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Influential Factors in the Adoption of Wearable and Environmental IoT-Enabled Smart Devices and Application to Cognitive-Affective Engineering Design

Dr. Lisa Massi, University of Central Florida

Dr. Lisa Massi is the Accreditation and Program Approval Specialist for the College of Engineering and Computer Science at the University of Central Florida (UCF). Her primary responsibilities are accreditation, assessment, and data administration. She has been Co-PI on two NSF-funded S-STEM grants, and program evaluator for three NSF-funded REUs at UCF. Dr. Massi has served in leadership roles as Board Chair for the Cooperative and Experiential Division (CEED) of the American Society for Engineering Education (ASEE) and Chair of the University Assessment Committee at UCF. She has been an active member in ASEE since 2003 as presenter, reviewer, moderator, and CEED conference program chair. Her research interests include student persistence, professional identity and development, and social and cultural capital in the STEM fields.

Salih Safa Bacanli, University of Central Florida

Salih Safa Bacanli is got his M.S. and Ph.D. from Department of Computer Science, University of Central Florida. He received his BS degree in Computer Engineering from Bilkent University, Turkey. His research interest include computer science education, unsupervised machine learning, wireless sensor networks. He is currently lecturer at Department of Computer Science, University of Central Florida

Dr. Pamela J. Wisniewski, Vanderbilt University

Dr. Pamela Wisniewski is an Associate Professor in Human-Computer Interaction and Flowers Family Faculty Fellow in Engineering at Vanderbilt University. Her work lies at the intersection of Social Computing and Privacy. She is the Director of the Socio-Technical Interaction Research (STIR) Lab. She has authored over 150 peer-reviewed publications and won multiple best papers (top 1%) and best paper honorable mentions (top 5%) at ACM SIGCHI conferences. She has been awarded $4.73 million in external grant funding, including the NSF CAREER Award, and her research has been featured by popular news media outlets, including Scientific American, ABC News, NPR, Psychology Today, and U.S. News and World Report.

Dr. Damla Turgut, University of Central Florida

Damla Turgut is Charles Millican Professor of Computer Science at University of Central Florida. She has secondary joint appointments in the Dept. of Electrical and Computer Engineering and the UCF Resilient, Intelligent and Sustainable Energy Systems (RISES) Cluster. She is the co-director of the AI Things Laboratory. She received her PhD from the Computer Science and Engineering Department of University of Texas at Arlington. She held visiting researcher positions at University of Rome "La Sapienza", Imperial College of London and KTH Royal Institute of Technology, Stockholm, Sweden.

Her research interests include wireless ad hoc, sensor, underwater, vehicular, and social networks, edge/cloud computing, smart cities, smart grids, IoT-enabled healthcare and augmented reality, as well as considerations of privacy in the Internet of Things. She is also interested in applying big data techniques for improving STEM education for women and minorities.

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Abstract

This paper fits under the category of "Intersection of Design and Affective-Cognitive Engineering Research."

As more IoT-enabled smart devices enter the market, there is a need to understand which consumers are attracted to what types of smart devices and why. This study examines how user experience, privacy beliefs, and motivation influence wearable and environmental smart devices adoption by college students and their parents in the United States. Therefore, this paper uniquely addresses the affective-cognitive factors of IoT adoption that can inform the future design of wearable and environmental smart devices. Based on a survey of 84 participants (42 pairs of college students and their parents), the findings suggest that college students preferred wearable smart devices and their parents, environmental smart devices. There were differences in how these smart devices were used and perceived by each group. Principal component analysis resulted in three components that influence attitude, intentions, and behaviors toward wearable and environmental smart devices adoption and use. The three components were: User Experience, Privacy Beliefs, and Motivation. Being a power user, ease of use, enjoyment, usefulness, risk beliefs, trust beliefs, social influences, and willingness to pay loaded on these components and were constructs of significance. These findings have implications for education and practice, in addition to the technical requirements, of engineering design to address user needs and preferences from a human-centered perspective.

Introduction

Advances in ubiquitous and pervasive computing technology (connected computing devices available anywhere and anytime with embedded intelligent systems) have led to a proliferation of smart devices [1], [2]. The adoption of smart devices requires consideration of user experiences in a sociotechnical context [3]. User-centered design is important in developing innovative products that are successful in the marketplace [4]. The emerging field of Internet of Things (IoT) connects physical devices and objects through the internet [5]. IoT provides the basis for new consumer smart products and services such as smart phones, health and fitness tracking devices, accident-avoidance technologies for vehicles, and home automation [6]. Consumer smart technology adoption has common overlaps in contributing factors in intention to use the technology but may also vary in their significance for different demographic groups and across different smart devices and services. Smart home technology English consumers [7], Korean consumers [8], and Finnish consumers [9] are influenced to varying degrees by perceived usability, affordability, accessibility, user friendliness, compatibility with lifestyle, and reliability and trust. These factors also influence smart technology adoption by elder consumers [10], Malaysian college students' use of smart phones for learning [11], and American college students and university staff adopters of smart wearable devices [12]. The decision to use smart wearable devices may also be affected by design aesthetics and connectivity to the world wide web [12]. Finnish consumers also consider the opportunity to experiment with smart home technology and perceived innovativeness of the product (with different effects for experienced vs. non-experienced consumers) with intention to use this technology; moreover, Finnish women are more concerned with lifestyle compatibility than men [9]. From the perspective of Korean postponers or rejectors of smart home technology, privacy risks are a greater barrier to adoption for rejectors [8]. Generational differences are apparent in level of skill and satisfaction with smart devices among Turkish Gen Xers, Gen Yers, and Gen Zers [13].

Kansei engineering (or affective engineering) plays an integral role in product design and subsequent customer acceptance and adoption of new technology [14], [15], [16]. Kim et al. [17] refer to three user-centered categories to be considered when designing smart homes: characteristics, lives, and physical ability. Frances-Morcillo et al. [18] proposed wearable devices design requirements based on three types of ergonomics (physical, emotional, and cognitive). This paper focuses on selected human factors in the cognitive and emotional domain and generational differences in the prevalence of adoption of IoT-enabled wearable smart devices and environmental smart devices among Millennials (specifically college students) and Baby Boomers (their parents) in the United States. Millennials (defined as anyone born between 1981-1996, i.e., ages 22-37 in 2018) [19] grew up with the internet and connective technology [20], [21], unlike Baby Boomers (defined as anyone born between 1946-1964, i.e., ages 54-72 years in 2018) [22]. Adoption rates for smart wearables and smart home technology among older adults (50 years and older) have been gradually increasing and are now comparable with younger generations (18-49 years), but notably skews toward those at the younger end of the scale (50-59 years) among older adults for smart wearables [23]. However, the motivation for adoption of smart wearables and smart home devices and services may vary among Millennials and older adults. Existing literature on smart technology adoption tends to center around consumers in foreign countries and a specific market segment (e.g., mature adults, seniors, or young people). User needs analysis is complex as it varies according to the product, scope of the project, type of users and their roles, implementation constraints, and development and design timeline [24]. The literature is scarce on comparisons of generational differences among consumers within the United States and their affective-cognitive decision making in adoption of smart devices. This study analyzes affective-cognitive constructs that contribute to adoption of wearable and environmental smart devices for college students and their parents and applies the findings to example use cases in engineering design.

The research questions for this study were:

RQ1. What types of IoT device adoption (wearable smart devices, environmental smart devices) are more prevalent among Millennials compared with older generations?

RQ2. What factors (e.g., motivation, disposable income, privacy concerns, etc.) play salient roles in IoT adoption?

Theoretical Framework

The Technology Acceptance Model (TAM) has been widely used to explain a user's acceptance and adoption of a variety of technologies, and the constructs *perceived usefulness* and *perceived ease of use* influence attitude toward technology adoption [9], [12], [25], [26], [27]. Subsequent research since the development of TAM in the 1980s has confirmed the constructs in TAM and revealed additional factors that contribute to smart technology adoption. Younger people are more likely to be technology *power users* and use the devices more innovatively [28], and *enjoyment* influences adopters continued use of technology [27], [29]. *Social influence* has been shown to be an influential factor in intention to use smart technology [27], [29], [30]. Consumers' *perceived value* of the convenience and connectedness of smart home technology determine their level of *trust belief* [31] and *privacy risk belief* in those devices as well as smart wearable devices [12], [31]. Moreover, consumer *trust belief* in the manufacturer or service provider can significantly mitigate *perceived privacy risk* and overcome consumer reluctance in providing personal information [32]. The monetary *cost* of smart technology influences *perceived value* and in turn adoption or continued use [29]. Consumers' willingness to pay for smart technology varies according to the type of device or service, for example, flat fee versus pay-per-use fee [33]. Ultimately, trade-offs among these factors influence consumer adoption of smart technology.

Methodology

This study was conducted with students participating in a Research Experiences for Undergraduates (REU) site: Research Experiences on the Internet of Things (IoT) funded by the National Science Foundation. This REU IoT site was located at a large, southeastern, public university in the United States. Its purpose was to train undergraduate students, majoring in selected engineering disciplines or computer science, in research-based theory and applications of smart technologies. Thirty undergraduate students (primarily from universities outside of the host institution) participated in the IoT REU in the summers of 2016-2018. Participants were given an Institutional Review Board-approved study description and asked to complete a web-based survey related to wearable and environmental IoT-enabled smart device usage. They were also asked to recruit their parent to complete the survey, as well as another young adult-parent matched pair from their family, relatives, or circle of acquaintances, preferably a student who was a non-STEM (science, technology, engineering, mathematics) major or had a non-STEM degree. The student-parent pair was offered a $10 Amazon gift card if both completed the survey. A total of 94 responses were received. Data from 42 matched student-parent pairs (total of 84 respondents) were used for this study after removing unmatched pairs and duplicated entries. Little's [34] missing completely at random (MCAR) test showed that there were no missing data in the responses.

By including non-STEM majors with REU STEM majors, the diversity of the student participant pool would more closely resemble the population and limit potential bias in the data for self-reported technological abilities. The level of experience using technology (reported on a scale of *1 = little to no experience* to *5 = expert*) was the same (*median* = 4.00) for REU students (n = 24) and non-REU students (n =18), and the same (*median* = 3.00) for REU parents (n = 24) and non-REU parents. This result is perhaps not surprising since the student age group grew up using the internet and connected technologies, and whether they were STEM or non-STEM majors was negligible. Parents' median score was significantly lower than the students since their age group was less likely to have grown up using the internet and connected technologies (Mann Whitney $U = 347$, $z = -5.0$, $p<.05$; medium effect size $r_{techexp} = -0.56$).

The demographic data for the student-parent participant groups are presented in Table 1. Women were about equally represented in the student sample (52%) but over-represented in the parent sample (67%). Under-represented groups were slightly over-represented in the student group (19%) compared with the parent group (14%). Since most students were still in college, it made sense that more than half reported their personal income to be under $25,000 and that they had not yet received a degree. Close to half (45%) of parents had a bachelor's degree or higher, and more than half (51%) made $55,000 or higher.

Table 1. Characteristics of Study Participants

Characteristics	Student n= 42	Parent n = 42
Age	95% (18-26 years) 5% (27-34 years)	2% (27-34 years) 12% (35-42 years) 48% (43-50 years) 33% (51-60 years) 5% (61-69 years)
Gender (Women)	52%	67%
Under-represented Minority (Hispanic, African American, Pacific Islander)	19%	14%
Household or personal income	52% (under $25,000) 7% ($25,000-$34,999) 5% ($35,000-$44,999) 7% ($55,000-$84,999) 5% ($105,000-$114,999) 7% (Over $125,000) 17% (Prefer not to answer)	7% (under $25,000) 21% ($25,000-$54,999) 10% ($55,000-$74,999) 10% ($75,000-$94,999) 7% ($95,000-$114,999) 24% (over $125,000) 21% (Prefer not to answer)
Highest degree or level of school completed	14% (high school graduate or GED) 64% (some college credit, no degree) 10% (associate degree) 12% (bachelor's degree)	12% (high school graduate) 29% (Associate) 21% (Bachelor) 17% (Master) 7% (PhD/Professional)

Survey Instrument

Student participants and their parents were asked to complete a web-based survey regarding their usage of wearable smart devices and environmental smart devices. Wearable smart devices were defined as devices used for body (such as for personal health or fitness) or location tracking, or such applications that can be installed on a mobile device, such as a smart phone. Environmental smart devices were defined as devices used for sensing (e.g., video surveillance), providing remote control (e.g., remotely control appliances, light switches, etc.), and automating aspects of the physical environment (e.g., air condition/heat thermostat), or such applications that can be installed on a mobile device, such as a smart phone. Eight constructs were adapted from previously validated surveys and used to create the survey for this study: p*ower user* [35], *perceived usefulness* [27], *perceived ease of use* [27], *social influence* [27], *perceived enjoyment* [27], t*rust beliefs* [32], *risk beliefs* [32], and *willingness to pay* [33]. Responses were based on five-point Likert scales, which were created by computing mean or sum composite scores of ordinal subscale items, thus approximating an interval measurement scale [36]. The resulting survey instrument is presented in the Appendix.

Table 2 shows the list of constructs and scale reliability, Cronbach's α, in the original source compared with the corresponding computed Cronbach's α for this study. The number of items in the subscale for each construct is indicated in ( ). Cronbach α values of 0.70 to 0.80 or higher are generally considered a good measure of internal consistency, and the correlation between each item and the overall score from the survey is at least 0.3 [37]. Corresponding items were dropped if the deleted item improved coefficient α if these conditions were met and α values were at least approximately comparable to values in the literature (see Table 2). For *willingness to pay*, if the first item were deleted, coefficient α would increase from over 0.80 (3 items) to over 0.90 (2 items) for students and parents in the study; no α value was reported by the authors in the original source, and the two-item construct was retained for this study.

Table 2. Reliability Coefficients (Cronbach's α) for Each Construct

Construct	**Original Source**	**Study**	
	Literature α =	**Student α =**	**Parent α =**
Power User (6 items)	0.83	0.82	0.87
Wearable Smart Devices			
Perceived Usefulness (4 items)	0.82	0.86	0.89
Perceived Ease of Use (3 items)	0.85	0.91	0.95
Social Influence (3 items)	0.86	0.90	0.84
Perceived Enjoyment (3 items)	0.83	0.90	0.94
Trust Beliefs (5 items)	0.78	0.88	0.93
Risk Beliefs (5 items)	0.92	0.91	0.92
Willingness to Pay (2 items)	Not available	0.95	0.91
Construct	**Original Source**	**Study**	
	Literature α =	**Student α =**	**Parent α =**
Environmental Smart Devices			
Perceived Usefulness (4 items)	0.82	0.91	0.90
Perceived Ease of Use (3 items)	0.85	0.93	0.96
Social Influence (3 items)	0.86	0.88	0.90
Perceived Enjoyment (3 items)	0.83	0.95	0.92
Trust Beliefs (5 items)	0.78	0.93	0.94
Risk Beliefs (5 items)	0.92	0.84	0.93
Willingness to Pay (2 items)	Not available	0.92	0.95

Results

The results are described below for *RQ1*.

RQ1. What types of IoT device adoption (wearable smart devices, environmental smart devices) are more prevalent among Millennials compared with older generations?

A larger percentage of students owned wearable smart devices compared to their parent (57% vs. 48%), though the majority in both groups reported owning one device than multiple devices; used the devices more for body tracking (75% vs. 53%) but about equally for location tracking (46% vs. 47%); and used the devices more frequently (63% vs. 58%). On the other hand, a larger percentage of parents owned environmental smart devices compared to the student (29% vs. 19%); used the devices more for sensing (50% vs. 25%) and remote control (67% vs. 25%) but less for automation (58% vs. 63%); and by far, used the devices more frequently (83% vs. 38%). (See Table 3.)

Table 3. Smart Device Usage

Student	**Wearable Smart Devices**	**Environmental Smart Devices**
% Own Device(s), (# Devices)	57% (1-3, majority 1), 43% (0)	19% (1-4^{+}, majority 1), 81% (0)
Purpose (if own)	75% body tracking, and/or 46% location tracking	25% sensing, 25% remote control, 63% automation, and/or 13% other (music-smart speaker)
How Often (if own)	63% (very frequently, frequently) 12% (occasionally) 25% (very rarely, rarely)	38% (very frequently, frequently), 25% (occasionally),37% (rarely)
Parent	**Wearable Smart Devices**	**Environmental Smart Devices**
% Own Devices, (# Devices)	48% (1-3, majority 1), 52% (0)	29% (1-4^{+}), 71% (0)
Purpose (if own)	53% body tracking, and/or 47% location tracking, and/or 16% other (GPS, make calls)	50% sensing, 67% remote control, 58% automation
How Often (if own)	58% (very frequently, frequently) 32% (occasionally) 10% (rarely)	83% (very frequently, frequently) 17% (occasionally)

Purpose (if owned): Percentages may not sum to 100% because multiple categories can be selected in the survey.

RQ2. What factors (e.g., motivation, disposable income, privacy concerns, etc.) play salient roles in IoT adoption?

Guided by prior literature [9], [25], [26], [27], [28], [29], [32], [33], [35] principal component analysis (PCA) was conducted on the eight constructs for wearable smart devices and environmental smart devices (see Table 2) with oblique rotation (direct oblimin) for three groups: *both* (student plus parents, n=84), *students* (n=42), and *parents* (n=42). The Kaiser-Meyer-Olkin (KMO) measure verified the sampling adequacy for the analysis. All KMO values were greater than the minimum acceptable limit of 0.5, where values in the 0.50s are just acceptable, and values in the .60s are mediocre [38]. For wearable smart devices, the KMO values were: KMO_{both} = 0.629, $KMO_{student}$ = 0.550, and KMO_{parent} = 0.650. For environmental smart devices, the KMO values were: $KMO_{both} = 0.654$, $KMO_{student} = 0.642$, and $KMO_{parent} = 0.655$. An initial analysis was run to obtain eigenvalues for each component in the data. For wearable smart devices, three components had eigenvalues over Kaiser's criterion of 1 for *both* and *student* categories, but only two components for the *parent* category. In combination, these components explained 69.84%, 67.74%, and 62.13% of the variance respectively. For environmental smart devices, three components had eigenvalues over Kaiser's criterion of 1 for all three groups (*both, student, parent)*. In combination, these components explained 68.95%, 67.81%, and 74.25% of the variance respectively. The components were retained because of the convergence of the scree plots, Kaiser's criterion on this value, and the higher component loadings in the pattern matrix. Tables 4 and 5 show the component loadings after rotation in the pattern matrix for wearable and environmental smart devices respectively. The items that clustered on the same component were labeled as: User Experience (component 1), Privacy Beliefs (component 2), and Motivation (component 3).

Table 4. Wearable Smart Devices: Summary of principal component analysis results

Item	Rotated Component Loadings								
	User Experience			Privacy Beliefs			Motivation		
	Both	**Student**	**Parent**	**Both**	**Student**	**Parent**	**Both**	**Student**	**Parent**
Power User	**0.840**	**-.662**	**0.854**	-0.133	-0.410	0.045	-0.022	0.044	n/a
Perceived Ease of Use	**0.931**	**-.843**	**0.781**	-0.046	0.057	0.008	-0.187	0.104	n/a
Perceived Enjoyment	**0.712**	-.326	**0.798**	0.058	0.249	-0.183	0.307	**0.737**	n/a
Trust Beliefs	-0.041	.168	-0.193	**-0.887**	**-0.898**	**-0.888**	0.029	0.036	n/a
Risk Beliefs	-0.175	.305	0.014	**0.864**	**0.770**	**0.889**	-0.055	0.039	n/a
Perceived Usefulness	0.426	-.116	**0.810**	0.196	0.055	0.099	**0.531**	**0.692**	n/a
Willingness to Pay (2 items)	0.003	0.376	**0.505**	0.196	-0.154	0.014	**0.691**	**0.834**	n/a
Social Influence	-0.115	-0.246	0.307	-0.227	-0.237	**-0.572**	**0.786**	**0.451**	n/a
Eigenvalues	2.85	1.09	3.11	1.586	1.51	1.86	1.151	2.82	n/a
% of Variance	35.62	13.66	38.87	19.83	18.88	23.26	14.39	35.20	n/a

Component loadings over 0.50 appear in bold. The bolded items shown in each column loaded under the three high-level constructs: User Experience, Privacy Beliefs, and Motivation.

Table 5. Environmental Smart Devices: Summary of principal component analysis results

Item	Rotated Component Loadings								
	User Experience			Privacy Beliefs			Motivation		
	Both	**Student**	**Parent**	**Both**	**Student**	**Parent**	**Both**	**Student**	**Parent**
Power User	**0.857**	**0.881**	**0.873**	-0.003	-0.121	0.030	-0.322	-0.125	0.030
Perceived Ease of Use	**0.776**	**0.767**	**0.568**	-0.016	0.179	-0.227	0.012	0.227	0.332
Perceived Enjoyment	**0.712**	0.144	**0.602**	-0.038	-0.052	-0.074	0.284	**0.786**	0.414
Perceived Usefulness	**0.676**	0.103	**0.876**	-0.016	-0.086	-0.050	0.148	**0.747**	-0.187
Trust Beliefs	-0.089	-0.004	-0.004	**-0.928**	**-0.897**	**-0.933**	-0.037	-0.072	-0.156
Risk Beliefs	-0.143	0.008	-0.155	**0.857**	**0.843**	**0.882**	-0.042	-0.181	0.016
Willingness to Pay (2 items)	0.136	0.009	0.085	0.070	-0.116	0.117	**0.767**	**0.531**	**0.906**
Social Influence	-0.093	-0.140	-0.315	-0.127	0.154	**-0.563**	**0.817**	**0.861**	0.485
Eigenvalues	2.777	1.09	2.98	1.598	1.49	1.95	1.142	2.84	1.02
% of Variance	34.71	13.65	37.22	19.97	18.61	24.31	14.28	35.55	12.73

Component loadings over 0.50 appear in bold. The bolded items shown in each column loaded under the three high-level constructs: User Experience, Privacy Beliefs, and Motivation.

For wearable smart devices, being a power user, ease of use, and enjoyment of the device clustered on User Experience for the *both* group; power user and ease of use for the *student* group; and power user, ease of use, enjoyment, usefulness, and willingness to pay for the *parent* group. For all *three groups*, trust beliefs and risk beliefs clustered on Privacy Beliefs. Trust beliefs showed a negative relationship with this component because the survey items were written as positive statements, whereas risk beliefs were written as negative statements. In terms of Motivation, usefulness, willingness to pay, and social influence clustered on the *both* and *student* groups, as well as enjoyment for the *student* group. The *parent* group was not applicable since only two components were retained.

For environmental smart devices, being a power user, ease of use, enjoyment, and usefulness clustered on User Experience for the *both* and *parent* group; and power user and ease of use for the *student* group. For all *three groups*, trust beliefs and risk beliefs clustered on Privacy Beliefs. Trust beliefs showed a negative relationship with this component because the survey items were written as positive statements, whereas risk beliefs were written as negative statements. In terms of Motivation, willingness to pay and social influence clustered on the *both* and *student* group, as well as enjoyment and usefulness for the *student* group. Willingness to pay clustered on the *parent* group.

The survey instrument is available in the Appendix.

Discussion

This paper had two goals: (1) to provide the results of a study on the generational differences in adoption of wearable and environmental smart devices, and (2) to apply the results to example design use cases.

Design research is multidisciplinary in nature, integrating aesthetics, marketing, ergonomic, and engineering skills throughout the product design process [39]. Mitsuo Nagamachi developed the concept of Kansei engineering, which translates customer emotions into design parameters [40]. The Kansei engineering process can be simply described as (a) defining the domain by semantic scale (collection of words) or product specification (features important to users), (b) synthesis of both domains (application of qualitative and/or quantitative methods), (c) validation (reliability and validity), and (d) model building [41]. Affective-cognitive needs of the user are a critical part of product experience engineering [15]. ABET's Engineering Accreditation Commission's definition of engineering design contains examples of affective-cognitive constraints such as aesthetics, ergonomics, marketability, and usability [42]. Incorporating a simplified affective-cognitive framework (such as the use cases presented below) into the senior design process may be beneficial to students operating under time constraints. This approach allows for a structured yet flexible method of considering both the emotional and cognitive aspects of design thinking.

The integration of smart device technologies into everyday life has revolutionized the way we interact with the environment. As adoption rates grow, factors such as usability, affordability, aesthetics, and lifestyle compatibility play crucial roles in influencing consumer behavior across diverse demographic groups [3, 4, 7-12]. These insights are vital for developers aiming to create user-centered designs that not only meet practical needs but also resonate with users on a personal level. This study fills a gap in the existing literature. The results suggest that generational differences between younger (students) and older (parents) consumers influence the type of smart device adoption and how they are used. Students are more likely to own wearable smart devices (57% vs, 48%) and use them frequently and for body tracking (see Table 3). Parents are more likely to own environmental smart devices (29% vs, 18%) and use them frequently for sensing and remote control (see Table 3). User Experience, Privacy Beliefs, and Motivation influence younger and older consumers attitudes, behavior, and intentions towards wearable and environmental smart devices adoption and use. How much control a user has over the smart device (power use); how simple and intuitive it is to operate (ease of use); how pleasant and satisfying it is to use (enjoyment); and how well it meets the user's needs and goals (usefulness) influence the user's experience with the product. The extent to which users feel safe that the smart device companies will protect their personal information (trust belief) and the degree of control users exercise control over their personal information (risk beliefs) influence the trustworthiness and potential risks of the technology. Social influence refers to the extent to which consumers are influenced by the opinions and behaviors of others (such as friends or family) when deciding whether to buy a smart device. Willingness to pay refers to the maximum amount of money a consumer is willing to spend on a smart device, given its features and benefits. Importantly, all these factors can be influenced through well-applied engineering design education, as teaching end users how to use an emerging technology, how to secure the technology to enhance trust and reduce risks, and the best practices for use will facilitate adoption and long-term use. Therefore, this underscores the importance of REU programs, such as the one described in this paper, for engaging multigenerational users (e.g., Millennials and their parents) in education-based research.

These findings may be used as a framework for developing user feedback questions to evaluate key factors that contribute to user satisfaction and engagement with smart devices. Further user feasibility studies can then gather additional data eliciting subjective user emotions and aesthetic preferences to the proposed product. Subsequently, this approach can ensure that cognitive and emotional needs are considered alongside technical specifications, allowing for the creation of more intuitive and user-friendly smart devices. The use of "task sequences" as described by Kujala et al. [43, p.47] facilitates this by providing a clear visual representation of user interactions with the device throughout the product design phase.

Example Use Cases in Engineering Design

An example of cognitive and emotional user needs considerations when designing a smart thermostat (environmental smart device) is presented in Table 6. The study results for *parents* are considered in creating this framework (Table 5).

Table 6. A use case framework for smart thermostat design incorporating cognitive-emotional user needs and education.

Use Case	Control heat and cooling energy use.	
Summary	User wants to save money and auto control temperature remotely in the home.	
Actors	User and vendor. Older consumers are more likely to purchase, especially those who like to use technology (power users).	
Basic Sequence	**Cognitive/Emotional Need Constructs**	**Steps**
Cost-Benefits	Willingness to Pay	Auto set to eco temperature when not at home. Auto generated reports on energy savings. Educate homeowner on potential cost savings.
Installation	Perceived Ease of Use	Simple installation and set-up by user to replace existing home thermostat within software. Create supplementary video and printed instructions with graphics to make educational materials accessible to older population.
Communication with Device/ Convenience	Perceived Ease of Use Perceived Usefulness Perceived Enjoyment	Simple, intuitive interface. Can control by voice from any room with a smart speaker. Can control remotely by smart phone, tablet, or computer. Can control manually from device if weak or failed internet connection. Intuitive prompts and easy-to-use help interfaces for troubleshooting unexpected problems.
Convenience	Perceived Enjoyment	Set schedule to auto change temperature control. Can learn from your behavior and auto program itself to adjust temperature. Transparent and explainable processes, so that the homeowner understands the algorithms embedded in the devices.
Privacy Concerns	Trust Beliefs Risk Beliefs	Opt out for optional services and third-party vendors data sharing. Security of data transmitted and stored. Security and privacy of tracking of household movements through temperature adjustments (e.g., when home, not home). Education and awareness training to mitigate potential privacy and security threats to maximize trusted use.

An example of cognitive and emotional user needs considerations when designing a smart watch (wearable smart device) is presented in Table 7. The study results for the *both* (students and parents) group are considered in creating this framework, since the percentage of respondents who are likely to purchase wearable smart devices although higher for students are also high for parents (Table 4).

Table 7. A use case framework for smart watch design incorporating cognitive-emotional user needs and education.

Use Case	Improve quality of life through tailored goal setting (health and fitness tracking and monitoring) and convenience of seamless communication.	
Summary	User wants to track and monitor health and fitness and integrate watch functionality with smart phones.	
Actors	User and vendor. While younger consumers are more likely to purchase, a large percentage of older consumers are also interested. Power users (those who like to use technology) are more likely to purchase.	
Basic Sequence	**Cognitive/Emotional Need Constructs**	**Steps**
Cost-Benefits	Willingness to Pay Perceived Usefulness	Clock, timer, alarm, reminders, weather. Goal tracking for fitness (steps taken, distance covered, speed, calories burned), sleep quality, heart rate. Make and receive phone calls; receive phone notifications. Play music. Long battery life. Waterproof. Provide practical tips on how to use the device to save money and maximize health and productivity.
Installation	Perceived Ease of Use	Simple installation and set-up after downloading app from the phone's app store. Quick start guides that are accessible to both younger and older wearable device users.
Communication with Device	Perceived Ease of Use	Simple, intuitive interface to simplify daily routines. Easy-to-read, digital, high-definition display watch face. Touch screen. Can control by smart phone, including voice activated. Embedded help and intelligent assistance to troubleshoot the device on the go.
Convenience	Perceived Enjoyment	Multiple sport modes tracking attractive to a wide age range (e.g., walk, running, bicycling, football, volleyball, tennis, baseball, sit-ups, jump rope, golf, yoga, badminton, basketball, ping pong, elliptical machine, mountain climbing). Heart monitoring (heart rate, body temperature). Stress monitoring. Blood oxygen monitoring. Sleep quality analysis (deep sleep, light sleep, REM, awake). Play music. Customizable watch faces from inventory or individual library. Alerts and suggestions to personalize the device to the users' daily routines.
Privacy Concerns	Trust Beliefs Risk Beliefs	Opt out for optional services and third-party vendors data sharing. Security of data transmitted and stored. Security and privacy of tracking of movements and health data. Education and awareness on the potential risks and ways to secure sensitive data collected and stored on the device.

For students engaged in the senior design process, conducting a literature review on affective-cognitive factors in engineering design offers a solid foundation for consumer-oriented projects.

This approach not only grounds their work in established research, but also helps them identify areas where they can innovate and contribute to the field. Thus, by incorporating and adapting a cognitive-affective framework to their projects, students can enhance their senior design project reports with a well-rounded analysis of their design's impact, ensuring a comprehensive documentation that aligns with academic and industry standards.

Limitations of the Study

The generalizability of the findings in this study may be limited to U.S. college students and parents and to wearable and environmental smart devices. The results may not be generalizable to other generational age cohorts, nor other types of IoT-enabled smart devices. A larger sample size is also needed to examine further generational differences and intersectionality of age, gender, race, and socioeconomic status as their attraction to and experiences with smart device adoption may differ.

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Appendix

Response options for Q3, Q7-12, Q17-Q22

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Response options for Q13, Q23

Very Unlikely	Unlikely	Neutral	Likely	Very Likely
1	2	3	4	5

REU Internet of Things Survey

Q1 Enter the survey code that was provided to you during the interview.

Q2 Are you the young adult or the parent/legal guardian?

- ❍ Young Adult (1)
- ❍ Parent/Legal Guardian (2)

Q3 Indicate the extent to which you agree or disagree with the following statements.
Power User [35]

I love to use technological gadgets.	1	2	3	4	5
I have to have the latest available upgrades of the technological devices that I use.	1	2	3	4	5
I would feel lost without technological gadgets.	1	2	3	4	5
I love exploring all the features that any technological gadget has to offer.	1	2	3	4	5
I feel like technological gadgets are a part of my daily life.	1	2	3	4	5
I like to challenge myself in figuring out how to use any new technology.	1	2	3	4	5

Before you answer the survey questions below related to wearable smart devices, please read this general definition.

Wearable smart devices are often used for body or location tracking.

Body tracking smart devices are often related to tracking personal health and/or fitness information, such as heart rate or the number of steps you take.

Location tracking smart devices track your physical location.

Wearable smart devices for body or location tracking may include applications that can be installed on a mobile device, such as a smart phone. When answering the following questions, please answer them specific to the context of wearable smart devices used for body or location tracking.

Q4 How many **wearable smart devices** do you own?

- ❍ None (1)
- ❍ 1 (2)
- ❍ 2 (3)
- ❍ 3 (4)
- ❍ 4 or more (5)

Q5 For what purpose(s) do you use **wearable smart devi**ces?

- ❑ Body tracking (1)
- ❑ Location tracking (2)
- ❑ Other (3) ____________________

Q6 How often do you use your **wearable smart devices** on a weekly basis?

- ❍ Very Rarely (1)
- ❍ Rarely (2)
- ❍ Occasionally (3)
- ❍ Frequently (4)
- ❍ Very Frequently (5)

Q7. Indicate to what extent you agree or disagree with the statements below relating to **wearable smart devices.**

Perceived usefulness [27]					
Using wearable smart devices would enable me to accomplish tasks more quickly.	1	2	3	4	5
Using wearable smart devices would make it easier for me to accomplish my goals.	1	2	3	4	5
Using wearable smart devices would significantly increase the quality or output of my life.	1	2	3	4	5
Overall, I would find using wearable smart devices advantageous.	1	2	3	4	5

Q8. Indicate to what extent you agree or disagree with the statements below relating to **wearable smart devices.**

Perceived ease of use [27]					
Learning to use wearable smart devices is easy for me.	1	2	3	4	5
I find my interaction with wearable smart devices clear and understandable.	1	2	3	4	5
I think using wearable smart devices is easy.	1	2	3	4	5

Q9. Indicate to what extent you agree or disagree with the statements below relating to **wearable smart devices.**

Social influence [27]					
People who are important to me would recommend using wearable smart devices.	1	2	3	4	5
People who are important to me would find using wearable smart devices beneficial.	1	2	3	4	5
People who are important to me would find using wearable smart devices a good idea.	1	2	3	4	5

Q10. Indicate to what extent you agree or disagree with the statements below relating to **wearable smart devices.**

Perceived enjoyment [27]

I have fun using wearable smart devices.	1	2	3	4	5
Using wearable smart devices is pleasurable.	1	2	3	4	5
Using wearable smart devices gives me enjoyment.	1	2	3	4	5

Q11. Indicate to what extent you agree or disagree with the statements below relating to **wearable smart devices.**

Trust beliefs [32]

Wearable smart device companies would be trustworthy in handling my information.	1	2	3	4	5
Wearable smart device companies would tell the truth and fulfill promises related to the information I provide.	1	2	3	4	5
I trust that wearable smart device companies would keep my best interests in mind when dealing with my information.	1	2	3	4	5
Wearable smart device companies are in general predictable and consistent regarding the usage of my information.	1	2	3	4	5
Wearable smart device companies are always honest with customers when it comes to using the information I would provide.	1	2	3	4	5

Q12. Indicate to what extent you agree or disagree with the statements below relating to **wearable smart devices.**

Risk beliefs [32]

In general, it would be risky to give information to wearable smart device companies.	1	2	3	4	5
There would be high potential for loss associated with giving information to wearable smart device companies.	1	2	3	4	5
There would be too much uncertainty associated with giving information to wearable smart device companies.	1	2	3	4	5
Providing wearable smart device companies with information would involve many unexpected problems.	1	2	3	4	5
I would feel safe giving information to wearable smart device companies. (Reverse code)	1	2	3	4	5

Q13. Indicate the extent to which you are likely or unlikely to purchase **wearable smart devices.**

Willingness to Pay [33]

If you actually had the money, how likely is it that you would pay a one-time fixed price for a wearable smart device?	1	2	3	4	5
If you actually had the money, how likely is it that you would pay a monthly fee for a wearable smart device?	1	2	3	4	5
If you actually had the money, how likely is it that you would pay a usage service fee for a wearable smart device?	1	2	3	4	5

Before you answer the survey questions below related to environmental smart devices, please read this general definition.

Environmental smart devices are used for sensing, providing remote control, and automating aspects of one's physical environment, such as one's home.

- **Sensing smart devices** may include video surveillance or other types of monitoring systems.
- **Remote control smart devices** allow users to control physical appliances, such as garage doors or light switches, via the Internet from a remote location.
- **Automation smart devices** include those that act independently based on the information that they sense, such as a Nest thermostat creating a customized schedule to control the A/C.

Environmental smart devices may also include applications that can be installed on a mobile device, such as a smart phone. When answering the following questions, please answer them specific to the context of environmental smart devices used for sensing, providing remote control, and automating aspects of one's physical environment.

Q14 How many **environmental smart devices** do you own?

- ❍ None (1)
- ❍ 1 (2)
- ❍ 2 (3)
- ❍ 3 (4)
- ❍ 4 or more (5)

Q15 For what purpose(s) do you use **environmental smart devices**?

- ❍ Sensing (1)
- ❍ Remote Control (2)
- ❍ Automation (3)
- ❍ Other (4) ____________________

Q16 How often do you use your **environmental smart devices** on a weekly basis?

- ❍ Very rarely (1)
- ❍ Rarely (2)
- ❍ Occasionally (3)
- ❍ Frequently (4)
- ❍ Very frequently (5)

Q17 Indicate to what extent you agree or disagree with the statements below relating to **environmental smart devices**. Perceived usefulness [27]

Using environmental smart devices would enable me to accomplish tasks more quickly.	1	2	3	4	5
Using environmental smart devices would make it easier for me to accomplish tasks.	1	2	3	4	5
Using environmental smart devices would significantly increase the quality or output of my life.	1	2	3	4	5
Overall, I would find using environmental smart devices advantageous.	1	2	3	4	5

Q18 Indicate to what extent you agree or disagree with the statements below relating to **environmental smart devices**. Perceived ease of use [27]

Learning to use environmental smart devices is easy for me.	1	2	3	4	5
I find my interaction with environmental smart devices clear and understandable.	1	2	3	4	5
I think using environmental smart devices is easy.	1	2	3	4	5

Q19 Indicate to what extent you agree or disagree with the statements below relating to **environmental smart devices**. Social influence [27]

People who are important to me would recommend using environmental smart devices.	1	2	3	4	5
People who are important to me would find using environmental smart devices beneficial.	1	2	3	4	5
People who are important to me would find using environmental smart devices a good idea.	1	2	3	4	5

Q20 Indicate to what extent you agree or disagree with the statements below relating to **environmental smart devices**. Perceived enjoyment [27]

I have fun using environmental smart devices.	1	2	3	4	5
Using environmental smart devices is pleasurable.	1	2	3	4	5
Using environmental smart devices gives enjoyment to me.	1	2	3	4	5

Q21 Indicate to what extent you agree or disagree with the statements below relating to **environmental smart devices**. Trust beliefs [32]

Environmental smart device companies would be trustworthy in handling my information.	1	2	3	4	5
Environmental smart device companies would tell the truth and fulfill promises related to the information provided.	1	2	3	4	5
I trust that environmental smart device companies would keep my best interests in mind when dealing with the information.	1	2	3	4	5
Environmental smart device companies are in general predictable and consistent regarding the usage of my information.	1	2	3	4	5
Environmental smart device companies are always honest with customers when it comes to using the information I would provide.	1	2	3	4	5

Q22 Indicate to what extent you agree or disagree with the statements below relating to **environmental smart devices**. Risk beliefs [32]

In general, it would be risky to give information to environmental smart device companies.	1	2	3	4	5
There would be high potential for loss associated with giving information to environmental smart device companies.	1	2	3	4	5
There would be too much uncertainty associated with giving information to environmental smart device companies.	1	2	3	4	5
Providing environmental smart device companies with information would involve many unexpected problems.	1	2	3	4	5
I would feel safe giving information to environmental smart device companies. (Reverse code)	1	2	3	4	5

Q23 Indicate to what extent you are likely or unlikely to purchase **environmental smart devices**. Willingness to pay [33]

If you actually had the money, how likely is it that you would pay a one-time fixed price for an environmental smart device?	1	2	3	4	5
If you actually had the money, how likely is it that you would pay a monthly fee for an environmental smart device?	1	2	3	4	5
If you actually had the money, how likely is it that you would pay a usage service fee for an environmental smart device?	1	2	3	4	5

You are almost done with this survey. In order to better understand our audience, can you please provide some background information about yourself?

Q24 Your Age

- ❍ 18-26 years (1)
- ❍ 27-34 years (2)
- ❍ 35-42 years (3)
- ❍ 43-50 years (4)
- ❍ 51-60 years (5)
- ❍ 61-69 years (6)
- ❍ 70 or more years (7)

Q25 Your Gender

- ❍ Male (1)
- ❍ Female (2)
- ❍ Other (3)

Q26 Your Ethnicity

- Hispanic (1)
- African American (2)
- American Indian (3)
- Asian (4)
- Pacific Islander (5)
- White (6)

Q27 Your household income or personal income.

- Under $25,000 (1)
- $25,000-34,999 (2)
- $35,000-$44,999 (3)
- $45,000-$54,999 (4)
- $55,000-$64,999 (5)
- $65,000-$74,999 (6)
- $75,000-$84,999 (7)
- $85,000-$94,999 (8)
- $95,000-$104,999 (9)
- $105,000-$114,999 (10)
- $115, 000-$124,999 (11)
- Over $125,000 (12)
- Prefer not to answer. (13)

Q28 What is the highest degree or level of school you have completed?

- No schooling completed (1)
- Kindergarten through 8th grade (2)
- Some high school, no diploma (3)
- High school graduate, diploma, or equivalent (e.g., GED) (4)
- Some college credit, no degree (5)
- Trade/technical/vocational training (6)
- Associate degree (7)
- Bachelor's degree (8)
- Master's degree (9)
- Doctorate/Professional Degree (10)

Q29 Was your degree/major in a technical or non-technical field?

- Technical (1)
- Non-technical (2)

Q30 What was your degree/major?

Q31 How would you describe your level of experience using technology?

- ❍ Little to no experience. Someone has to help me use technological gadgets. (1)
- ❍ Not very experienced. I can use technological gadgets but I am not very comfortable with it. (2)
- ❍ Somewhat experienced. I have been using technological gadgets for at least a year, and I am comfortable using it. (3)
- ❍ Very experienced. I have been using technological gadgets for several years. (4)
- ❍ Expert level user of technological gadgets. (5)