she ji
[ʃə: dʒi:]

Characterizing Interaction Design by Its Ideals: A Discipline in Transition

Kristina Höök
Jonas Löwgren

Keywords
Interaction design
Ideals

Received
January 30, 2020
Accepted
December 22, 2020

KRISTINA HÖÖK
Media Technology and Interaction Design, Royal Institute of Technology (KTH), Sweden (corresponding author)
khook@kth.se

JONAS LÖWGREN
Media and Information Technology, Linköping University, Sweden
jonas.lowgren@liu.se

Abstract
As a way to capture a broadly acceptable high-level characterization of design, we focus on the guiding values or ideals of the discipline. We first reason from the notion of engineering interfaces for usability and utility up to the 1990s to the current ideal of designing interfaces for experience and meaning. Next, we identify three recent technical and societal developments that are challenging the existing ideals of interaction design, namely the move towards hybrid physical/digital materials, the emergence of an increasingly complex and fluid digital ecology, and the increasing proportion of autonomous or partially autonomous systems changing their behavior over time and with use. These challenges in turn motivate us to propose three directions in which new ideals for interaction design might be sought: the first is to go beyond the language-body divide that implicitly frames most of our current understandings of experience and meaning, the second is to extend the scope of interaction design from individual interfaces to the complex sociotechnical fabric of human and nonhuman actors, and the third is to go beyond predictability by learning to design with machine learning.

http://www.journals.elsevier.com/she-ji-the-journal-of-design-economics-and-innovation
https://doi.org/10.1016/j.sheji.2020.12.001

Introduction

This article was written to address the question "What is design?" This kind of question comes up from time to time in every field, and asking the question is a way to ask what it is that we are doing. Predictably, we find the question far too intimidating to address head on. In order to contribute to the understanding of what design is, and what distinguishes it from other fields, disciplines, and practices, we have chosen a reflective case study approach of sorts, where we try to articulate some core traits of our own design discipline. Our aim is to provide an example of how one design discipline might answer the question of what design is, and that the example can be reconciled with other accounts to gradually build a larger picture of design across the specific disciplines.

Both authors represent the field of interaction design, a recent addition to the ever-growing list of design disciplines, which can be characterized loosely as the shaping of digital things for people's use.[1] We have been active as designers, teachers, and researchers since the late 1980s, predominantly in academic environments. During this time, we have acquired a certain sense of the distinctive traits of the discipline of interaction design.

This is not to say that there is a simple and homogeneous notion of what interaction design is, to be sure. But we feel that there are some guiding values, or ideals, that most members of the interaction design discipline would consider to be typical, even if they do not necessarily support them fully. By framing what those ideals are and why they are questioned, we address what interaction design is — the problems, societal changes, and technological developments the field is grappling with, and also what designing entails in interaction design.

We find that the ideals of interaction design are changing quite rapidly. This may be due to the relative immaturity of the discipline, with its origins dating back only thirty-odd years, or perhaps a case of working with rapidly developing material, and ever new technical possibilities and challenges. Or it follows from our aiming to provide useful and meaningful results in a rapidly changing society — a phenomenon in no small part due to those very same interactive technologies entering or even disrupting all sorts of processes in society. Or it may simply be that flux is a normal state for any design discipline to find itself in. Whatever the reason, our communicative task is somewhat akin to hitting a moving target.

Rather than attempting to disentangle these complex drivers of change, we choose to focus solely on technological advances as a means of framing and understanding why these ideals not only *are* changing, but *must* do so.[2]

Interaction design was once clearly delimited to digital materials — computers enabling services, where interaction happens through a screen (and possibly speakers) using mouse and keyboard as input devices. Since the early days of interaction design, computer processors, sensors, and actuators have become miniaturized; the capacity of computer systems has dramatically increased; and computers and services have become networked. The miniaturization of technology has enabled a range of hybrid physical/digital materials where tiny processors, actuators, and sensors are embedded in other materials. Networked processing capacity has led to

1 Jonas Löwgren, "Interaction Design — Brief Intro," in *The Encyclopedia of Human-Computer Interaction*, 2nd ed. (Interaction Design Foundation, 2013), https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/interaction-design-brief-intro.

2 Similar arguments have been made by Liam Bannon, in "Reimagining HCI: Toward a More Human-Centered Perspective," *Interactions* 18, no. 4 (2011): 50–57, DOI: https://doi.org/10.1145/1978822.1978833; and Yvonne Rogers, in "New Theoretical Approaches for Human-Computer Interaction," *Annual Review of Information Science and Technology* 38, no. 1 (2004): 87–143, DOI: https://doi.org/10.1002/aris.1440380103.

the emergence of an increasingly complex and fluid digital ecology where services are tightly interlinked, functioning across different hardware platforms. The increased capacity of networked computers has enabled data-driven AI-solutions, allowing for an increasing proportion of autonomous or partially autonomous systems changing their behavior over time and with use. Digital material is no longer delimited to a tight interaction between a user and some services. Novel digital materials demand novel design ideals.

Our approach is to start with a historical sketch of the progression towards the current ideals of interaction design. We then identify three contemporary technological developments that are challenging the discipline in a number of ways. First, interaction design's existing ideals clash — or even contradict — what these materials afford. For example, interaction design emphasizes predictability in an interface so that users know what happens next, but the whole point of autonomous systems is that they may change over time, inherently making future interactions unpredictable. Second, some design methods employed in the field no longer apply. For example, the prevailing research through design (RtD) stance[3] emphasizes designing standalone systems, fully integrating an intended functionality, which does not cater for how the design must integrate with other services, platforms, and technologies. Third, the theoretical foundations of the field place user needs at the center stage, but many interactions will instead place technology on par with, or even governing how a task is performed. To address some of these challenges, we suggest three new directions that we believe hold promise as eventual sources of inspiration for novel ideals the field can use today. Our hope is that this map can be the interaction design piece in the larger puzzle that is understanding of what design is and where its lines of demarcation sit at this particular moment in time.

A (Very) Brief History of Interaction Design

Interaction design is a young discipline, as mentioned earlier, originating primarily from the academic subject of human-computer interaction (HCI), which in turn emerged at the intersection of computer science with cognitive science and human factors. HCI started to attract attention in the late 1970s and early 80s, at a time when computers were used almost exclusively as professional tools for calculation and data processing. In this context, the aim for human-computer interaction was to design computers and software such that people could carry out their tasks efficiently and accomplish their goals effectively. These instrumental ideals dominated what Suzanne Bødker[4] calls the first wave of HCI, focusing on humans as subjects for experimentation and modelling, as well as the second wave, where the focus turned to groups of people in their actual work environments. We might summarize the interaction designs at this level as "engineering interfaces for usability and utility."

Then, computers moved out of factories and offices and into homes and public spaces, and onto people's bodies, to be used in all kinds of situations for all kinds of purposes — most importantly, at the individual's discretion.

3 John Zimmerman, Jodi Forlizzi, and Shelley Evenson, "Research Through Design as a Method for Interaction Design Research," in *CHI '07: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York: ACM, 2007), 493–502, DOI: https://doi.org/10.1145/1240624.1240704; Johan Redström, *Making Design Theory* (Cambridge, MA: MIT Press, 2017).

4 Susanne Bødker, "When Second Wave HCI Meets Third Wave Challenges," in *NordiCHI '06: Proceedings of the 4th Nordic Conference on Human-Computer Interaction: Changing Roles* (New York: ACM, 2006), 1–8, DOI: https://doi.org/10.1145/1182475.1182476.

As long as we focus on tools for work, it makes sense to talk about the efficient execution of tasks and the effective achievement of goals. But leisure, play, and everyday communication are driven largely by intrinsic motivation and hedonistic values. As argued by Bødker,[5] and supported by Steve Harrison and colleagues'[6] parallel and complementary line of reasoning, the third wave of HCI formed around the ideals of user experience and meaning making.

Working on the shaping of digital things for people's everyday use at home or on the move also meant that our discipline came in much closer contact with product design, industrial design, graphic design, architecture, and other mature design disciplines where experience and meaning have been prioritized concerns for a long time. It is arguably fair to claim that this was the period in which interaction design started consolidating itself more broadly as a design discipline. This entailed appropriating more designerly ways of working, teaching, and producing academic knowledge.

To summarize, interaction design as a discipline in 2020 is characterized by rather widespread professional adoption, where UX designers and (digital) product designers are involved in determining the behavior and appearance of more or less all digital things being produced. It is an established discipline in higher education, taught in schools of engineering, design, and art around the world. It is a vital research field, drawing on its solid academic heritage from HCI but also increasingly orienting itself towards the increasing academization of the traditional design disciplines. In terms of scope, interaction design still concentrates largely on the interfaces between people and devices (including, of course, the functions and features that the device provides for its users), and the details of the interaction. If interaction design today can be said to have one dominating ideal, it might be summarized as "designing interfaces for experience and meaning."

Current Challenges for Interaction Design

Interaction design concerns the shaping of digital things for people's use. But "digital things" is not a very stable concept. As any design discipline, interaction design is conditioned by its materials — and digital materials are changing and evolving rapidly, due to technological advances and emergent forms of use and appropriation.

We observe three ways that digital things are creating new conditions for interaction design. First, the material objects of interaction design used to consist of custom software running on generic hardware, always involving glass screens — now we are moving beyond the borders of the screen towards interactive, hybrid physical/digital design materials. Second, a digital thing used to be a standalone product with its own value proposition and design specs, developed in line with a hard delivery date — now every job has become an unpredictable intervention inside a complex and fluid digital ecology of digital services and hardware platforms. And finally, the digital thing used to be a predictable tool for instrumental use — but recent developments in AI and machine learning are hinting at partially autonomous systems with behaviors and capabilities that change over time and with use.

5 Bødker, "When Second Wave HCI Meets Third Wave Challenges."

6 Steve Harrison, Deborah Tatar, and Phoebe Sengers, "The Three Paradigms of HCI" (paper presented at alt.chi — CHI '07, Session at the SIGCHI Conference on Human Factors in Computing Systems, San Jose, CA, USA, April 28, 2007), 1–18, available at https://people.cs.vt.edu/~srh/Downloads/TheThreeParadigmsofHCI.pdf.

Beyond the Borders of the Screen

Hybrid physical/digital materials are finally becoming a reality for interaction design. For example, shape-changing interfaces[7] make it possible to dynamically change the form of physical objects.

Recent trends in material science, using fluid or organic materials to create soft sensors and actuators, allows for miniaturized, extremely dense sensor-actuator networks, in turn significantly pushing the boundaries for computation and communication. We have shifted away from digital interactions solely enabled by computers and radio waves. Instead, communication between nodes in these dense sensor-actuator networks might take place through light or sound, or even based on the movements of our bodies, creating contacts if and when we move. Computation may be enacted through (for example) valves opening or closing in the material. These possibilities enable a plethora of materials relying on wireless ad hoc networks of low-power sensor nodes or intelligent devices that are embedded into wearables and gadgets, woven into our clothing, affixed on our skin, and implanted in our bodies.

These developments, combined with advances in multimodal interaction and distributed communication infrastructures, point to how the domain of body-, movement-, and biosensor-based interactions is a growing and important interaction design field. This topic moves interaction design even closer to product design but also requires engagement with movement-based crafts and bodily practices. It affects a range of domains, such as work tasks, crafts, exertion games, arts, and health.

Emergent Systemic Properties

The proliferation of the Internet—especially high-speed, mobile Internet—is contributing to an increasingly ubiquitous global digital infrastructure. This in turn fuels the increased use of digital products and services, to the extent where they can be truly considered pervasive in many parts of the world. The consequences of this development for interaction design are considerable.

There is arguably a majority orientation within interaction design towards the creation of isolated products, one at a time. This is a natural consequence of focusing on device interfaces and the details of the interaction, and it is underlined by the recent industry trend of UX designers starting to identify themselves as product designers. But it is becoming increasingly difficult to practice in situations where users spend much of their time in complex multifaceted ecologies of digital infrastructures, products, and services.

A simple illustration of the challenge would be an ordinary smartphone. The user expects to move effortlessly between tens or hundreds of apps throughout the day, even though most of the apps were designed in isolation and without complete knowledge of the specific micro-environment in which the app would be used. What did the user do before using our app? What will they do after? What expectations and interaction habits have they formed by using other apps? How will they modify the settings of the app, and the phone's operating system, to suit their personal preferences

7 Marcelo Coelho and Jamie Zigelbaum, "Shape-Changing Interfaces," *Personal and Ubiquitous Computing* 15, no. 2 (2011): 161–73, DOI: https://doi.org/10.1007/s00779-010-0311-y; Jason Alexander et al., "Grand Challenges in Shape—Changing Interface Research," in *CHI '18: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (New York: ACM, 2018), paper no. 14, DOI: https://doi.org/10.1145/3173574.3173873; Hiroshi Ishii et al., "TRANSFORM: Embodiment of 'Radical Atoms' at Milano Design Week," in *CHI EA '15: Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (New York: ACM, 2015), 687–94, DOI: https://doi.org/10.1145/2702613.2702969.

and needs? These are only the questions pertaining to the detailed interface design of an app.

We must also consider that the user's smartphone will be collecting unknown quantities of interaction and location data that we would like to use to create individual value through personalized and adaptive app functions. Controlling a large enough portion of the aggregated data and infrastructure may be a competitive advantage or even ultimately a necessity, as in the case where Google Maps is sometimes already able to provide more useful travel plans than the local public transportation app. Moreover, we are often facing the task of designing a collaborative media platform[8] where the actual content of the app — and hence its value in use — are produced by other users in communicative processes extending over long periods of time.

On the whole, it is clear that the emergent and systemic properties of the overall digital ecology inhabited by the user are very hard to grasp for any designer aiming to formulate a value proposition and a design specification for an isolated mobile app to be developed and delivered according to a fixed deadline. It is no longer clear how much control an individual interaction designer has over the user experience of a digital product in a particular use situation. As a corollary, it is no longer clear how much agency rests with the interaction designer when it comes to shaping digital things for people's use.

Artificial Intelligence

The field of Artificial Intelligence (AI) was inaugurated some 70 years ago and has largely worked in two main areas. One is oriented towards understanding and emulating human intelligence, whereas the other (which is more relevant to us here) aims at developing autonomous or partially autonomous system components to perform tasks for our benefit. In recent years, innovation in machine learning techniques have enabled major advances in the automation of perception and pattern recognition in application domains such as natural language processing, image analysis, and data mining. This in turn makes it possible for systems to generate output such as language, images, and control signals. Often this means that a system may rely on machine learning to drive one or several of its subcomponents: it may appear in music recommendations, it may run in the background of a map direction system, or it may have labelled photos automatically to make them searchable. In addition to such mundane machine learning applications, novel advances have formed the basis for much aspiration and speculation about the potential autonomous systems have to perform a variety of human tasks, such as driving a car or serving customers in a support center.

Even if much of this speculation is inflated and unwarranted, the notion of non-human actors helping people with various tasks, or even doing the tasks for them, is very much a factor in contemporary interaction design discourse. The heritage of HCI developed around the perspective of computers as malleable tools for people's instrumental use. Artificial Intelligence introduces an assumed level of agency in the computers that HCI, and, by extension, interaction design is not very well prepared to deal with. As Jonathan Grudin[9] points out, there seems to be a historical pattern of ebb and flow between the autonomous agents' perspective and the

8 Jonas Löwgren and Bo Reimer, *Collaborative Media: Production, Consumption, and Design Interventions* (Cambridge, MA: MIT Press, 2013).

9 Jonathan Grudin, "AI and HCI: Two Fields Divided by a Common Focus," *AI Magazine* 30, no. 4 (2009): 48. DOI: https://doi.org/10.1609/aimag.v30i4.2271.

malleable tools one, where great hope in the potential of AI implied less resources devoted to HCI, and vice versa. The first wave of AI hype held that AI could compensate for human inadequacies and automate tasks to the extent that HCI would become a non-topic. The subsequent "AI winter" entailed the realization that it was probably too early to discard human-centered design. The current AI hype around machine learning similarly promotes automation.

The difference between the current wave of interest in AI and earlier ones is arguably that the non-human actors are now much closer to our everyday lives. The most obvious illustrations are self-driving cars and voice-controlled personal home assistants, even though more mundane and embedded applications driving customized search engine outputs and advertising in digital media are much more ubiquitous and perhaps also of greater significance on the whole.

What is challenging the status quo of interaction design, then, is how interactive systems containing machine learning components have the ability to change and develop over time depending on how they are used. This in turn makes it hard for designers to engage with AI as a material—often referred to as designing with data in the field. Designers—humans—look for correlations and patterns that fit with their understanding of how the world works. Machine learning, on the other hand, finds machine-recognizable correlations and patterns in data, sometimes appearing strange in the eyes of a designer, and even creating bizarre errors. Second, machine learning means that system functionality—not just data—will evolve over time. Design becomes more like non-design—we leave space for machine learning to do its thing.

In sum, we find that autonomous or partially autonomous systems are entering the realm of contemporary interaction design, introducing questions that the discipline is not very well prepared to address. To echo Grudin's argument, interaction design is currently at a point where we need to start designing by orchestrating the interaction with ensembles of more or less autonomous components.

Towards New Ideals for Interaction Design

So far, our claim is (1) that the discipline of interaction design is currently dominated by the ideal of designing interfaces for experience and meaning, but (2) it is also currently in transition, facing a threefold challenge in terms of recent developments in hybrid physical/digital materials, an increasingly complex sociotechnical fabric, and increasingly autonomous systems.

In recent years, the interaction design discipline has been searching high and low for new and more appropriate theoretical frameworks moving us beyond usability and utility ideals; some examples include embodied interaction,[10] pragmatist accounts of experience,[11] post-phenomenology,[12] and the material turn.[13]

To us, this suggests that the dominating ideal of interaction design is perhaps becoming outdated. The approach we take in the following sections is simply to suggest three ways of extending the dominant interaction design

10 Paul Dourish, *Where the Action Is: The Foundations of Embodied Interaction* (Cambridge, MA: MIT Press, 2001).
11 John McCarthy and Peter Wright, *Technology as Experience* (Cambridge, MA: MIT Press, 2004).
12 Don Ihde, *Postphenomenology: Essays in the Postmodern Context* (Evanston, IL: Northwestern University Press, 1995); Robert Rosenberger and Peter-Paul Verbeek, eds., *Postphenomenological Investigations: Essays on Human-Technology Relations* (Lanham, MD: Lexington Books, 2015).
13 Mikael Wiberg, *The Materiality of Interaction: Notes on the Materials of Interaction Design* (Cambridge, MA: MIT Press, 2018).

ideal. One is to go beyond the language-body divide that implicitly frames most of our current understandings of experience and meaning. Another is to extend the scope of interaction design from individual interfaces to engage with the complex sociotechnical fabric of human and nonhuman actors. The third is to go beyond predictability in learning to design with machine learning.

To state the obvious, there is no deductive path leading to these exact directions even if the characterization of the current state of the discipline and its challenges is accepted. What we are doing in this section is merely to draw upon our experience as long-standing members of the interaction design discipline to indicate directions we think might be fruitful as well as potentially actionable.

Most importantly, it is a way for us to address the question of how to define and demarcate (interaction) design. Ours is a subjective account of some shortcomings in the interaction design discipline's current self-conception.

Designing for the Whole Person: Soma Design and Other Frameworks

The shift from predominantly screen-based interactions[14] to new materials embedded in everything asks for novel ways of doing interaction design for the whole body — all our senses — bridging the language-body-divide that permeates most interaction design today.

The origins of this shift can be found in work by Marc Weiser on ubiquitous computing.[15] He saw the potential to make digital interactive processes part of everything, everywhere. This was picked up by Paul Dourish in his seminal work *Where the Action Is*. Dourish offers readers a theoretical, phenomenological lens through which to see what it would mean to live interaction everywhere; he calls this embodied interaction.[16] An embodied interaction, to Dourish, is an engaged one. People create, manipulate, and change meaning during their bodily experience with artifacts. Granted, Dourish was writing about design(ing) in and for information-intensive environments, where the limits of human cognition and available data — both constantly changing — are often the fluid boundaries of a project's scope. Nevertheless, considering how the artifact/system will be integrated by (not only human) systems as experience, learning, meaning, and material impact in the world is likely important for any design process.

Dourish's argument sparked a wave of creativity and a new approach that has been very useful to interaction design. But the very notion of embodied interaction implies that interactions between users and designs can be disembodied at times — which is never the case. As humans, we are always embodied, always in the world, always part of a social context, always moving our bodies, always in contact with a range of designed tools that our culture offers. This is the case even though some tools are badly designed, while other tools fit perfectly with the task and context. By placing the word "embodied" in front of other nouns, such as design, robot, or application, are we really on the road to better design? Or are we reemphasizing a dualistic stance? In short, Dourish's embodied interactions did not provide us with

14 Lars-Erik Janlert and Erik Stolterman, "Faceless Interaction — A Conceptual Examination of the Notion of Interface: Past, Present, and Future," *Human-Computer Interaction* 30, no. 6 (2015): 507–39, DOI: https://doi.org/10.1080/07370024.2014.944313; Wendy Ju, "The Design of Implicit Interactions," *Synthesis Lectures on Human-Centered Informatics* 8, no. 2 (2015): 1–93, DOI: https://doi.org/10.2200/S00619ED1V01Y201412HCI028.

15 Mark Weiser, "The Computer for the 21st Century," *Scientific American* 265, no. 3 (1991): 94–105, DOI: https://www.jstor.org/stable/24938718; Yvonne Rogers, "Moving on from Weiser's Vision of Calm Computing: Engaging Ubicomp Experiences," in *UbiComp'06: Proceedings of the 8th International Conference on Ubiquitous Computing* (Orange County, CA: Springer-Verlag, 2006), 404–21, DOI: https://doi.org/10.1007/11853565_24.

16 Dourish, *Where the Action Is*.

any ideals for what to design, beyond recognizing that any technology will be part of us as well as part of the context we live in.

Furthermore, since Dourish's book was published in 2001, more and more close-to-the-body technologies have arrived on the scene—interactive textiles, sensors, position-based interactions, remote controls, and so on. These novel materials, alongside the need to address the mind-body divide, demand novel ideals.

One proposed design framework addressing this rift is soma design.[17] Soma design builds on two pillars defining the human condition. The first is the primacy of movement[18] arguing that human perception and reasoning is first and foremost grounded in movement. Without movement, there is no life, no perception, no experience. It is in movement that meaning making arises. Furthermore, movement is always varied, always adapting, and always in dialogue with the changing world around us. Intelligence is enacted in action in and through movement.[19]

More importantly, soma design argues that deepening our awareness of our own proprioceptive and sensorial bodily engagements with the world enables us to enhance intelligence, meaning making, and a richer, deeper engagement with ourselves, one another, and the world.

This is the core of the second pillar in soma design: somaesthetics, a pragmatist theory: soma + aesthetics.[20] Richard Shusterman associates soma with bodily subjectivity—a living, purposive, sentient, perceptive body, in which movement, corporeality, emotion, cognition, perception, and sociality are tightly interlinked. That contrasts with a perspective in which we separate intellectual reasoning from our bodily realities, or an ethnographic perspective in which we do not speculate on the inner, subjective experiences of people. It is a full recognition of our subjective selves.

Aesthetics, in turn, is a notably complex concept, taking on many different meanings depending on the purpose and context. Shusterman approaches aesthetics as an active skill, an ability to appreciate through all our senses—an ability that can be trained and sharpened. He argues that if we develop our perception and senses through close attention to our experiences, we can reap from them more richness, depth, and interest. If, for example, we attend to how we eat food, we can more richly experience its texture, taste, fragrance, its movement from the plate to our mouth, the way we swallow, and the overall sensation of letting food enter into our body.

Beyond this firm grounding in human morphology and somaesthetic appreciation ideals, the soma design framework imparts an active, creative design attitude. The fundamental promise of soma design is that if designers train their own somaesthetic sensibilities—engaging in form-giving processes, gaining tacit knowledge of the technological materials at hand—they can learn how to better shape the somaesthetics of the whole interaction gestalt,[21] in turn spurring improved aesthetic engagement for users.

In a sense, as designers, we leave behind a set of sedimented movements embedded in the particulars of the designed system that will literally shape users' somas—affecting muscles, nervous system reactions, behaviors, experiences, and feelings, influencing users' capacity for aesthetic appreciation. Hence, when designing, the material being shaped is both the

17 Kristina Höök, *Designing with the Body: Somaesthetic Interaction Design* (Cambridge, MA: MIT Press, 2018).

18 Maxine Sheets-Johnstone, *The Primacy of Movement* (Amsterdam: John Benjamins Publishing, 2011).

19 Lucy A. Suchman, *Plans and Situated Actions: The Problem of Human-Machine Communication* (Cambridge: Cambridge University Press, 1987); Sheets-Johnstone, *The Primacy of Movement*; James J. Gibson, *The Ecological Approach to Visual Perception*, Classic ed. (New York: Psychology Press, 2015).

20 Richard Shusterman, *Body Consciousness: A Philosophy of Mindfulness and Somaesthetics* (Cambridge: Cambridge University Press, 2008).

21 Youn-kyung Lim et al., "Interaction Gestalt and the Design of Aesthetic Interactions," in *DPPI '07: Proceedings of the 2007 Conference on Designing Pleasurable Products and Interfaces* (New York: ACM, 2007), 239–54, DOI: https://doi.org/10.1145/1314161.1314183.

close-to-the-body technologies, but also designers' and users' somatic selves. Both are subject to change. They form an entanglement of soma and technology, interacting and changing over time.

In summary, soma design shares the same roots as Dourish's notion of embodied interaction, but offers a clear direction, an ideal, as it speaks of "designing interactions to improve our somatic selves, deepening our aesthetic appreciation" in order to lead a better, richer life with interactive technologies.

Soma design is not the only framework that has been proposed in order to handle the challenges that arrives with materials beyond the borders of the screen. For tangible interactions, Ylva Fernaeus and colleagues propose engaging with a practice turn,[22] shifting from individual use to collective action, from objective to subjective, and from information to interaction. Daniel Fallman,[23] on the other hand, draws on Borgmann[24] to introduce ideals related to authenticity and being in contact with the material world instead of putting layers between ourselves and the material world.

Designing the Sociotechnical Fabric: Post-Phenomenology and Other Frameworks

At the macro level, we seem to be ever more deeply embedding ourselves in a complex ecology or sociotechnical fabric of people, digital infrastructures, tools, services, and partially autonomous and fully autonomous agents. Communication and action happen in transient constellations and more persistent ensembles of all these components. Everything is connected to everything else; the paths of various stakeholder groups keep crossing; conflicting agendas intersect at every point of contact.

Interaction design is supposed to be a discipline that specializes in shaping digital things for people's use, but how can interaction designers plan and act when the things they aim to shape are connected to a plenitude of other things; when things behave autonomously and opaquely; when they are situated at the nexus of opposing interests?

We believe that interaction design, perhaps like other design disciplines, needs to think of design as a work in progress. In the context of the then-emerging Internet infrastructure enabling software as a service, the mid-00s notion of Web 2.0 included a challenge to established software development practices by arguing for rapid iterations with users engaged as co-developers.[25] Since then, the idea of perpetual beta has become a commonplace conceptualization of the interaction design of online software, through many iterations of users-facing functions and behaviors. Interaction design has a long tradition of user testing, of course, which was assimilated seamlessly in iterative development of online software. But more importantly, innovation in this context was not limited to designers seeking answers to known questions. Instead, the notion of the designer in control was increasingly challenged by various propositions introduced by the ideas of lead users[26] and open innovation.[27] A well-known example is the hashtag function on Twitter, developed by early adopters, which was picked up by the developers and quickly became an indispensable part of the core functionality of the Twitter sub-ecology of content and services.[28]

22 Ylva Fernaeus, Jakob Tholander, and Martin Jonsson, "Towards a New Set of Ideals: Consequences of the Practice Turn in Tangible Interaction," in *TEI '08: Proceedings of the 2nd International Conference on Tangible and Embedded Interaction* (Bonn, Germany: Association for Computing Machinery, 2008), 223–30, DOI: https://doi.org/10.1145/1347390.1347441.

23 Daniel Fallman, "The New Good: Exploring the Potential of Philosophy of Technology to Contribute to Human-Computer Interaction," in *CHI '11: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York: ACM, 2011), 1051–60, DOI: https://doi.org/10.1145/1978942.1979099.

24 Albert Borgmann, *Technology and the Character of Contemporary Life: A Philosophical Inquiry* (University of Chicago Press, 1987).

25 "What Is Web 2.0 — O'Reilly Media," accessed January 29, 2020, https://www.oreilly.com/pub/a/web2/archive/what-is-web-20.html.

26 Eric von Hippel, "Lead Users: A Source of Novel Product Concepts," *Management Science* 32, no. 7 (1986): 791–805, DOI: https://doi.org/10.1287/mnsc.32.7.791.

27 Henry W. Chesbrough, *Open Innovation: The New Imperative for Creating and Profiting from Technology* (Boston, MA: Harvard Business Press, 2003).

28 Löwgren and Reimer, *Collaborative Media*.

Similarly, the direction and development of a collaborative media initiatives are more often than not shaped by loose networks of evangelists and influencers having only indirect ties with the provider of the technical platform in question.[29] What these and other examples show is design engaging in shaping a complex sociotechnical fabric rather than executing a process to meet a delivery deadline, and where designers play new roles as catalysts and facilitators rather than specifiers of function and givers of form.

The sociotechnical fabric contains many elements. Interaction design allows us to shape some of them, but not all. Many groups of stakeholders are woven into the fabric, each with the capabilities and power to shape different parts of it. Design in this context amounts to the drawing together of stakeholders to catalyze and facilitate changes in and transformation of that fabric—a practice known as infrastructuring.[30] More often than not, stakeholders have conflicting agendas. Agonistic and deliberative processes are of the essence.[31]

One theoretical framework gaining traction in interaction design is the post-phenomenology of Don Ihde,[32] Peter-Paul Verbeek[33] and others. While phenomenology studies the relation between humans and the world to find what it means to be human, post-phenomenology looks at all the different relationships humans, technologies, and the world can be in. By understanding technologies as non-neutral mediators, post-phenomenology differs from other prevailing theories that place human agency at their core. Ihde proposes four main ways technology mediates human relationships: as embodiment; as a hermeneutic relation; as residing in the background; or as alterity.[34] Embodied relations are characterized by a symbiosis of a person and a technology, such as eyeglasses. Hermeneutic relations let us see the world through a technology, such as with a thermometer. Background relations reside in the periphery of human attention, such as the heating system of our home. Finally, the alterity relationship occurs in situations where the technology itself is in focus and the rest of the world is only a distant referent. The technological artifact becomes the other, as in the case of intelligent robots.

Defining different relationships between humans, technology, and the world helps us see that the ideals of interaction design in complex sociotechnical settings may need to be less unequivocal. For example, designing a piece of intended background technology should perhaps focus on making it unremarkable and properly receding into the background, rather than emphasizing its instrumental tool properties or its ability to engage and provide a meaningful experience.

The complexity of the sociotechnical fabric in which interaction design finds itself clearly precludes any simple, prescriptive recommendations for new ideals. Our summary at this point amounts to the recognition that "interaction designers need to think of their work as interventions into ongoing transformations over which they have only limited control."

Designing with Machine Learning: Leaving Predictability Behind

Artificial Intelligence is another technological advancement that puts the

29 Löwgren and Reimer, *Collaborative Media*.
30 Erling Björgvinsson, Pelle Ehn, and Per-Anders Hillgren, "Agonistic Participatory Design: Working with Marginalised Social Movements," *CoDesign* 8, no. 2-3 (2012): 127–44, DOI: https://doi.org/10.1080/15710882.2012.672577.
31 Thomas Binder et al., *Design Things* (Cambridge MA: MIT Press, 2011).
32 Ihde, *Postphenomenology*.
33 Peter-Paul Verbeek, "Materializing Morality Design Ethics and Technological Mediation," *Science, Technology, & Human Values* 31, no. 3 (2006): 361–80, DOI: https://doi.org/10.1177/0162243905285847.
34 Ihde, *Postphenomenology*.

user centered, tool based ideals into question. Ever since the earliest AI wave, it has been clear that old usability ideals do not work in AI-based systems. For example, the first author discussed how AI upturns usability principles derived from the ideals of the engineering era — control, predictability, transparency, trust, and reversibility — way back in 1990.[35] The whole point of an interface building on learning is that it will change and drift with the data, thereby losing predictability. Many AI systems act as agents with their own intentionality, in turn breaking the idea of a tool over which users have total control and where the tool is transparent in its inner workings. Actions taken are sometimes not reversible. As the first AI wave mainly offered rule-based solutions that did not really scale, the risk of erroneous behavior was way higher than what we get with the AI solutions building on massive amounts of data feeding statistically-based machine learning we see today. In that sense, loss of trust is reduced, but when something goes wrong, the (partially) autonomous systems are even more opaque and mysterious to both users and designers.

But what about the current interaction design ideals of *experience* and *meaning*? Can the contemporary AI wave contribute to those ideals or do they need to be rearticulated or even changed?

Grudin argued in 2009 that a marriage between AI and interaction design would be possible when machine learning becomes available (and affordable) on PCs, smartphones, and other platforms of interest to interaction design[36] — an effect we can already see today. AI-based functions such as facial recognition, speech, translation, and image recognition, and outputs like deepfakes and recommenders are commonplace. Oftentimes such functions harmonize with the current interaction design ideals, emphasizing experience and meaning, aiming to create delight and personalization. The fact that they are like black boxes that cannot be inspected or explained does not (seem to) trouble users much — at least not in those situations. We may speculate, however, that there is a certain amount of infatuation at work and in fact, critical voices are starting to be heard on the uses and implications of AI functionality in everyday life. One obvious example, drawing much recent attention, would be the echo chambers created by automatically curated social media feeds.

Furthermore, novel platforms embodying different autonomous behaviors are becoming commonplace, such as personal home assistants, robotic vacuum cleaners, robotic lawn mowers, and self-driving cars. This has forced interaction design to take note, spurring a lively debate on how to design with data and machine learning. More importantly, the general public has started to get used to interaction ideals that speak of *delegation* of certain tasks and sometimes even full *automation*. Interaction design researchers discuss ideals such as "implicit interactions"[37] — interactions that reside in the background, following users' activities, learning, adapting, but without explicitly interacting using the otherwise prevalent dialogue-model that most direct manipulation interfaces build on. The calm computing ideal proposed by Mark Weiser and John Brown in 1997 is frequently mentioned.[38] But as discussed by Yvonne Rogers,[39] calm computing interactions are not what we got, and for many reasons highly unlikely to be what we will get as

35 Kristina Höök, "Steps to Take before Intelligent User Interfaces Become Real," *Interacting with Computers* 12, no. 4 (2000): 409–26, DOI: https://doi.org/10.1016/S0953-5438(99)00006-5.
36 Grudin, "AI and HCI."
37 Ju, "The Design of Implicit Interactions."
38 Mark Weiser and John Seely Brown, "The Coming Age of Calm Technology," in *Beyond Calculation* (New York: Springer, 1997), 75–85, DOI: https://doi.org/10.1007/978-1-4612-0685-9_6.
39 Rogers, "Moving on from Weiser's Vision of Calm Computing."

there is no commercial value in designing interactions that are not trying to attract users' attention.

When AI is used in professional situations to support decisions with real and sometimes grave consequences, there is (predictably) a greater concern for transparency and accountability. Much research is currently being devoted to what is called "explainable" AI, even though it is still largely an open question what it means for an AI to explain, and indeed whether explanation is the most appropriate conceptual model at all for building trust and accountability in support of decision making. Other approaches may be more apposite for designing reasonable ensembles of human and non-human actors. In the related field of human factors, for example, we notice with interest that the old concept of human-in-the-loop—with its implicit focus on automation and allocation of tasks between operator and system—is being refined into a more complex view of networks of human and non-human actors.[40] Similarly, recent research in decision support offers the more concept of algorithm-in-the-loop as a more user-focused alternative.[41]

To summarize, we find that recent developments in AI are posing serious questions to the conceptual foundations of interaction design, and interaction design is currently debating those questions with some vigor. It would be premature to point to any specific emerging ideals, but we find it relatively clear that the notion of non-human actors in our sociotechnical fabric is taking on a much more concrete and literal meaning in the form of autonomous or semi-autonomous systems.

Tying Together

The three directions we have indicated here do not seem to be closely related in any obvious way. One is turning inward, focusing on the felt bodily experience of individuals, whereas the second and the third appear to be extending out towards all of (technology-infused) society. However, as is often the case in multilevel structures, the micro and the macro are interrelated—albeit sometimes in complex ways.

Soma design and related approaches to interaction design are characterized by a strong sense of empathy and compassion,[42] and it might seem like this is limited to a specific individual in a specific interaction situation. However, the individual whose bodily experience takes center stage in a soma design project is never only an individual, but always also an actor within the wider sociotechnical fabric. Providing "a path to living better lives through connecting with ourselves"[43] becomes a way of influencing the sociotechnical fabric in the vicinity of the individual involved in the seemingly narrowly defined design project at hand.

As an example, consider the interaction design work of Raune Frankjaer and specifically her *Flora Luma* project[44] revealing the "inner life" of plants by connecting them to EEG sensors and visualizing the captured signals in the form of temporal color patterns illuminating spherical forms handcrafted in fiber materials. Working on the project led Frankjaer herself to discover what she chooses to discuss in terms of sentience and awareness

40 Emilie M. Roth and Amy R. Pritchett, "Preface to the Special Issue on Advancing Models of Human–Automation Interaction," *Journal of Cognitive Engineering and Decision Making* 12, no. 1 (2018): 3–6, DOI: https://doi.org/10.1177/1555343417749192.

41 Ben Green and Yiling Chen, "The Principles and Limits of Algorithm-in-the-Loop Decision Making," *Proceedings of the ACM on Human-Computer Interaction* 3, no. CSCW (2019): article 50, DOI: https://doi.org/10.1145/3359152.

42 Höök, *Designing with the Body*.

43 Ibid., 206.

44 Raune Frankjaer, "Fostering Care and Peaceful Multispecies Coexistence with Agential Provotypes," in *Proceedings of ISEA 17* (Manizales, Colombia, June, 2017), available at https://www.researchgate.net/publication/318494034.

in regular house plants, including the unmistakable existence of a circadian rhythm and the ability of the plant to get used to being touched (by reacting less vividly over time to repeated touches). What is even more important, visitors to her exhibitions in public spaces reported similar insights and, in many cases, an increased sense of respect and awe for a fellow member of the ecology that was previously more or less seen as a commodity.

Of course, we have intentionally selected the *Flora Luma* example because it illustrates the point we want to make. With climate change becoming a mainstream topic in recent years, ecological sustainability may be one of the few areas in which the relation between the individual and the greater whole is actually felt and recognized by many. It should be possible for most readers to sense how spending time in a space where regular plants react in an evocative way to your presence and your physical actions (the individual bodily experience; the micro level) can do something for your subsequent views on nature and the coexistence of species within planetary boundaries (the sociotechnical fabric; the macro level).

Still, we believe that similar relations between micro and macro exist in many design situations. Articulating the ideals of designing for the whole person and designing the sociotechnical fabric (including non-human actors) can be a first step towards exploring their interrelations in other design situations, eventually leading to a revitalized discipline of interaction design built on empathy and compassion in the small as well as in the large.

However, some modesty is in order here. There are many situations in which the connections between micro and macro levels are, and perhaps always will be, emergent and impossible to predict. In such cases, design efforts can never amount to more than local interventions based on limited knowledge and some guiding values. The designers' degree of agency and control is inherently limited, as pointed out above. Still, we feel that an awareness of the small as well as the large must be a useful starting point for doing the best we can.

In Conclusion

In an attempt to address the question of what design is and how it is delimited, we have chosen a case study approach of looking at the current state and some possible future trajectories of the interaction design discipline.

By letting design ideals serve as a lens to characterize interaction design, we have started unpacking a field in flux with an ongoing lively debate on what we can and should be designing. The foundations of interaction design are being questioned, even to the point of what some call an existential crisis.[45] While it used to be shaping of dialogue-based interactions through a glass interface aiming to let users work efficiently, later expanding to meaningful experiences in all walks of life, the field now faces a whole range of challenges.

We argue that on a micro scale, new hybrid digital/physical materials are shifting our attention from glass interfaces to physical-bodily interactions. On a macro scale, whole ecologies of artifacts and services linked together by infrastructures challenge a design practice geared for producing one

45 Janlert and Stolterman, "Faceless Interaction."

design at a time. And the recent developments in AI imply a new and still somewhat bewildering notion of what non-human sociotechnical actors might be.

For the foreseeable future, many domains will be best served by usability- or user-centered design practice aimed at delivering effective tools and meaningful experiences. But the technological advances and changes in society that we have discussed also demand novel design ideals, making interaction design even more diverse. Frameworks such as soma design, infrastructuring, or post-phenomenology introduce other ways of designing, other demands on interdisciplinary knowhow, other material explorations, sometimes even aiming for non-design or design where the human user is no longer at the core. Moreover, collaboration with other design disciplines and other change making practices in society increasingly seems to be necessary rather than optional.

To the question of what interaction design is, our tentative answer would be: it is a field that seems to change in the wake of emerging materials and technologies, where the resulting designs penetrate one use domain after another, therefore constantly requiring new ideals, new design frameworks, and novel interdisciplinary knowhow. But in the midst of all this change, we believe that interaction designers will continue to serve as catalysts of the ongoing interplay involving human and nonhuman actors, driven by empathy and compassion to care for the human condition—our corporeality, experience, and how practice and culture complete us.

Acknowledgments

This work was supported by Swedish Research Council project 2016-04709; Swedish Foundation for Strategic Research project RIT15-0046; Knut and Alice Wallenberg Foundation project KAW 2015.0080; and Marianne and Marcus Wallenberg Foundation project MMW 2019.0228.

Declaration of Interests

There are no conflicts of interest involved in this article.

References

Alexander, Jason, Anne Roudaut, Jürgen Steimle, Kasper Hornbæk, Miguel Bruns Alonso, Sean Follmer, and Timothy Merritt. "Grand Challenges in Shape—Changing Interface Research." In *CHI '18: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, paper no. 14. New York: ACM, 2018. DOI: https://doi.org/10.1145/3173574.3173873.

Bannon, Liam. "Reimagining HCI: Toward a More Human-Centered Perspective." *Interactions* 18, no. 4 (2011): 50–57. DOI: https://doi.org/10.1145/1978822.1978833.

Binder, Thomas, Giorgio De Michelis, Pelle Ehn, Giulio Jacucci, Per Linde, and Ina Wagner. *Design Things*. Cambridge MA: MIT Press, 2011.

Björgvinsson, Erling, Pelle Ehn, and Per-Anders Hillgren. "Agonistic Participatory Design: Working with Marginalised Social Movements." *CoDesign* 8, no. 2–3 (2012): 127–44. DOI: https://doi.org/10.1080/15710882.2012.672577.

Bødker, Susanne. "When Second Wave HCI Meets Third Wave Challenges." In *NordiCHI '06: Proceedings of the 4th Nordic Conference on Human-Computer Interaction: Changing Roles* (New York: ACM, 2006), 1–8. DOI: https://doi.org/10.1145/1182475.1182476.

Borgmann, Albert. *Technology and the Character of Contemporary Life: A Philosophical Inquiry*. Chicago: University of Chicago Press, 1987.

Chesbrough, Henry W. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business Press, 2003.

Coelho, Marcelo, and Jamie Zigelbaum. "Shape-Changing Interfaces." *Personal and Ubiquitous Computing* 15, no. 2 (2011): 161–73. DOI: https://doi.org/10.1007/s00779-010-0311-y.

Dourish, Paul. *Where the Action Is: The Foundations of Embodied Interaction*. Cambridge, MA: MIT Press, 2001.

Fallman, Daniel. "The New Good: Exploring the Potential of Philosophy of Technology to Contribute to Human-Computer Interaction." In *CHI '11: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1051–60. New York: ACM, 2011. DOI: https://doi.org/10.1145/1978942.1979099.

Fernaeus, Ylva, Jakob Tholander, and Martin Jonsson. "Towards a New Set of Ideals: Consequences of the Practice Turn in Tangible Interaction." In *TEI '08: Proceedings of the 2nd International Conference on Tangible and Embedded Interaction*, 223–30. Bonn, Germany: Association for Computing Machinery, 2008. DOI: https://doi.org/10.1145/1347390.1347441.

Frankjaer, Raune. "Fostering Care and Peaceful Multispecies Coexistence with Agential Provotypes." In *Proceedings of ISEA 17*. Manizales, Colombia, June, 2017. https://www.researchgate.net/publication/318494034.

Gibson, James J. *The Ecological Approach to Visual Perception*, Classic ed. New York: Psychology Press, 2015.

Green, Ben, and Yiling Chen. "The Principles and Limits of Algorithm-in-the-Loop Decision Making." *Proceedings of the ACM on Human-Computer Interaction* 3, no. CSCW (2019): article 50. DOI: https://doi.org/10.1145/3359152.

Grudin, Jonathan. "AI and HCI: Two Fields Divided by a Common Focus." *AI Magazine* 30, no. 4 (2009): 48. DOI: https://doi.org/10.1609/aimag.v30i4.2271.

Harrison, Steve, Deborah Tatar, and Phoebe Sengers. "The Three Paradigms of HCI." Paper presented at alt.chi — CHI '07, Session at the SIGCHI Conference on Human Factors in Computing Systems, 1–18. San Jose, CA, USA, April 28, 2007. https://people.cs.vt.edu/~srh/Downloads/TheThreeParadigmsofHCI.pdf.

von Hippel, Eric. "Lead Users: A Source of Novel Product Concepts." *Management Science* 32, no. 7 (1986): 791–805. DOI: https://doi.org/10.1287/mnsc.32.7.791.

Höök, Kristina. "Steps to Take before Intelligent User Interfaces Become Real." *Interacting with Computers* 12, no. 4 (2000): 409–26. DOI: https://doi.org/10.1016/S0953-5438(99)00006-5.

Höök, Kristina. *Designing with the Body: Somaesthetic Interaction Design*. Cambridge, MA: MIT Press, 2018.

Ihde, Don. *Postphenomenology: Essays in the Postmodern Context*. Evanston, IL: Northwestern University Press, 1995.

Ishii, Hiroshi, Daniel Leithinger, Sean Follmer, Amit Zoran, Philipp Schoessler, and Jared Counts. "TRANSFORM: Embodiment of 'Radical Atoms' at Milano Design Week." In *CHI EA '15: Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, 687–94. New York: ACM, 2015. DOI: https://doi.org/10.1145/2702613.2702969.

Janlert, Lars-Erik, and Erik Stolterman. "Faceless Interaction — A Conceptual Examination of the Notion of Interface: Past, Present, and Future." *Human–Computer Interaction* 30, no. 6 (2015): 507–39. DOI: https://doi.org/10.1080/07370024.2014.944313.

Ju, Wendy. "The Design of Implicit Interactions." *Synthesis Lectures on Human-Centered Informatics* 8, no. 2 (2015): 1–93. DOI: https://doi.org/10.2200/S00619ED1V01Y201412HCI028.

Lim, Youn-kyung, Erik Stolterman, Heekyoung Jung, and Justin Donaldson. "Interaction Gestalt and the Design of Aesthetic Interactions." In *DPPI '07: Proceedings of the 2007 Conference on Designing Pleasurable Products and Interfaces*, 239–54. New York: ACM, 2007. DOI: https://doi.org/10.1145/1314161.1314183.

Löwgren, Jonas, and Bo Reimer. *Collaborative Media: Production, Consumption, and Design Interventions*. Cambridge, MA: MIT Press, 2013.

Löwgren, Jonas. "Interaction Design — Brief Intro." In *The Encyclopedia of Human-Computer Interaction*, 2nd ed. Interaction Design Foundation, 2013. https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/interaction-design-brief-intro.

McCarthy, John, and Peter Wright. *Technology as Experience*. Cambridge, MA: MIT Press, 2004.

Redström, Johan. *Making Design Theory*. Cambridge, MA: MIT Press, 2017.

Rogers, Yvonne. "New Theoretical Approaches for Human-Computer Interaction." *Annual Review of Information Science and Technology* 38, no. 1 (2004): 87–143. DOI: https://doi.org/10.1002/aris.1440380103.

Rogers, Yvonne. "Moving on from Weiser's Vision of Calm Computing: Engaging Ubicomp Experiences." In *UbiComp'06: Proceedings of the 8th International Conference on Ubiquitous Computing,* 404–21. Orange County, CA: Springer-Verlag, 2006. DOI: https://doi.org/10.1007/11853565_24.

Rosenberger, Robert, and Peter-Paul Verbeek, eds. *Postphenomenological Investigations: Essays on Human-Technology Relations*. Lanham, MD: Lexington Books, 2015.

Roth, Emilie M., and Amy R. Pritchett. "Preface to the Special Issue on Advancing Models of Human–Automation Interaction." *Journal of Cognitive Engineering and Decision Making* 12, no. 1 (2018): 3–6. DOI: https://doi.org/10.1177/1555343417749192.

Sheets-Johnstone, Maxine. *The Primacy of Movement*. Amsterdam: John Benjamins Publishing, 2011.

Shusterman, Richard. *Body Consciousness: A Philosophy of Mindfulness and Somaesthetics*. Cambridge: Cambridge University Press, 2008.

Suchman, Lucy A. *Plans and Situated Actions: The Problem of Human-Machine Communication*. Cambridge: Cambridge University Press, 1987.

Verbeek, Peter-Paul. "Materializing Morality Design Ethics and Technological Mediation." *Science, Technology, & Human Values* 31, no. 3 (2006): 361–80. DOI: https://doi.org/10.1177/0162243905285847.

Weiser, Mark. "The Computer for the 21st Century." *Scientific American* 265, no. 3 (1991): 94–105. DOI: https://www.jstor.org/stable/24938718.

Weiser, Mark, and John Seely Brown. "The Coming Age of Calm Technology." In *Beyond Calculation: The Next Fifty Years of Computins*, edited by Peter J. Denning and Robert M. Metcalfe, 75–85. New York: Springer, 1997. DOI: https://doi.org/10.1007/978-1-4612-0685-9_6.

Wiberg, Mikael. *The Materiality of Interaction: Notes on the Materials of Interaction Design*. Cambridge, MA: MIT Press, 2018.

Zimmerman, John, Jodi Forlizzi, and Shelley Evenson. "Research through Design as a Method for Interaction Design Research." In *HCI '07: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 493–502. New York: ACM, 2007. DOI: https://doi.org/10.1145/1240624.1240704.