat senses patterns to be able to automate cooling in the home, she fell back on the user-centric model when thinking about how she would use it. 8P believed that the automatic sensing feature is an initial setup process, rather than an ongoing, dynamic process the device manages. Thus, she perceived that it is up to the user to continue following that pattern to gain the benefits of using that IoT device. Changes in user behavior would negatively impact the technology’s ability to regulate temperature efficiently. The idea that the thermostat could detect and adjust to a new pattern did not cross her mind. Individuals drawing on such a user-centric model found it difficult to conceptualize use cases where devices, such as sensors, can connect to and interact with other devices through the internet without end-user intervention.

Compared to parents, most of the students drew from either the agentic or a mixed model of IoT when discussing benefits:

> “It would be very beneficial on a (uh) large institutional scale where people will have (um) like a situation where you have a bunch of different buildings and there’s basically just a guy that is entirely responsible for managing how energy is used in those buildings. You know like turning on and off lights remotely and heat and all that stuff. Would the (um) fridge fall into that category as well? Where it’ll like it keeps track of how old the milk is and when you’re running low on sauce.” (2Y)

2Y draws from both perspectives; he describes how IoT could be controlled by the user or do useful tasks on its own.

4.2.2 A Focus on the Physical. The user-centric technology model was also characterized by thinking about the physical and tangible aspects of the IoT device. Participants’ attitudes about the benefits and drawbacks of IoT reflected similar attitudes one might have towards other tangible consumer products. Interviewees thought of devices and sometimes even the information stored as tangible and physical. They used terms like “battery operated” to describe the devices, or “microfiche” to describe their expectation that information is stored permanently and accessible later. One interviewee even pushed back on being able to delete information collected by the devices: “To destroy it? Is that what you’re saying? To like delete it? It only saves the data for so long and then it gets rid of it? We know that that’s not possible, it’s always saved somewhere.” (4P)

Commonly, among user-centric thinkers, one of the concerns was that the IoT device might break, get damaged, or get lost or stolen. A number of interviewees expressed concerns about damaging wearable devices, “Is it waterproof?” (2P) Those who had the devices talked about practical matters, such as “the wristband doesn’t match my outfit and sometimes it’s a little, if it’s really hot out sometimes, based on whatever material it is made of, it’s kind of sticky and sweaty.” (8P)

Another concern was about needing an internet connection for the device to function. Individuals describe situations of being in a remote or low signal location, or an “interruption in a power. Like a black out.” (3P) “Not having service or data on your phone" (14Y) might leave the device unable to access needed information to function.

One user-centric concern was that the device might malfunction and have tangible consequences. Sometimes the problem was giving incorrect information that would make the user do something unintended or undesirable, such as "when it gives you an incorrect location and instead of helping you it is getting you lost." Other times it was an issue with the device itself, "if it has errors in the programming" (12Y) and could result in mishaps that ranged from minor to major. For example, if "you could open and close blinds on your windows, and if it malfunctions and opens while you are dressing" (1P), this could result in embarrassment. However, 1P contrasts this with more major problems that could arise "if that is related to things electrical, or you could have some flooding problems or, if you're not there, I wouldn't want to, I'm thinking of the washer or dryer, I wouldn't want to operate that when I'm not here."

Many interviewees also recognized the potential for someone to maliciously gain access to IoT devices by hacking in or taking advantage of the end-user's negligence (e.g., "forgot to lock your door"). Although participants were not always sure how the hacking would happen, it seemed likely to them, and they were concerned about how this could negatively affect their environment and physical safety: "I hear everybody getting hacked so how about if they hack your email or whatever it is. I think they would be able to control your, whatever it is, devices… I think, you know, especially turning on a stove or a microwave." (17P)

Interviewees would often emphasize how this is a new possibility that would not be a problem in a less connected and less automated world. For instance, 16Y viewed physical locks as more secure than virtual ones: "Well, the garage opening, if the doors are able to [be controlled] wirelessly, if somebody can hack into that, they would have a lot of access to things they would not normally have. Any sort of physical locks would be able to [control] it." (16Y)

The potential for something to go wrong with remote or automated control over physical objects, was a prevalent concern for most participants (regardless of age). Many interviewees who otherwise did not take on a user-centric technology attitude, did recognize and focus on physical consequences resulting from errors or vulnerabilities that would prevent IoT devices from working correctly. 6Y summed up how there are "more problems with the automation one than any of the other ones cause I guess that's when information can be stored incorrectly or it could act on its own in a wrong way." The idea that IoT devices could cause real-world problems was a significant concern for many who had a user-centric view of IoT.

4.4 The "Agentic" Technology Conceptual Model

The Participants who approached IoT with an *agentic* technology model saw IoT devices as a facilitator that acts on its own, as well as coordinates between the user, other people, other devices, and the environment. Only a few interviewees took a purely agentic technology perspective and, interestingly, this perspective did not appear to be connected with whether or not the participant had an accurate understanding of IoT. Many participants drew on this agentic technology conceptual model to some extent, with Millennials generally doing more so than parents. We describe the key dimensions that emerged from this technology perspective.

4.3.1 The Device as Facilitator. In contrast to the user-centric technology models, the agentic technology perspective de-emphasizes the role of a single end-user and acknowledges the distributed nature of the actors and origins of control. 13P recognized that there could be "multiple people having (uh) access" to a surveillance system and the implications of that distributed access. He goes on to describe the device-driven climate control of an IoT thermostat, and the negotiation process that should happen between the user and the device: "Let's say all of a sudden the system goes to 60 degrees instead. I just know something's wrong with it and…then it should manually ask, 'do you really want to go to the certain temperature?' or something like that." (13P) Here, the device has control but also the responsibility to confirm whether the user really wants to make a change.

Another common agentic technology sentiment was that IoT devices can ensure everything is working, much better than end-users. As 14Y explained:

> "I would definitely use those devices for my garage door, because there are moments when I forget and have to drive ten miles back to see if I closed my garage. I think systems where they automatically,

> they are able to get a feel of their environment and set it to what it thinks, is right. Cause I honestly, I think they make the best choices.” (14Y)

This interviewee felt that the IoT device can get more contextual information, and be less forgetful, so trusts its judgement to make a better choice than he would be able to. In fact, several other people expressed similar optimistic views on how “I don’t believe they could be problematic, I believe they were made to make our lives easier.” (5P) Rather, it was the user who is likely to be the weak link if there are problems. 4Y felt the responsibility rested on the user to guard against messing up: “You should just take the time to learn how to use it.” And, it is also up to the user to behave appropriately to avoid embarrassment: “I just feel that, you know, it’s all basic truth coming out onto a device. So basically it’s whether or not you trust yourself and whether or not, you know, you believe what you’re saying.” (4Y)

This perspective shaped these participants’ attitudes about how the IoT devices should function. In particular, they trusted the devices to collect any sort of information they needed: “I think they should be able to collect everything.” (9Y) Agentic technology perspectives also led participants to assume that information collected by the device, as well as any actions taken, would be appropriate: “Even if device is always on, it still helps us.” (5P) Agentic technology mentalities led to participants having faith that, overall, IoT devices facilitate a positive outcome.

This understanding of IoT also made some individuals think beyond the end-user when evaluating benefits and drawbacks of IoT. For instance, having social connection with others through the device was something that IoT could facilitate: “I think whoever you’re sharing your day-to-day lifestyle with should be able to have access to all of that.” (14Y) The social component of interconnectivity allowed them to build comradery in their personal life and in the workplace. 18P described her experience using the Fitbit as “everybody at the hospital... just by pushing a button every day... they could see it about me and everything that we were doing.” She appreciated how IoT makes getting healthier a group event.

4.3.2 Focus on the Intangible. In contrast to the user-centric technology model, those using an agentic technology perspective focused more on intangible benefits and consequences of using IoT. For instance, privacy was a commonly voiced concern from agentic technology viewpoints. There are times “when you don’t want anyone to know where you are and just want to be alone.” (4Y) Some also acknowledged the privacy issues beyond the individual to groups and communities: “Maybe your neighbor’s not liking that they were being [watched], you know, our houses are very close together and people feeling like they were being videoed of their daily comings and goings and, you know, their privacy is being violated.” (8P) Here, it is not the end-users’ privacy concern, but concern for those of neighbors who are affected by an individuals’ decision to adopt IoT devices. A few participants also brought up stalking and obsession being a potential problem.

Individuals drawing from the agentic technology perspective also saw the information used and sensed by IoT as dynamic and moving. Rather than just focusing on static pieces of information, such as address and social security number (like those from user-centric views), they understood that IoT can detect and analyze trends, going beyond just the raw information it collects. They perceived personal benefits, such as “lifelogging” (11Y) by keeping track of where they’ve been over the years, or societal benefits in “keeping track of general trends.” (13Y) As opposed to information being something that sticks around forever, several agentic technology interviewees described the information sensed by IoT devices as more fleeting. When asked about how she thought information was stored on in-home IoT, 19P replied, “You know, it might not even be keeping it, just using the information as a way to trigger some type of action or non-action.” Others even expressed the hope that information could be kept for longer than they thought it was being retained:

> “Like say you had an app or device that you wanted to keep, even though you are living in another house or something. So you turn the device off, obviously, and turn on after you get to your house. I do not think after they turn it off they should, like, must scrap all that information...They should just rest the data.” (3Y)

This focus beyond what is tangible, and on the fluidity of information and interaction, characterized the agentic technology perspective. Next, we turn to IoT adoption and how the user-centric and agentic technology perspectives shaped attitudes, beliefs, and adoption choices for our participants.

4.5 The Adoption and Non Adoption of Consumer-based IoT

We found three primary drivers of IoT adoption; participants' differing conceptual models were a determining factor in which adoption triggers were relevant. Overall, interviewees who had adopted IoT often either had a very compelling reason (e.g., health, safety) or obtained IoT at a low (or even free) price point. Non-adopters saw current commercially available IoT as just making life more convenient, rather than solving a real problem. This combined with a high price was often not enough reason to adopt, especially for user-centric thinkers, who were more pessimistic these devices would work as intended.

4.5.1 Convenience. Participants across the board felt that IoT is supposed to make their lives easier and bring convenience to everyday tasks. Several interviewees literally defined IoT as "devices that make our lives easier." (6Y) Whether the individual actually thought IoT devices did or not, the belief was pervasive that they are intended to do so. We noticed that those drawing from an agentic technology model tended to feel that IoT devices indeed made life easier. 16Y expressed that having a device take over is easier than doing something himself: "It would be just easier to automate instead of doing it." IoT also allows flexibility without having to plan: "It's easier to run places and then see how far you ran, than planning a route and run it." (1Y) Overall, agentic technology perceptions framed IoT as helpful for saving time on menial tasks: "I believe it is beneficial as well… for convenience. Umm just make sure it is easier to keep track and not waste time doing these things so you can have time for something else. If you can feed your animal from your phone." (18Y) As a result, these agentic technology individuals often were users who adopted IoT to help make things easier in their lives. However, many also pointed to the high price tag as a temporary barrier (which we will discuss later).

On the other end of the spectrum, those drawing from a user-centric technology model often viewed IoT as introducing complexity (not ease) to their lives. They viewed IoT devices as another thing that they would have to manage and oversee: "When you have more things, that are making it easier for you, I have more things that can break. So I'm not too automated. I still believe in physical contact with things." (4P) This feeling of complexity often came from user-centric participants focusing on the tangible, breakable aspects of IoT objects that are susceptible to malfunctioning. Rather than giving people peace of mind, those drawing on this model felt more anxious that something could go wrong:

> "Let's say you want to turn something on in your house and it's something that may be about cooking or generating heat or something. And so you turn it on and, thinking, okay, in three hours, I'll be able to turn it off, and the system breaks down in some way and you can't turn it out." (19P)

Instead, it was much easier to "just walk over" and turn on a light or push a button. Even just the mental shift of adding an IoT device into one's routine seemed more work than help for those with user-centric perspectives, who were "used to doing things a certain way." (8P) Furthermore, turning over control to the device was not desirable for individuals coming from this perspective. They perceived that the best one to know the right course of action is the end user. 14P explained about the Nest thermostat installed in their home, "If you want to not be smart like if I have a door open and I still want my air-conditioning going, it doesn't work. Sometimes that is just inconvenient." (14P)

This presents a "convenience trade-off" for consumer-based IoT that may conflict with the *user-centric* technology perspective: To make life convenient, IoT devices automate and take over decisions and tasks that users would normally do themselves. However, those coming from a *user-centric* technology perspective believed it is important for the user to be in control. Thus, the conflict arises from the fact that IoT users have to give up control in order to gain convenience. For instance, 2Y described what he believes could be a beneficial IoT device and understands how it works, but takes issue about having a device telling people what to do: "The fridge [that] keeps track of how old the milk is and when you're running low on sauce… Like if it could sync to something on my phone. The drawbacks with those is that people just kind of don't like being instructed by machines at a certain level." (2Y) In saying this, he reveals, as a non-user, a very user-centric way of thinking that keeps him from adopting this type of IoT.

4.5.2 Solving Big Problems. Users saw many more compelling IoT benefits beyond convenience. However, participants who drew from the agentic technology perspective are more likely to see the true value of these benefits. For instance, health and safety were common reasons why these participants were adopters of IoT. Parents were more likely to adopt stand-alone health monitoring IoT devices, like the Fitbit, while most students who used wearable IoT devices did so from apps on their mobile smartphone. 12P found the Fitbit helpful in making sure he does not live a sedentary life: "[I use] the Fitbit to keep track of my heart rate. It really encourages me to keep moving." (12P)

Parents were also more likely to use smart home technologies than their children, likely because they own property that they feel they need to keep secure. For instance, 13P used in-home video surveillance:

> "Well, I do use video surveillance...I cannot be in two places so...it gives you a piece of mind like you know what is going on at your locations. If any of your places gets a false alarm, or something like that, and you get a call from a security company then you want to just make sure everything is okay over there. Those devices come very handy at that point." (13P)

A number of other parents used other forms of in-home IoT, such as being able to turn on and off lights, so that people do not know when they are not home for an extended period of time. Even those who had not adopted IoT recognized that these would be reasons to do so in the future: "[I am] satisfied with my weight, but if I ever had the need I'd get a Fitbit." (19P) Several pointed out that people with disabilities could also find IoT useful.

However, even though solving these real problems could get some people to adopt, *user-centric* thinkers had reservations about IoT causing even bigger problems, where accuracy and reliability of the device can mean life or death. 6Y described how wearable devices can give people a false sense of their health: "If you rely on them, like instead of going to a physician, like if you know you have a heart condition, but you're relying on a certain wearable device or an app to keep track of your heart rate, then it could be inaccurate and that could be dangerous." (6Y) This user-centric view of the tangible and real-world problems IoT may introduce influenced their non-adoption decisions. It consequently created another trade-off between usefulness and trust, where many interviewees saw the *potential* of IoT to solve big problems; yet, their hesitancy to fully trust these devices made them feel like IoT is unsuitable for handling such important tasks. Others simply just did not see the benefit of IoT; 1Y described in detail: "It's hard to come up with these [benefits] cause they're not really like huge problems. They're just like, my life is pretty easy, I'm gonna make it even easier." (1Y) Here, 1Y drew from the agentic technology perspective by understanding how IoT can act on his behalf, but he was not convinced that he really needed the help.

15Y reinforced how IoT devices are often not necessary "in my life when everything that I am doing currently is perfectly fine. I don't need it to like control this or automate this for me. Everything is like okay. I don't feel like it's a necessity." (15Y) In this case, we saw a fairly clear trend where students, as opposed to their parents, were less likely to see the need to manage everyday tasks.

4.4.3 Cost as Barrier to Entry: IoT devices were seen as a luxury item by many interviewees, who were both adopters and non-adopters. A continuation of 1Y's agentic technology perspective of not needing to automate his daily life:

> "In the home realm, it's just a luxury item. You know, I really believe that while it may be convenient, it's never going to be something I prioritize. The Nest is sort of cool, you're going to save money on your energy bill. That would probably be like the first thing I would get just because it's practical." (1Y)

Others only adopted when the IoT was free or low cost. Two-thirds of the wearable IoT adopters actually used apps on their smartphone, many explaining that these apps came pre-installed. Interestingly, participants' desire to not have to pay for using IoT devices also influenced their attitudes around privacy. 1Y concluded that, "many people would rather [the company] go take advantage of the data that is collected, then pay for the app, which is usually the trade-off." Overall, the potential privacy risks and data breaches, although noted by many, were also generally accepted as part of using IoT devices. Both participants from user-centric and agentic technology perspectives felt that consumers just “have to accept information [is] being used to sell to third parties etc. in the license, because [you] need to use it.” (2P) Even with potentially sensitive information, such as location, “even if it’s inappropriate for them to have the info, [I] still have to go with it.” (5Y) Thus, privacy concerns did not seem to be a primary deterrent to IoT adoption for most.

5 DISCUSSION

Our initial goal of this research was to study generational differences in IoT attitudes and adoption (**RQ3**). While we do find some generational differences in our study, these differences were superseded by differences in users’ conceptualization of IoT (**RQ1**) which, in turn, influenced users’ and non-users’ perceptions and adoption of IoT (**RQ2**). We found that attitudes and adoption patterns mostly did not align with generational differences; instead, they were better explained by participants’ conceptual models. Participants with a *user-centric* perspective invariably saw commercially-available IoT as unnecessary and even suboptimal for doing something they already do with relative ease. Given this lack of perceived benefits, the cost of investment and setting up the device was simply too high. In contrast, participants with an agentic technology perspective, treated IoT as a ubiquitous, pervasive technology; they focused on the personalized and automated aspects of IoT, considered being able to give up control as one of its desirable features, and they wanted these devices to collect more data to do even more useful, personalized things. For some, the benefits of automation justified the cost.

Drawing from Fallman’s [16] reflection on the philosophy of technology, we provide a possible explanation for the disconnect between the user-centric and agentic conceptual models based on Borgmann’s “device paradigm.” Borgmann uses a metaphor of a fireplace (i.e., a “focal thing”) to illustrate that objects can serve a more powerful role than their primary function. While a thermostat (i.e., a “device”) can replace the function of providing heat and regulating temperature, it cannot fill the social role that arises for the fireplace of being a gathering place for family members in the home or alternative uses, such as a heat source for cooking food.

Similarly, the user-centric view might consider IoT as “devices” that are limited in purpose, performing a discreet and decontextualized tasks. They replace the original non-IoT “focal thing,” which was embedded in a larger context that supported a wider variety of tasks and purposes. For example, a light switch (focal thing) being replaced by an IoT-controlled switch (device) serves the purpose of activating the light without physically having to be in the room. However, physically going to turn on/off the light switch would have additionally served the purpose of deciding whether to flip the switch upon seeing whether, e.g., anyone is still in that room, or the sun is already shining in and providing light. It would also provide an opportunity for a safety check of locked windows or noticing an envelope on the table that needs to be mailed. Thus, using the IoT device may end up performing a decontextualized task, but miss the bigger picture.

On the other hand, those drawing on the agentic perspective might assign roles in the opposite direction and feel that the IoT technology can better understand and contextualize to make better decisions than the original object it is replacing. They may feel they are more likely to forget to turn off the lights or fail to notice that it is getting dark and that the light should be turned on. Therefore, it is important to understand the differing values in which users (and non-users) attribute to focal objects prior to assuming that they should or can be replaced by IoT devices. As such, in the next section, we elaborate on the specific values that emerged from our interviews and discuss these values in relationship to the user-centric and agentic views of consumer-based IoT.

5.1 Addressing the Trade-offs between User-Centric and Agentic Values in IoT Adoption and Use

Value-sensitive design [17] is a paradigm that takes into account the human values that are embedded in the design of systems and acknowledges that tension may arise when different stakeholders share different sets of values, especially when these values do not converge or are in conflict. For instance, in our analyses, we uncovered three different conflicts in commercially available IoT that appear to favor the *agentic* view of IoT over the *user-centric* viewpoint of IoT.

First, there is a trade-off between *control* versus *ease of use* and *usefulness* of consumer-based IoT technologies: Only when users gave up control did they realize the benefits of IoT use. However, relinquishing control was easier for agentic-oriented participants than for user-centric participants. This helps explain why user-centric thinkers needed a stronger value proposition and lower barriers of cost in order to adopt and use these technologies. In Venkatesh's [32] extended version of the widely used Technology Acceptance Model [14], control, ease of use, and perceived usefulness are all positively associated with users' attitudes toward and intent to adopt a new system. In the case of consumer-based wearable and in-home IoT adoption, control appeared to be inversely related to ease of use and perceived usefulness, presenting attitudinal barriers to adoption for those who predominantly drew from the user-centric view of IoT. This finding suggests that existing models that explain technology adoption may need to be revisited and revised to address more agentic-leaning technologies, such as IoT. Further, from a value-based standpoint, considerations for designing consumer-based IoT products that give users more control, yet still afford meaningful benefits, is needed. For example, some Nest thermostat users may highly value the ability to remotely control their thermostat while away, but find the feature that learns one's patterns and automates temperature regulation as invasive and not useful. Therefore, both IoT affordances and behavioral models to predict adoption and usage patterns need to account for the differing value systems of user-centric versus agentic IoT end users.

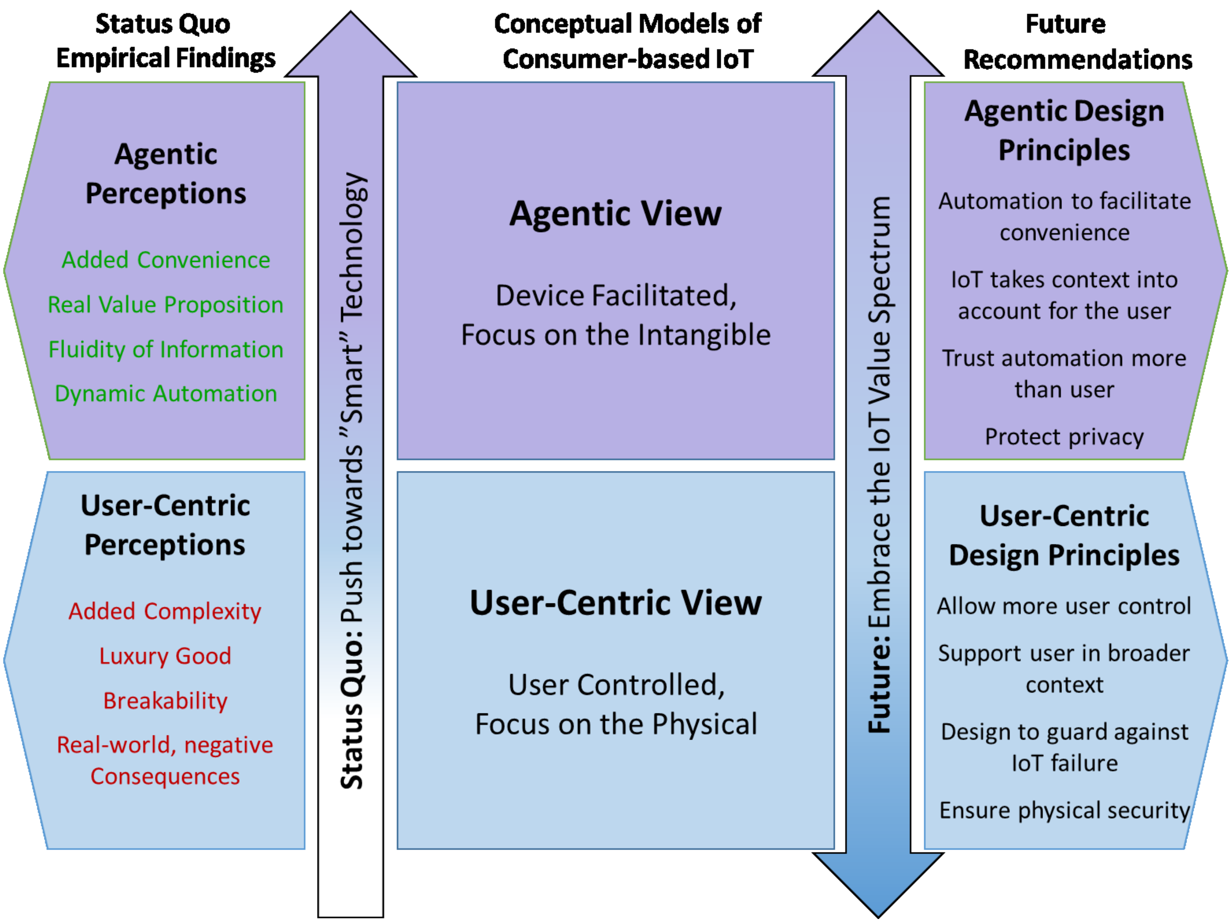

Fig. 1. Perceptions of existing consumer-oriented IoT (left side) and recommended approach (right side).

Even though convenience was a shared value among most of our participants, we found that there was another significant trade-off they had to make between *trust* and *usefulness*. Our participants believed that IoT should make their lives easier, but many of those who were early adopters or non-adopters found (or felt) that it did not. Either due to the IoT technology not working correctly or the IoT device providing a service that many participants thought was a superfluous luxury (e.g., turning on a light switch or coffee maker), many non-adopters simply did not trust IoT devices to deliver strong benefits that counteracted real consequences (e.g., privacy violations or physical safety concerns) that might occur when using IoT wearable or in-home consumer products. In order for user-centric thinkers to adopt IoT, they need to have a strong value proposition; yet, they find it hard to trust IoT devices with consequential needs, such as securing their home or managing their health. Thus, the tasks they feel would be most beneficial to them are the same ones they do not want to relinquish control. This speaks to the opportunity for creating better use cases around IoT devices, such as Cila et al.'s "products as agents" [12], where they proposed three different ways that smart products could display agency as Collectors, Actors, and Creators. Yet, doing so would only exacerbate the control tension identified earlier, and, if these agentic IoT devices do not perfectly (without error) meet the needs of users, this agentic framing could create a potential backlash calling for more end-user control for IoT devices. As such, we agree and validate Jia et al.'s earlier work that calls for a balance between human and object agency in the context of IoT [22]. These researchers predicted that user-agentic and technology-agentic factors would play into IoT attitudes and pointed towards personalization as a way to give users more control over IoT. Our findings build upon Jia et al.'s earlier work to show individuals' conceptual models around IoT have as much, if not more, influence on their attitudes about IoT as the affordances of the IoT devices themselves. Resolving the tensions between user-centric and agentic viewpoints may not be possible in many cases. However, we offer some suggestions in Table 3 for ways to alleviate these tensions by balancing trade-offs in a way that might resolve the conflicts between control, ease of use, trust, and usefulness.

To summarize our discussion, current commercially-available consumer-oriented IoT favor agentic-leaning perspectives and are cause for concern from the user-centric perspective. Future IoT research and development should use design principles that consider both agentic and user-centric perspectives. Consumer-based IoT needs to embrace the spectrum between full end-user control and complete automation in order to cater to the differing needs of a variety of IoT perspectives. Supporting both ends of the spectrum, as well as providing solutions that lie in between those extremes, will allow IoT to balance the right amount of user control with automation to match each user's preferred interaction paradigm. We summarize the different perceptions of current commercially-available IoT, as well as future design suggestions for supporting the different perspectives, in Figure 1.

5.2 Limitations and Opportunities for Future Research and Design

We found that current consumer-oriented IoT predominantly cater towards an agentic perspective, but argue that there is an opportunity to introduce IoT technologies that can meet the needs of non-adopters and IoT users with a user-centric leaning perspective as well. A potential limitation of our study was that we provided participants with a general definition of IoT that focused on sensors that perform various functions (e.g., collect, store, and transmit information), which may have predisposed some to take a more agentic view of IoT. Yet, interestingly, only four students and five parents predominantly drew from an agentic perspective of IoT. In contrast, four students and eleven parents predominantly drew from a user-centric perspective, suggesting that the conceptual differences may be somewhat attributable to generational differences, not the definition of IoT given during the study. However, there was enough variation in the interviews where participants (regardless of age) drew from both conceptual models (11 students and 3 parents) or from opposing models (e.g., students from user-centric and parents from agentic) to show that these conceptual models subsumed generational differences and better explained people's attitudes, adoption (or non-adoption), and use (or non-use) of consumer-based IoT products. We also saw a number of instances of intergenerational influence on IoT adoption. For instance, 19P (user-centric perspective) explained that she had a security camera at home because her son (hybrid perspective) set it up for her. Therefore, even though we found that agentic perspectives tended to lead to more positive attitudes about consumer-based IoT products, a key take-away from our findings is the importance of not discounting the user-centric view many participants had towards IoT.

In the more recent IoT literature, the "internet-oriented" and "agentic" vision of IoT is much more prevalent [12,23], but we found that a "things-oriented" vision may be a better match with those who prefer a user-centric model of IoT. Various technologies have been developed that fall under this thing-oriented paradigm such as business-oriented IoT (e.g., supply-chain management where, say, an RFID on each box allows the business to track its inventory). However, the use cases naturally supported by a thing-oriented paradigm may not sufficiently cover the use scenarios to be supported in consumer-oriented IoT such as wearables and in-home devices. Researchers and developers should focus on a solution that involves some hybrid or combination of these visions and supporting technologies. An additional challenge will be to satisfy individuals on both sides of the agentic and user-centric perspectives – deciding between one-size-fits-all, user personalization, and multiple product lines will be important to accommodate different conceptual models.

Table 3. IoT Design Recommendations

Perceptions	Design Recommendations
Perceived Control	Control should be negotiated between the user and the device, and periodically reconfirmed, so that the device becomes a "proxy" [9] for the user. Agentic-oriented users may be willing to relinquish control to the IoT device, while User-centric individuals may prefer recommendations that they can choose to accept or not.
Ease of Use/ Convenience	The set-up costs of IoT need to be low and devices need to truly "make life easier." Agentic-leaning users felt that not having to monitor and perform the task themselves simplifies their lives, but user-centric individuals felt that the work to ensure the device is functioning the way it should, and the extra steps to manage and guard against undesirable device behavior, is more trouble than a help.
Usefulness	Use cases need to extend beyond the simple things that IoT can readily do and account for the broader context of functions that were performed by the object it is replacing. The agentic perspective is that IoT took into account many contextual factors to make the right decision, while the user-centric view is that many additional use cases and contextual understanding are not being supported by the IoT device.
Trust	The technology must be reliable. Those coming from an agentic perspective trust the device to make better decisions than themselves. Many of them did voice privacy concerns about their data being available and used, but seemed resigned that it was a necessary evil for using IoT. Addressing these concerns could further strengthen trust in the device. On the other hand, those who were user-centric demanded that the technology must work seamlessly (nearly perfectly), otherwise it becomes a burden to constantly worry about the device. They also are particularly concerned about physical security risks such as the device being used by the wrong person or a malfunction leading to property damage or threatening one's safety. Developers should not only strive to eliminate points of failure (i.e., errors), they should also introduce safeguards in case of device failure so that users can believe that the benefits of use outweigh potential real-world consequences.

Instead of the status quo, which pushes towards agentic IoT, we propose embracing the full spectrum of IoT possibilities, ranging from user-centric to agentic (Figure 1 Design Principles). Since this study was conducted, we have seen some IoT developers move into the direction of embracing a wider spectrum of IoT perspectives. Intel, for instance, has a vision of giving users more direct control over the data tracked by public IoT devices [11]—although substantial research is needed to reduce the complexity of such control [4]. Likewise, while Amazon's Alexa-powered "Echo" platform takes a predominantly agentic approach, its "Dash" buttons bring tangible, user-centric control to the home shopping scenario. Google and Apple do not offer similar "buttons," but their Home and HomePod systems are deeply integrated with their smartphone platform, allowing users to control these devices either by voice or through their phones. We note, though, that some functionalities of these smart speakers are exclusively available through voice (mostly their Q&A system), while other functionalities are exclusively available through the phone (mostly their settings interface). We see a similar hybrid approach in many other household IoT devices: most smart TVs, music systems, and other household devices still allow control via a traditional control panel or remote but augment this functionality with smart automation services. Our recommendations point to how it should be easy for users with a predominantly user-centric view to turn these "smart" functionalities off. Better yet, these devices should offer similar functionalities through traditional user interfaces for those users who prefer manual control. The findings of this paper strongly advocate for further research regarding the "hybrid" control of IoT functionality.

Although developing interactions that support either or both paradigms is important, it is only one piece of the puzzle. This work highlights the need to reevaluate the value of HCI design for IoT (see Atzori et al. [3]). The historically recognized values of utility and efficiency are designed into existing IoT devices and align, to some extent, with an agentic leaning. However, user-oriented individuals often emphasized a broader picture and larger set of values at stake. The need to feel human or consider a broader set of factors was not supported by overly-agentic IoT devices. This highlights the importance of research to understand the holistic role of the technologies, objects, or people being replaced by IoT devices. Usefulness is not the only criteria for consumers to adopt IoT.

Finally, while it is important to recognize that people may subscribe more strongly to one or the other conceptual model, future research will be crucial to understand why and how individual perspectives are shaped. Whether it is shaped by past experience, framing, individual traits, or other mechanisms. In our study, there was not a clear connection between our participant's self-made definitions of IoT and the conceptual model that influenced them. Nor was there a connection with framing since all participants were exposed to the exact same definitions. Individual differences such as gender, generational differences, or having a technical background (i.e., STEM) also did not seem to determine whether someone was more agentic or user-centric. Even past experience was not indicative. Future research (such as longitudinal studies or even controlled experiments) would be able to investigate how conceptual models are formed.

In fact, research from other contexts acknowledge that the factors relevant to understanding technology adoption have been shown to be different than the factors for understanding continued usage [18]. Although this work focuses on adoption attitudes, future research should draw on theories such as habituation [1,2] and appropriation [10,18,25] to understand how IoT devices are successfully or unsuccessfully used in practice, beyond the initial adoption. Technology affordances, task fit, and individual characteristics are all likely to play a role [2,18]. Understanding ongoing usage would have implications for whether training would be effective for helping potential users understand a different conceptual model (to better understand how the device operates). It will be key to understand whether the values associated with a user-centric or agentic perspective persist through usage or whether they can easily morph. Understanding if experience with a product can change one's perspective also would have implications for how to encourage adoption – if using IoT is the most effective way to teach a different conceptual model and illustrate the value of the device, companies may decide to offer trial periods to help consumers ease into using IoT and realize its value. If, on the other hand, conceptual models are more deep-rooted, this approach may only frustrate users and reinforce their negative perceptions. Rather, designing for different models may be the better approach. Regardless, in all of this research and in the design process, we emphasize the importance of considering values beyond usability, learnability, and efficiency. If one does not consider the values that must be supported, none of these solutions will succeed – experiencing how efficient and usable the IoT device would not be enough.

Finally, our study was an initial exploration with the limitations that come from the specific sample used. Because exploratory work is generative, we were able to identify a number of perspectives and trends that are relevant to understanding attitudes towards adopting existing commercial consumer-oriented IoT. However, a different sample may reveal additional insight and nuance. Furthermore, while studying the predominant paradigm in commercially available IoT helped us understand the real-world factors that contribute the most to attitudes and adoption decisions, studying future technologies will be useful for uncovering potential benefits. Nonetheless, even with future technologies it is only when they are introduced into the market that researchers can focus on understanding adoption attitudes and real-world factors that most influence attitudes and usage.

6 CONCLUSION

We found that participants' conceptual models overrode their demographic characteristics and led us to uncover interesting patterns between their perceptions, attitudes, and adoption (or non-adoption) decisions that can inform design, or more generally, help us understand how people view IoT. Improving usability or increasing privacy alone may not be enough to convince some people that using IoT to turn on a light switch is desirable. In fact, many non-adopters felt that having tangible interactions is a part of "being human," and rightfully did not want to give that up for the sake of ease. However, understanding the larger context of the object being replaced by the IoT device and the values of non-adopters allows us to better anticipate and design for their needs.

It is crucial to anticipate problems surrounding IoT attitudes and usage given the projected ubiquity of IoT devices over the coming years [33]. A wider range of consumer-based IoT are now available on the market—with many that support automatic customizations inferred by the IoT devices—and align well with an agentic view of IoT. Despite this, we uncovered that many individuals still have a user-centric (preference and) view of IoT. Designing and building to accommodate these different perspectives will be key to understanding their (non)adoption decisions and to better supporting their needs and overcoming concerns and adoption barriers.

APPENDIX A

The table below shows questions asked to participants during the interview:

Table 4. Interview Questions asked to participants (Same questions repeated for in-home IoT devices)

Question Type	Question
Adoption	Do you use any type of wearable smart devices for body or location tracking? • If so, please describe what you use and why. • If not, please explain why you don't choose to use any of these smart devices.
Other uses	Do you use any wearable smart devices for any other purposes than body or location tracking? If so, please explain.
Mobile	• [If use] Are the wearable smart devices that you use integrated with your phone or separate devices. Please explain.
Benefits	In what situations do you feel wearable smart devices for body or personal location tracking may be beneficial? • [If use] How have these smart devices been personally beneficial to you?
Drawbacks	In what situations do you feel wearable smart devices for body or personal location tracking may be problematic? • [If use] Have you personally had a negative experience with any of these smart devices in the past? If so, please explain.

APPENDIX B

The table below shows the survey questions asked to participants:

Table 5. Survey Questions asked to participants

Question Type	Question
Demographics	Age Gender Household Income Ethnicity
Actual Usage (asked separately for each type of IoT)	1. How many *wearable/environmental* devices you own? 2. How often do you use your *wearable/environmental* smart devices on a weekly basis? 3. For what purpose do you use Environmental Smart Devices? Possible responses included - *Sensing, Remote Control, Automation* and *other* 4. For what purpose do you use Wearable Smart Devices? Possible responses included – *Body Tracking*, *Location Tracking* and *other*

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