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Technology futures: Towards understanding how to design awe-inspiring futures

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ABSTRACT

Future technology can inspire "awe", the deep feeling of astonishment that can include fear, resulting in often "awe-some" but sometimes also "aw(e)-ful" experiences. We are interested in exploring the potential of future technology beyond any immediate obvious application domain and hence draw from prior work and our own design research (through three case studies) to propose the "technology futures" approach that uses awe as a driver for exploring future technology's potential. Guided by awe's need for sense-making, the approach suggests that experiencing future technology in alternative, playful ways and through a first-hand approach can allow for shared reflections, leading to a more informed view of future technology's potential. Our "technology futures" approach has three stages (envisioning, concretizing, and futuring) towards awe-inspiring futures. We illustrate these stages using three case studies: jogging with a quadcopter, ingestible play, and shape-changing furniture. Furthermore, we use these case studies to articulate a set of strategies to help those who want to engage with the technology futures approach. Ultimately, with our work, we aim to enhance our understanding of how HCI can engage with designing awe-inspiring futures to support reflections around possible futures.

1. Introduction

When we refer to "future technology", we mean technology characterized by "radical novelty" but also "uncertainty" as it is on the cusp of emerging (Rotolo et al., 2015). Such future technology can inspire "awe", the "deep feeling of […] astonishment [that can include] sometimes fear" (Chirico et al., 2017). Most people probably use the word "awe" when describing an "awe-some" but sometimes also "aw (e)-ful" experience with future technology (while occasionally these experiences can be both). This matches our personal experiences with future technology, however, when we look at prior work, HCI's focus on such user experiences resulting from engagement with future technology seem to be rather single-sided, for example there is prior work on designing for "cool" (Sundar et al., 2014) and "wow" (Desmet et al., 2005), and of course HCI engaged with "novelty" (Fernald et al., 2012; Koch et al., 2018; Shavitt and Stellner, 2011; Shin et al., 2019). We do not find much structured understanding being developed so far when it comes to helping people to engage with their often seemingly conflicting feelings regarding future technology, hence in this article, we look to the notion of "awe".

The word "awe" originally comes from aghe, meaning "fear" and "great reverence" in the 14th century, while the current sense of "dread mixed with admiration or veneration" is due to the biblical use with reference to the Supreme Being. The word "awesome" is a combination of "awe" plus "-some" and has emerged in the 16th century meaning "profoundly reverential", which speaks nicely to our use of the word, while the weakened colloquial sense of "impressive, very good" became in vogue after ca. 1980 (Online etymology dictionary 2022b). The word "awful" comes from the same aghe origin and means "worthy of respect or fear, striking with awe; causing dread". The weakened sense of "very bad" is from 1809. Interestingly, in the 16th century, it was also occasionally used in the same sense of "profoundly reverential", just like "awesome" (Online etymology dictionary 2022a), speaking nicely to our proposal that "awesome" and "awful" experiences with future technology can often be very close to each other.

HCI has a long history of engaging with such future technology, however, this relationship has been neither easy nor straightforward (Korsgaard et al., 2016), especially as it appears that design researchers can find it difficult to manage the fine balancing act (Korsgaard et al., 2016) between technological solutionism (which sees "awe-some"

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future technology as providing answers to all the world's problems (Morozov, 2013) and dystopian futures (which only warns of the "aw (e)-ful" prospects of technology use) (Purpura et al., 2011; Zivanovic et al., 2009).

In particular, we find that existing HCI approaches, especially those around engineering-focused projects, often prioritize awe-some technical achievements, but miss out on considering the aw(e)-ful potential of the future technology (Morozov, 2013). More critical approaches, particularly those of the design community, have been lamented for being too futuristic and conceptual (and hence focused on the "aw (e)-ful"), leading to the potential of design research losing its advantage that it can facilitate technical innovation (forgetting the awe-some) (Korsgaard et al., 2016). Prior work has expressed the fear that if the design research community continues to focus on conceptual work, it might miss the opportunity to help HCI "take control and partake in the shaping and delivery of [future] technology" (Bødker and Kyng, 2018). Taken together, we find that engaging with future technology from a design research perspective can be challenging. Borgman (Borgmann, 2008) points out that this can be further exacerbated by the fact that the user's intention has a significant influence on whether future technology results in awe-some or aw(e)-ful experiences, while Toyama and Fallows [2011] builds on this by arguing that public policy, institutions and cultural change also play a role. We extend this prior work by discussing the role of the designer in this challenging balancing act. In particular, we argue that balancing the potential that engaging with future technology can facilitate awe-some and aw(e)-ful experiences, while ensuring that HCI design research makes a valuable contribution to society, is a difficult challenge. We believe that this is hindered by the fact that there is only limited practical guidance for researchers on approaching engagements with future technology, and little theoretical knowledge has been developed, such as a guiding design research framework. In addition, there is limited articulation of how to support societal reflections beyond design experiments and exhibitions, with notable exceptions (Gaver et al., 2022; Gaver et al., 2019).

In this article, we offer an initial response to assist design researchers working with future technology in the form of the "technology futures" approach that uses awe as a driver for exploring future technology's potential. The technology futures approach has been developed through the collaborative reflections of the authors, who have been working with future technology in different labs across two continents, and the three stages of the approach reflect the application of both practical and tacit knowledge. The articulation of the technology futures approach was triggered by discussions and joint reflections around a set of design research cases, which were independently developed but turned out to share common beliefs and ambitions. While others appear to have followed similar approaches, we have not yet found an articulation of the process or stages in any associated papers. Hence, with our work, we hope that we begin to more systematically articulate and theorize the connection between novel technology, awe and the quality of the public debate regarding future technologies. Our belief in experience before judgement has informed our research work over the last couple of years. This article aims to articulate the tacit knowledge we gained from this work and translate it into guidance for others who want to engage with this approach in their own HCI research practice. The technology futures approach responds to prior calls for more accessible and usable articulations of how HCI can engage with future technology (Reeves, 2012) and how to capture and communicate the often implicit approaches to engagement with design research that are not always well-articulated (Stolterman and Wiberg, 2010).

In this article, we first introduce design researchers to the notion of awe: the deep feeling of astonishment that can include fear but also comes with a need for sense-making (Chirico et al., 2017; Chirico et al., 2016; Keltner and Haidt, 2003; Krause and Hayward, 2015; Krogh-Jespersen et al., 2020; Yaden et al., 2016). We believe that this need for sense-making aligns well with our interest in future technology as people often try to make sense of when encountering it, especially the first time. We then present "technology futures" that centers around awe in the form of a three-stage approach to engage with future technology. The three stages are "envisioning", "concretizing", and "futuring", and each stage has "goals", "objectives" and "activities" associated with it, forming a 3×3 matrix (Fig. 6). The three stages of the approach focus on alternative and playful ways to experiencing technology through a first-hand approach. We use these three stages (speaking to research through design's three stages (Dow et al., 2013; Gaver, 2012; Zimmerman et al., 2007)) to offer practical guidance via the "goals", "objectives", and "activities" to make use of awe's feeling of astonishment when people make sense of their experience with future technology.

The stages themselves do not seek engineering responses to technology futures. Instead, they seek to explore human responses, speaking to prior HCI work that asked for more research on sociological enquiry (Dourish and Button, 1998). Furthermore, the stages emphasize the exploration of the future technology's potential, unlike prior HCI work on engaging with future technology that focused on advancing an existing political or critical stance (Dunne, 2008; Strengers et al., 2021). Importantly, the technology futures approach is underpinned by the deep feeling of awe that can occur when encountering future technology and the value of awe for productive engagements with that technology. While we are not contending that all future technology needs to facilitate awe, we believe that an approach that considers awe can be beneficial for design researchers when aiming to engage with future technology because awe's feeling of astonishment and a need for sense-making (Chirico et al., 2017; Chirico et al., 2016; Keltner and Haidt, 2003; Krause and Hayward, 2015; Krogh-Jespersen et al., 2020; Yaden et al., 2016) aligns nicely with the intention of a more engaged and informed view of future technology's potential, for both design researchers and the public.

As our three stages align with the common stages around prototyping, evaluating and dissemination in many HCI projects (Dow et al., 2013; Gaver, 2012; Zimmerman et al., 2007), we believe that designers might find it easy to engage with our approach and adopt it in their practice. By doing so, we hope that designers gain additional guidance in the form of a structure around goals, objectives and activities for each stage that promotes playful interactions to achieve a level of awe. With this, we hope that our work offers value through this novel contribution that might appeal to designers interested in creating future systems as well as research aiming to understand associated user experiences, all while promoting a discussion of awe in HCI that designers might want to draw on in their own work.

To articulate the technology futures approach, we have drawn upon prior work and from our own design research through three case studies that explicitly engage with future technology (drones, ingestible technology, and shape-changing interfaces). Our practice-based oriented approach combines design methods that have been previously and separately developed, and it complements prior methodological work that is concerned with the future (however, this work is often theoretical and speculative (Cairns and Cox, 2008; Dunne, 2008; Hornbæk, 2013; Olson and Kellogg, 2014; Wobbrock and Kientz, 2016).

Encouraging and supporting shared reflections on future technologies is a key element to our technology futures approach. We want to achieve this by bringing humans into direct contact with future technology, in everyday settings, and in ways that generate awe-inspiring experiences, which we believe can facilitate more engaged and informed debates about what role future technologies can play in people's lives. Participants will have rich accounts of first-hand experiences based on their engagement with the prototypes, making the associated debates hopefully less abstract, more relatable, and possibly even entertaining. Ultimately, we hope that these debates will lead to better use of insights and consequently better-designed future technology and, in turn, even more awe-inspiring experiences.

Taken together, our article presents the technology futures approach. It is not a completely new approach, but rather sits along other approaches, such as critical design and research through design, complementing them through the presentation of a detailed framework that features three stages (envisioning, concretizing, and futuring), each with goals, objectives and activities. Unlike other approaches, the framework focuses on future technology and hence the notion of awe permeates all three stages. Unlike more abstract and high-level approaches, the technology futures approach is characterized by its detailed structure that we believe can readily serve as guide for interaction designers interested in engaging with future technology. Another advantage of our framework is the use of playful approaches to future technology in order to elicit a deeper understanding of potentially both awe-some and aw(e)-ful futures, a critical user experience perspective that prior research through design often left to the critical discourse literature rather than sees it as integrated, hence our work also helps bring (design) practice and (critical) theory closer together. An advantage of not presenting a completely new, but rather complementary approach is that designers might avoid facing a steep learning curve as they can build on their existing methodological knowledge. Furthermore, we believe that it is more likely that designers might give this approach a go in comparison to a completely new approach where designers might be fearful of engaging with as it could be seen as unfamiliar and hence difficult to engage with.

In presenting the technology futures approach, we make four contributions to knowledge:

1 We present three stages that introduce design researchers to the notion of awe. Research managers can use the three stages as structured guidance for research planning. Design researchers can use the associated terminology when communicating and publishing more accessible articulations of their often very tacit approaches, which will support methodological design research advances. Methods researchers can use the three stages to analyze, discuss and compare different methods for future technology engagement. Lastly, designers can use the three stages when aiming to engage with future technology in a concrete and practical way, rather than in the more abstract ways expressed in previous design research approaches (Reeves, 2012; Tanenbaum and Tanenbaum, 2015).
2 We also tell three stories of three projects that aimed to engage with future technology (drones, ingestible technology, and shape-changing interfaces) and how they unfolded, extending their articulations in prior publications that previously focused on answering their individual research questions but did not present the underlying approach nor lessons learned from failures, challenges and also opportunities. As such, we are presenting these stories to provide an insight into our design practice through an honest account of what current practice is like in design research labs that aim to engage with future technology but struggle with the existing approaches currently available in design research within HCI. We hope that with these stories, we can help illuminate the technology futures approach.
3 We also articulate a set of challenges practitioners might encounter when aiming to engage with the technology futures approach. An understanding of these challenges will help practitioners know what to look out for when beginning with the technology futures approach, and so avoid common pitfalls. Design researchers will also benefit from an understanding of these challenges because they can better identify underexplored areas and know what to focus on in future research.
4 We also articulate a set of strategies using our case studies to help those who want to engage with the technology futures approach. Practitioners might find these strategies useful for enhancing their development efforts.

Section 2 of this article discusses the prior work from which we draw knowledge and insight. Section 3 presents our case studies. Section 4 presents the technology futures approach with its three stages. Section 5 compares the three case studies in relation to the technology futures approach. Sections 6 discusses challenges for designers during each stage of the technology futures approach and recommends strategies to respond to those challenges. Section 7 depicts limitations and future work. Finally, section 8 presents conclusions.

2. Prior work

In terms of background research, we learned mostly from previous design-oriented approaches in HCI and prior work around awe.

2.1. Learnings from design-oriented approaches

While the construction of novel prototypes is often at the heart of HCI projects, the field embraces several methodological approaches for engaging with future technology's awe-inspiring potential. However, when future technology is foregrounded, it is often unclear whether the associated envisioning is meant as a fiction, a forecast, or an extrapolation of the existing situation (Reeves, 2012), leaving researchers with little guidance on how to go about engaging with future technology. Consequently, there have been calls for research to fully understand how HCI should engage with the potential of future technology and for the field to be more explicit about associated approaches (Reeves, 2012). We now review some of the key prior works used in HCI to engage with future technology and facilitate awe-inspiring experiences. This allows to articulate the knowledge gap relating to structured approaches to engaging with future technology and outline how our approach aims to fill this gap.

Our work mostly draws from participatory design-oriented approaches that focus on the dialectics between tradition and transcendence (Ehn, 1992), where future technology design is grounded in current practices and, at the same time, tries to transcend them. The participatory design community has developed a range of approaches to give users a role in exploring future technology (Greenbaum and Kyng, 1992) and to identify specific solutions (Bødker and Kyng, 2018), which can potentially lead to awe-inspiring experiences. However, it has been argued that, over time, participatory design has lost its commitment to technical innovation (Korsgaard et al., 2016) and to the potential "for people, in various communities and practices, to take control and partake in the shaping and delivery of technological solutions" (Bødker and Kyng, 2018). This is echoed by Orlikowski and Iacono who lamented that the IT research community has not deeply engaged with its core subject matter, the technology artifact (Orlikowski and Iacono, 2001). With our approach, we aim to help regain some of this lost commitment.

Given our contention that future technologies can facilitate a feeling of astonishment that characterizes awe, we also draw from more technical approaches in HCI. For example, works published at the UIST conference, or in the CHI "Engineering Interactive Systems and Technologies" sub-committee, often embrace the awe-inspiring potential of future technology. While significant differences in focus exist—for example, many projects prioritize the engineering perspective and focus on inventing new technology or technically optimizing existing solutions—the results of these more technical approaches could still serve as the basis for our approach. Like our approach, some projects with UIST-oriented approaches often include a design stage and a subsequent study. However, we find that these studies often aim to evaluate the effectiveness of a particular aspect of the technology, guide the user towards a particular way of using it to determine if it "solves its purpose", and compare the technology with an existing solution. In addition, these studies often use quantitative methods to evaluate how a specific feature works for a user. As a result, they offer limited insights into what a future technology might mean for people's lives. In contrast, our approach is oriented towards studying the user experience and the opportunities and challenges that arise from people's appropriation of the technology and hence focuses on qualitative methods, ultimately aiming to offer insights into what a future technology might mean for people's lives.

In contrast to the UIST-approaches mentioned above, Ishii et al. proposed to develop a "vision", based on the authors' belief that a "strong vision can last beyond our lifespan" (Ishii et al., 2012). This proposal aligns well with our focus on awe, as in such a vision, inventive researchers chart the future and communicate it through novel artifacts using future technologies (e.g. Umapathi et al. (2018)), which is what we aim for, too. However, our work focuses on future technologies that are accessible to design researchers, which is not often the case in such visions (e.g., radical atoms Ishii et al. (2012)).

Research through design approaches in HCI also aim to explore possible futures (e.g. Dow et al., 2013; Gaver, 2012; Kozubaev et al., 2020; Wakkary et al., 2015; Zimmerman et al., 2007), often with the aim of addressing complex and wicked problems (Blythe, 2014; Buchanan, 1992). The common research through design outcomes of a prototype, and results from deployment of the prototype in-situ (Gaver et al., 1999, 2004) align with our approach. However, research through design usually emphasizes the exploration of alternatives (Blythe, 2014) and the eliciting of the underlying assumptions behind the design of technology (Dunne, 2008). As such, research through design does not necessarily explore a future technology per se. Our approach is consistent with the research through design approach to the extent that we are concerned with exploring possible futures through the system's design. However, while wicked problems often prompt research through design research, our starting point is future technology.

While critical and speculative design approaches have similarities to our approach (critiquing assumptions about technologies (Auger, 2013; Dunne, 2008; Dunne and Raby, 2013), use of public venues for debate and exhibition (Auger, 2013), and, especially, the production of design outcomes that generate awe (Biggs and Büchler, 2007; Dunne and Raby, 2002; Wakkary et al., 2015), the technology futures approach takes a different path. First, our approach begins with hands-on design activities involving the future technology (rather than, for example, trying to make an argument that is then illustrated with a technology (Auger, 2013; Blythe, 2014; Blythe and Encinas, 2018; Dunne and Raby, 2013)). Second, our approach offers participants the chance to engage directly with the technology, rather than stand at a distance from it. Third, our approach aims to facilitate reflections on awe-some and awe-ful futures rather than giving one perspective, such as a dystopian future (Wakkary et al., 2015).

We also learned from prior work around technology probes (Hutchinson et al., 2003) and potential enactments (Elsden et al., 2017) that often speculate about a possible future (Lindley and Coulton, 2016) as we are also interested in understanding what possible futures exist and how we can design them. Taken together, these prior works highlight that speculating about the future can be a key component in HCI research that even finds its way into associated publications (which is also our goal); however, most such prior research focuses on speculative design that is not implemented or where it is unclear whether it can be implemented as it is so far ahead in the future. In contrast, with our work, we aim to support speculative design but keep future technology at the forefront as we are stressing actual implementation work.

Finally, we acknowledge that concept-driven research (Stolterman and Wiberg, 2010) has strong affinities with our approach. While our three-stage approach responds to the concept-driven model of prototyping, theory development, and user studies (Stolterman and Wiberg, 2010), our focus and outcomes differ. Concept-driven research focuses on "manifesting theoretical concepts in concrete designs", with constructed and verified theoretical constructs as outcomes (Stolterman and Wiberg, 2010). Our work is more practice-based, evident by, for example, involving concrete design strategies.

2.2. Learning from prior work on awe

We have also learned from prior work on awe because it permeates the three stages of our technology futures approach. This prior work is mostly non-digital and describes awe as a powerful and complex emotion arising from profound and often meaningful experiences (Chirico et al., 2017, 2016), associated with deep feelings of astonishment and sometimes even fear (Chirico et al., 2017; Keltner and Haidt, 2003; Krause and Hayward, 2015; Yaden et al., 2016). We found that this description of awe spoke very much to our personal experiences with future technology throughout our careers; something we discovered through conversations the first time we met in person that ultimately sparked the desire to write this article. Awe's deep feeling of astonishment comes with a need for sense-making (Chirico et al., 2017; Chirico et al., 2016; Keltner and Haidt, 2003; Krause and Hayward, 2015; Krogh-Jespersen et al., 2020; Yaden et al., 2016). This is the result of a person's inability to assimilate an experience into current mental structures and hence awe has been described as the feeling people get when confronted with something vast, that transcends their frame of reference and that they might struggle to understand, combining amazement with an edge of fear (Keltner and Haidt, 2003). Prior work has used the overview effect, the cognitive shift in awareness reported by some astronauts during spaceflight, often while viewing the Earth from outer space, to provide an example of awe (Yaden et al., 2016) and contrasted awe with wonder, which can be seen as more intellectual: a cognitive state in which one is trying to understand the mysterious (Marchant, 2017). Furthermore, awe can be pleasurable, uncomfortable or even overwhelming (Chirico et al., 2017; Keltner and Haidt, 2003; Krause and Hayward, 2015; Yaden et al., 2016), but always comes with a need for accommodation and a perceived vastness (Keltner and Haidt, 2003). Perceived vastness can refer to "conceptual breadth, explanatory power, perceptual-sensory detail, and the volume of unexpected information" (Shiota et al., 2014). Therefore, it is believed that awe can be facilitated by stimuli that are both vast and difficult to accommodate, such as grand theories and big ideas (Chirico et al., 2017, Chirico et al., 2016; Keltner and Haidt, 2003). The association of the need for accommodation with novelty, surprise, and even astonishment (Chirico et al., 2016; Keltner and Haidt, 2003) aligns with our focus on future technology and our contention that its novel characteristics can often lead to astonishment and surprise. Moreover, awe can have a positive or negative valence depending, in part, on how the experience is interpreted (Chirico et al., 2016; Keltner and Haidt, 2003; Silvia, 2010). Therefore, our focus on awe supports a dualistic view on future technology – astonishment as well as fear – and hence differs from prior approaches in HCI that aim to design for a particular individual user experience such as novelty (Fernald et al., 2012; Koch et al., 2018; Shavitt and Stellner, 2011; Shin et al., 2019), "coolnesss" (Sundar et al., 2014) or "wow" (Desmet et al., 2005). As such, we see our work not as a replacement, but rather complementary to these prior approaches because it helps people to engage with their often seemingly conflicting feelings regarding future technology. Furthermore, psychological research that aimed to stimulate awe through virtual reality (Chirico et al., 2017, 2016; Nelson-Coffey et al., 2019) has some parallels with our work, but it was mostly concerned with stimulating awe through virtual panoramas (Chirico et al., 2016).

Our interest in awe-inspiring experiences enabled by future technology speaks nicely to prior work into the benefits of evoking awe. If a person cannot accommodate the aforementioned vastness through their existing knowledge – for example, when confronted by an "entirely novel" (Krogh-Jespersen et al., 2020) technology – then they are motivated to make sense of the experience by reducing the knowledge gap (Krogh-Jespersen et al., 2020). This insight led us to belief that if we aim to facilitate awe, we can "promote critical thinking and learning" (Krogh-Jespersen et al., 2020) as well as "ethical decision-making" (Piff et al., 2015), all the while increasing "skeptical thinking" (Price et al., 2019). These benefits appear to be useful in the context of engaging people with future technology. For example, researchers refer to awe when describing the features and effects that museums and other science-themed cultural institutions should seek to achieve when attempting to "educate and inform" (Valdesolo et al., 2017). This approach has been extended to STEM experiences more generally (Krogh-Jespersen et al., 2020), suggesting that people exposed to our approach might reap similar benefits.

Even though some awe experiences are not accessible to most people (such as awe facilitated by seeing earth from outer space (Nelson-Coffey et al., 2019)), prior research highlighted that awe can also be found in more common situations, such as when encountering a beautiful scene like a sunset, entering a cathedral, visiting a dinosaur skeleton in a museum, gazing up a tall tree, or absorbing nature when going for a walk outside (Ballew and Omoto, 2018; Marchant, 2017). In fact, it has been argued that the notion that awe is rare is a myth, as research revealed that people can feel low-level awe on average a couple of times a week (Marchant, 2017).

Awe can have also social benefits, for example, research found that participants experiencing awe can feel more connected to people in general afterwards (Piff et al., 2015), are more likely to help someone (Piff et al., 2015) and describe themselves as part of a group (Shiota et al., 2007), all while making people happier and less stressed (Stellar et al., 2015). It has also been suggested that experiencing awe can make people more willing to give up their time to help others, expand people's perception of time, alter decision making and enhance wellbeing (Rudd et al., 2012). Accordingly, prior research has identified that helping people discover awe in their everyday lives can contribute to their general wellbeing (Ballew and Omoto, 2018; Lopes et al., 2020; Sturm et al., 2020). Taken together, the benefits of awe align well with our approach.

2.3. Opportunity

Overall, while many interaction design projects appear to implicitly acknowledge and possibly even appreciate that future technology can facilitate awe, exploration of awe as part of research approaches in HCI remains uncommon. Furthermore, prior work outside HCI has highlighted the benefits of awe. We see an opportunity to combine both, but find that there is only limited structured articulation of how to go about it. In order to begin closing this gap in knowledge, in the next sections we articulate what we have learned from our design practice that involved future technology, which we structure across three stages (envisioning, concretizing, futuring) along with their goals, objectives and activities revolving around awe, which forms our technology futures approach.

3. Case Studies

The following sections discuss three case studies from two independent research labs. The technologies employed in the three case studies are drones, ingestible devices and shape-changing interfaces. At the time of the work, these technologies were on the cusp of emerging and featured "radical novelty" as well as "uncertainty", hence they can be considered "future technology" (Rotolo et al., 2015). In the case of drones, they facilitated feelings of astonishment about how such a device can seemingly sit stable in the air (defying gravity as well as air flow) and fear relating to the sense that the device might fall from the sky onto the user, both feelings being characteristic of awe (Chirico et al., 2017). Ingestible devices facilitated a feeling of astonishment concerning how the device could function inside the body, as well as where it might be located inside the body, and how, in the end, it leaves the body. These devices might also elicit fear concerning their potential to become stuck inside the user's intestine or even break and release toxins from the battery, speaking to awe's fear. Shape-changing interfaces facilitated a feeling of astonishment concerning how physical objects can, seemingly, magically change their shape without any visible external force. They also promote fear of autonomously moving objects that might be indifferent to nearby humans and could consequently harm them. In these ways, shape-changing interfaces have the potential to facilitate awe-some as well as awe-ful experiences, speaking to our notion of awe. We describe our experiences for each case study across three stages (envisioning, concretizing, futuring), and discuss our positive learnings and the opportunities to improve.

3.1. Joggobot: experiencing quadcopters for physical exercise

The work on "Joggobot" (Mueller and Muirhead, 2014, 2015; Graether and Mueller, 2012, Mueller et al., 2013) (Fig. 1) arose at a time when the media was giving attention to the military use of drones and quadcopters as an emerging future technology. Although these technologies had already found civil uses, many people had never seen a quadcopter (except in Hollywood war movies). However, enthusiasts had begun to design their own. The "Joggobot" project aimed to build on this technology trend and provoke people to think about the roles that quadcopters might play in their lives (beyond military surveillance). We note that at the time of the project, drones could have been regarded as an emerging technology that had awe-inspiring potential, (Delfa et al., 2020, 2020, 2019) which the public might had some awareness of through the media, but no direct experience with it. Having previously worked with (Altimira et al., 2016, Andres et al., 2018, Hamalainen et al., 2015, Khot et al., 2015, Mueller et al., 2002, 2012, Mueller and Gibbs, 2006, Pijnappel and Mueller, 2013, 2014) joggers (non-competitive amateurs who run for reasons including enjoyment, health, and relaxation), (Jensen and Mueller, 2014, Mueller et al., 2007, 2010b,a, 2014, 2015, 2016, 2017, Mueller and Agamanolis, 2007, Mueller and Berthouze, 2010, Nylander et al., 2014, 2015, O'Brien and Mueller, 2007, Tan et al., 2015) our envisioning stage resulted in our goal to facilitate awe through playful jogging experiences (we consider jogging a form of play as in prior work (Mueller et al., 2017) and to investigate jogging experiences with quadcopter technology. We designed our own drone to allow joggers to have an encounter with this future technology in order to have the opportunity to experience the awe-inspiring component, that is, the hovering. Therefore, our work can be seen as speaking to prior work that investigated what role people with "everyday knowledge or experience in a specific area of technology use" can play in what the authors call "near future technology" (Vavoula and Sharples, 2007), however, unlike this prior work, we are focusing on the designer in this relationship and investigate designer-led, instead of user-led, prototype developments.

3.1.1. Joggobot: Envisioning

We began envisioning by engaging with the do-it-yourself (DIY) quadcopter community. We learned how to build our own quadcopters and produced several prototypes. However, our desire to design for alternative futures of jogging with quadcopters raised several issues, including inadequate speed, battery life, instability, reliability, elevation, and visibility. Consequently, our repurposing of the future technology required several compromises. Our objective of exploring the design space through prototyping included drawing upon our lab design experiences relating to sensors and lightweight materials, and slowly

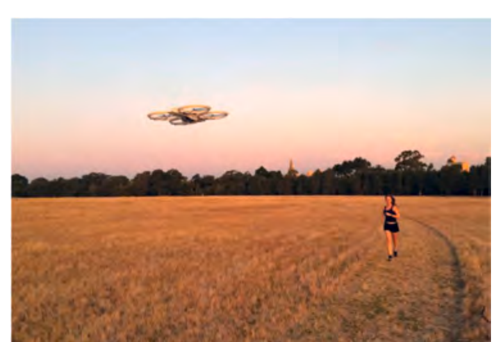

Fig. 1. The "Joggobot" system allows joggers to run with a quadcopter.

expanding the design space through a unique feature set that we repeatedly tried out while jogging. We jogged at various speeds, across various terrains, with quadcopters of differing sizes and functionalities. This approach allowed us to identify alternative applications for our target group within the technical constraints. We tried several approaches to connect the jogger with the quadcopter's position, using GPS and assisting sensors. However, we were not satisfied that any of our location systems worked well enough. Consequently, we compromised: the quadcopter would fly at a constant speed, which the jogger set beforehand. As such, our alternative application changed from a quadcopter being a pace-aware jogging partner to a pace-setting trainer. This change limited the context for our aim (the "concretizing aim", explained below) because people would not be able to use a pace-setting trainer quadcopter if they had not jogged before and did not know their target pace. With this in mind, we recruited only participants with jogging experience for the associated in-situ study with 13 volunteers.

3.1.2. Joggobot: Concretizing

The in-situ study suggested that participants might have experienced awe, comprising feelings of astonishment and fear: astonishment at how the quadcopter stayed in the air and seemingly guided their jog, and fear that the quadcopter might crash into trees or fall onto them. Furthermore, the joggers reported that they experienced a sense of astonishment jogging behind a flying jogging partner that seemingly knew where and how fast they wanted to go, which often resulted in a playful competition to run "at least until her/his batteries ran out". This assignment of gender, and anthropomorphizing, appeared to indicate that our participants were trying to make sense of what they experienced, aligning with our understanding of accommodation as part of the experience of awe.

The interviews revealed that participants reflected on how their Joggobot experience was so different from their usual experience of using jogging apps on their mobile phones; they said things such as "he made me go faster". The joggers reported a belief that they ran faster and further than they had without a quadcopter. Along with the anthropomorphization noted above, these responses suggested that quadcopter technology could be seen as a partner in physical exertion contexts, speaking to a human-computer partnership approach around shared agency as promoted through human-computer integration (Farooq and Grudin, 2016, Mehta et al., 2018, Mueller et al., 2020). Participants said that because the quadcopter "seemed to get tired" (which they apparently perceived by hearing "the [quadcopter's] batteries dying"), the Joggobot, like them, was exerting too much energy and, like them, needed a rest. This experience seemed to facilitate a closer relatedness with a system that they often compared to a dog accompanying them during their run.

3.1.3. Joggobot: Futuring

We then concerned ourselves with futuring, meaning reflections on awe-inspiring futures. We speculated about what this Joggobot experience might mean more generally for experiencing awe around systems that exhibit bodily characteristics of exertion, such as "tiredness" and how we might relate to those systems when we exert ourselves. We articulated a design space around the dimensions of perceived control, focus, and bodily interactions, demarcating quadcopter-support possibilities during exertion experiences (Mueller and Muirhead, 2014; Mueller and Muirhead, 2015). Along with our CHI and UIST publications, we convened a special interest group and a workshop to facilitate further reflections on awe-inspiring futures (Mueller et al., 2013). We shared our proposal that awe-inspiring technologies that appear to exhibit exertion can give users a sense of close relatedness, especially when the user exerts themself. This work led to collaborations with other researchers interested in SportsHCI (Marshall et al., 2016) and an "Interactions" article (Nylander et al., 2015). Other efforts complemented these developments. We organized jogging activities around the CHI conference for those interested in discussing SportsHCI (Mueller et al., 2014; Mueller et al., 2015; Mueller et al., 2016), which facilitated dialogue among CHI community members around the potential of such future technologies.

Numerous media outlets, technical magazines, and jogging and sports publications reported our work. A popular national science program featured our work on TV, which significantly increased the research outreach and led to conversations (via blog comments and social media) on alternative applications for quadcopters for joggers. Examples include online videos of people jogging with quadcopters (Kofuzi 2017), manufacturers implementing follow-me functions (which we proposed) to video their jogs (DJI, 2020), and individuals posting evidence of their quadcopter taking their dog for a walk (Wilkinson, 2020). Although it is difficult to assess the extent to which the vast publicity led to impactful discussions, the number and variety of ideas we observed coming out of these discussions significantly exceeded our expectations (and our ability to generate such ideas ourselves). Hence, we believe that this stage has contributed (albeit possibly to a limited extent) to shifts in perspective – quadcopters no longer being seen only as "dangerous" but also as offering possible benefits in people's lives – and has encouraged reflections on the personal (sporting) use of future technologies.

3.2. The Guts Game: Experiencing ingestible sensors for play

We are fascinated that computers are getting so small that they cannot just be worn on the human body (becoming wearables), they can also be placed inside the body. We initially approached a very successful research group investigating ingestible sensors that can wirelessly stream data to a recorder and help medical experts better understand the human body. In one instance, the group developed wireless capsules that can sense several gas components inside the human gut, potentially enhancing our understanding of the relationship between intestinal gases and human health (Kalantar-Zadeh et al., 2018). We were intrigued by these wireless capsules and believed that, like the drones, they had awe-inspiring potential, which the public might have had some awareness of through the media, but no direct experience with it, unless someone had previously gone through a capsule endoscopy. In the end, we designed an accompanying technology, a mobile phone app, (Brandmueller and Li, 2017, Li et al., 2017, 2018, 2020, 2021) in order to allow people to have an encounter with this future technology to have the opportunity to experience the awe-inspiring component, that is, the ingestibility.

3.2.1. The Gust Game: Envisioning

As part of the first stage, we investigated the potential these wireless capsules possess to facilitate novel ways to experience the body as play (Mueller et al., 2018, 2020). Working directly with the hard- and software developers allowed us to access the system's low-level features. However, we encountered a roadblock. We understood that an ethics approval process had already been completed successfully for the technology. However, lacking a medical background, we had not understood that our country's medical approval process is specific to application domains. Since our intended application was play, not medical, we discovered that we would have to undergo a new approval process. This highlights that the first stage's activity of prototyping alternative systems can often be constrained by external factors. We therefore looked for alternatives and discovered temperature-sensing capsules that firefighters and athletes use to capture their core body temperature. We went through a shorter ethics approval process with the temperature-sensing capsules because the device was already available in the open market. While we would have preferred to explore the more extensive functionality provided by our colleague's state-of-the-art capsules, the use of only one sensor input appeared to be enough to facilitate an engaging play experience with ingestible sensors. We called the resulting functional prototype the "Guts Game" (Brandmueller and Li, 2017; Li et al., 2018) (Fig. 2).

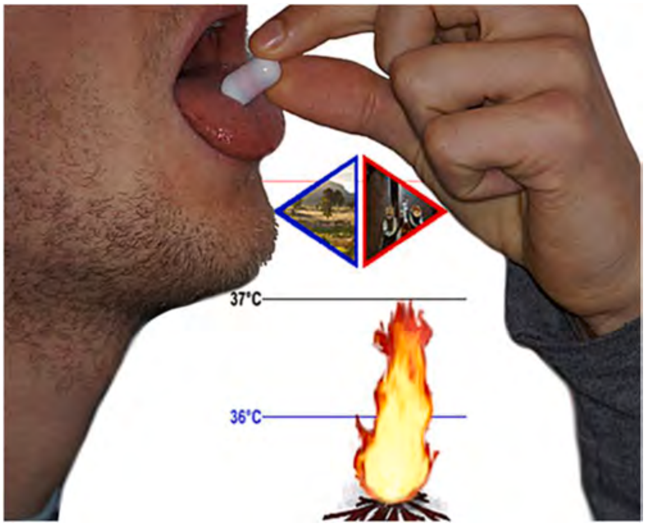

Fig. 2. The "Guts Game" explores the use of ingestible sensors for play.

The "Guts Game" (Fig. 2) explores the use of ingestible sensors as an ingredient in playful experiences. The Guts Game requires two players who begin playing by swallowing a capsule that transmits sensed temperature data to a wireless data recorder that the players wear on their bodies. After that, the players are free to roam around and go about their regular daily activities. The game usually ends after 8-36 hours, which is the duration of the capsule's journey through the human digestive system.

During this time, the player's smartphone app, which we developed through an iterative refinement, presents them with various challenges. For example, the app might ask the player to guess their temperature and award game points depending on how close their answer is to the actual value. Similarly, the game might ask the players to reach a certain temperature that the system or the other player sets. The app shows an animated flame that displays the player's body temperature throughout the experience and awards points for success. To foster social dialogue, we implemented a photo- and text-sharing capability in the app that helped players express their emotions to one another and display how they could manipulate their temperature to achieve certain goals. For example, players sent pictures showing how they performed physical activity to raise their temperature or drank cold drinks to lower it. The game ends when either player excretes the sensor.

3.2.2. The Gust Game: Concretizing

The concretizing stage involved an in-situ deployment where 14 participants could use the system as part of their daily life. While this deployment allowed us to ground how participants would incorporate such future technology into their everyday lives, ethics requirements did not allow for intense physical activity that might impact the torso and damage the capsule. This constraint might have affected feelings of fear as part of awe: participants raised questions and they made playful comments and jokes about what would happen if the capsule became stuck inside their intestines or accidentally broke. We tried to minimize any associated risk through extensive consultations with our ethics board. However, we note that the inherent nature of an ingestible capsule appeared to facilitate feelings of astonishment as well as awfulness as characterized by awe. We acknowledge that the ethics requirements might have limited the users' exploration of alternative contexts. Nevertheless, users' appropriations inspired alternative design ideas. For example, participants reported that the system was affected by wireless interference. They used this knowledge to investigate their level of exposure to interference in their various locations during a typical day (living room, office, and so on). We noted this idea and implemented it with a novel design in a subsequent project: turning the ability to sense interference "through your stomach" into a design feature (Li et al., 2018, 2019).

The concretizing stage revealed that participants could enjoy games that utilize future intracorporeal technology. Participants reported that they experienced a sense of astonishment and tried to accommodate it. In particular, they tried to make sense of what they experienced through their own body, speaking to our previously mentioned understanding of awe while also aligning with prior work on somaesthetics, which emphasizes the role of the body in the way we make sense of the worldTEI (Höök, 2018). In particular, our study highlighted two distinct ways the game affected participants' thinking about future technology. First, participants expressed how the game made them think about the boundary between themselves and technology, and asked themselves challenging questions such as "where does my body end and where does the technology begin?" As a result, participants began to wonder where the boundaries of an interface lie and whether a body can be an interface if a technology becomes a part of it. Second, participants valued how the system helped them make sense of their experience and learn about their own body and hence themselves more broadly. For example, participants were astonished by how much their inner body temperature changed over a day. They were also surprised at how much control they had over their temperature and they appreciated how the system allowed them to explore ways to affect their temperature, such as trying various foods and tracking their different impacts.

3.2.3. The Gust Game: Futuring

The futuring stage included wide media coverage of the project, including international publications such as New Scientist. The idea of using medical technology for play appeared to appeal to the public, and also to medical experts (evidenced through personal communications during conferences and industry events) who explained that they appreciated how play could complement traditional treatments to support their patients' general wellbeing. These insights speak to prior research that drew upon the idea of play as a way to humanize healthcare for patients (Huerga et al., 2016). In response, we were invited to speak at health forums outside our usual academic presentation circles, resulting in substantive discussions with people outside the HCI field. These dialogues resulted in suggestions that could offer exciting avenues for future research, such as the potential for playful experiences to reduce patient anxiety when undergoing treatments involving ingestibles (capsule endoscopy, for example). Also, public dialogues included questions about how long it takes to excrete the capsule. We decided to consider these questions in our interviews. The design space we developed triggered bigger questions about how we take different perspectives on our body when engaging with future technology. These insights have led to the delivery of theoretical papers on the future of bodily play at the "Conference on Tangible Embedded and Embodied Interaction (TEI)" (Mueller et al., 2020, 2020b,a). Furthermore, the reflections have also led to discussions about opening up avenues for future ingestible technology development. We understand that it is challenging to find volunteers willing to try new pills for medical studies. In this regard, our work has led to discussions that could have a real-world impact on medical research studies, as it might make volunteering to undergo such study procedures more appealing, thereby reducing the required monetary incentives and assisting the development of novel technologies.

3.3. CoMotion Bench: Experiencing shape-changing technology as furniture

We increasingly find shape-changing interfaces and interiors featuring in future visions and vision-driven research (Ishii et al., 2015). We became curious about how people would experience shape-changing furniture as part of their everyday environment. We wanted to know more about the futures in which these interior interfaces participate: could versions of these technologies elicit awe and, by doing so, generate different reflections on self-actuated technology in this space? On the one hand, shape-changing interiors open avenues for the built environment to adapt to different users, purposes, and situations, giving furniture entirely new (interactive) roles in people's lives. On the other hand, we do not usually expect our environment and building interior to suddenly change shape or move around, so can we accommodate and make sense of such behaviors? Unlike the drones and wireless capsules, the CoMotion Bench looks like a regular bench from the outset (we worked with interior architects and furniture designers to produce a professionally looking and aesthetically pleasing object, rather than a prototype), but reveals its awe-inspiring potential only as a result of the interaction, that is, when sitting on it. As such, we hope that the CoMotion project complements our previous two case studies nicely by explicating how awe in relation to future technology is not just concerned with physical form.

3.3.1. CoMotion Bench: Envisioning

We designed a shape-changing bench to investigate these questions (Kinch et al., 2014) (Fig. 3, Fig. 4, Fig. 5). A bench is a typical furniture piece used for sitting in public spaces. We designed the bench with a rather open-ended functionality because it was not intended to address a specific problem or task (besides supporting people who want to sit down) and had no specific context beyond a public space. During the envisioning stage, we worked with a range of proposals for how a shape-changing furniture could be awe-inspiring. We explored the overall purpose of inducing encounters that we hoped would be slightly provocative, triggering positive and negative emotions. We also explored the bench's physical design, especially how to balance the visibility-invisibility of the shape-changing mechanisms. In the final version of the prototype, the actuation mechanism was hidden, and the bench's shape could change across its three sections. Each section of the bench could be leveraged while still connected to the others, and each end could levitate to push people towards the middle (we thought that this might bring people playfully together and facilitate social interactions).

3.3.2. CoMotion Bench: Concretizing

We deployed the bench in three different locations during the concretizing stage – a concert hall foyer, an airport departure hall, and a shopping mall – to investigate how people would engage with and appropriate it in different contexts. Over five days, 129 people sat on the bench (Grönvall et al., 2014). We observed and interviewed people during the CoMotion Bench concretizing stage and found that they reacted quite differently when encountering it: from curiosity to confusion and from amusement to annoyance. Some users found the experience awe-ful, speaking to awe's sense of fear, while others reported that they found it awe-some, speaking to awe's feeling of astonishment. Some participants reported mixed feelings about their experience, speaking to awe's dualistic notion of being able to facilitate both astonishment and awe.

Fig. 3. The "CoMotion Bench" in a concert hall foyer (faces blurred).

Fig.4. The "CoMotion Bench" in an airport departure hall (faces blurred).

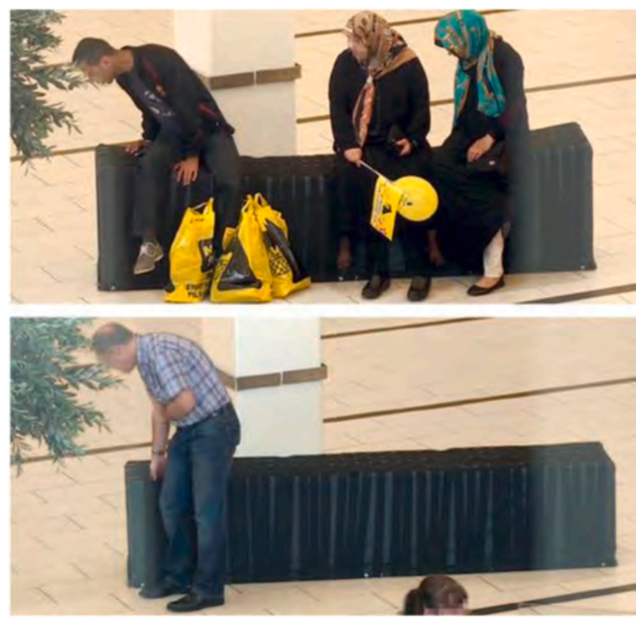

Fig. 5. The "CoMotion Bench" in a shopping mall (faces blurred).

The study illustrated how novel shape-changing technologies could pose challenges for people, especially when the technologies' capabilities are not immediately visible. For example, some people reported distressing reactions. They did not realize that the bench was moving; some even felt dizzy and thought better to go home because they believed their health was deteriorating. For example, one person reported that they felt their previous vertigo issues had come back and thought they needed to return home to look after it (during post-deployment interviews, we explained the situation immediately after these experiences). On the other hand, the bench amused most participants, and some interpreted it as entertainment.

In general, we found that user interpretations of the bench related to the use context. For example, in the concert hall, people interpreted it as a piece of art or as something they were allowed to take turns trying. On the other hand, in the airport departure hall, some people thought the bench was nudging them to exercise before the flight or giving them a pre-experience of their upcoming flight. It was also in the airport context that the highest number of people were distressed by the bench. This outcome may have been because the participants were slightly nervous and excited about their flights. Overall, the bench triggered social encounters through playful sitting experiences. These social encounters appeared to be fueled by participants collaboratively arriving at a sense of what was going on. In other words, participants felt a sense of astonishment and tried to make sense, or accommodate, what they were experiencing, which aligns with our understanding of awe.

3.3.3. CoMotion Bench: Futuring

The futuring stage work occurred primarily during post-experience interviews with users, and with the airport, concert hall, and shopping mall invigilators and decision-makers involved. We found that the study successfully triggered awe among the people experiencing it in use and among invigilators, including security personnel. In addition, the awe experience could spill over to bystanders and organizers who might, even though they are aware of the project's aims, still be able to experience a sense of astonishment. This insight has led to further discussions about how visitors in the various locations can be playfully engaged, despite being in very different contexts (the hectic and sometimes stressful environment of the airport, the art context where people expect to be intellectually challenged, and the mall and its many competing attractions). Our in-situ study fueled these reflections on awe-inspiring future possibilities in these different contexts and facilitated novel discussions about future technologies' roles in each. Conversations on the use of future technologies in these contexts included the consideration of employing them to facilitate notions of belonging, such as providing artistic shape-changing furniture for theatre subscribers, and providing additional safety within the space, such as by using shape-changing devices to enhance particular security aspects in the airport.

This project highlighted the promise embodied in the playful applications of shape-changing technologies, along with the risk of potentially detrimental encounters, during which people may experience a loss of control over their senses and feel ill. These contrasting outcomes and prospects point to the need to carefully craft such awe experiences and consider their specific contexts.

4. Technology Futures

Our technology futures approach features three stages (Fig. 6)– envisioning, concretizing, and futuring– and follows other HCI methods that use three stages to explore the future (Benford et al., 2013; Salovaara et al., 2017). The notion of awe can be seen as an overall guiding feature of the technology futures approach that permeates all three stages. We unpack each stage into the following aspects: its overall goal, the objective that needs to be achieved to get there, and the associated research activity.

4.1. Stage 1: Envisioning

The first stage of the technology futures approach is "envisioning", with the goal of designing with awe-inspiring technology. The objective is to explore the design space for awe. The associated activity is the prototyping of alternative and playful systems. This stage directly responds to prior work's call for envisioning to be brought to the fore in HCI (Reeves, 2012).

4.1.1. Goal: Designing with awe-inspiring technology

Designers should have a goal of facilitating awe-inspiring experiences. Achieving this goal might be difficult, but we think that by designing novel, playful systems and allowing people to engage with the future technology, designers can promote an emotional response, which can facilitate awe. In particular, the use of future technology can contribute to the need for accommodation (a component of awe) while participants try to make sense of their novel experiences.

4.1.2. Objective: Exploring the design space for awe

The objective of the envisioning stage is for designers to explore the design space for awe, including its "edges" or extremes, which highlight the possibilities that exist to create engaging systems using future technology. Because future technologies are often presented with one application in mind (for example, envisioning that people would only use early mobile phones to make calls), we are less able to imagine both the potential benefits and the risks of turning those technologies to other uses. Hence, identifying alternative and playful applications might expand people's understanding of the technology's potential reach and impact on everyday life. Design researchers can construct a design space

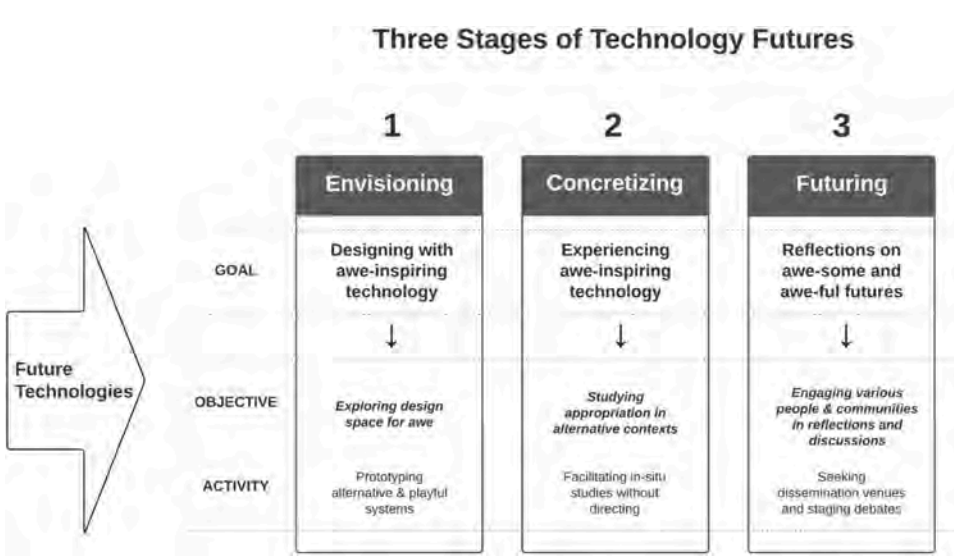

Fig. 6. The three stages of the technology futures approach.

by determining the key "aspects to consider" when designing systems that use the future technology. Through exploring design spaces, designers of future technology systems can understand the range of current opportunities, including underexplored areas. Additional, future designs will further populate the design space, producing a future technology system portfolio (Gaver and Bowers, 2012).

4.1.3. Activity: Prototyping alternative and playful systems

The envisioning stage's activity involves prototyping alternative and playful systems, resulting in one or more functional prototypes conceived during the design exploration. The fact that awe depends on "how the experience is interpreted" (Chirico et al., 2016) suggests s that alternative and playful systems could facilitate positive feelings when people experience the awe-inspiring technology (Silvia, 2010). Prototype development helps designers identify alternative applications (preferably those not yet believed to be technically feasible) by gaining a "feel" for the technology's potential and challenges.

We advocate for the design of playful systems because play can allow for a reframing (Huerga et al., 2016) of the "fearful" aspects of an awe experience, possibly stressing to users that if the technology were designed properly, feelings of astonishment could predominate (Chirico et al., 2017). Furthermore, research has also highlighted that playful design can reframe existing activities, especially in the context of gamification and playful design (Mildner and Mueller, 2016; Deterding et al., 2011a, 2011b). In these respects, we propose that designing playful systems using future technology could positively contribute to feelings of awe.

We believe that the design research "tinkering" process (Holmquist, 2012), involving hands-on experiences with the material and a playful attitude towards the design, can be valuable for generating alternative and playful ways to engage. In addition, the implementation of prototypes should be at a level that enables participants to experience the future technology in-situ. However, we acknowledge that advanced prototype development is often difficult because future technology documentation, support, and development kits are not always available as the technology is so new. Hence, it is often necessary to devote additional development time to this activity in comparison to working with established technologies.

4.2. Stage 2: Concretizing

Concretizing refers to making the envisioning concrete, allowing people first-hand experiences with awe-inspiring technology. The objective is to study the appropriation and adoption of the technology in alternative contexts. The associated activity includes in-situ studies, without researchers directing what the user should (and should not) do. This stage responds to the call by Salovaara et al. (2017) that HCI needs more open in-situ deployments.

4.2.1. Goal: Experiencing awe-inspiring technology

The goal of the stage is to allow people to experience awe-inspiring technology.

4.2.2. Objective: Studying appropriation in alternative contexts

Studying users' appropriation of the future technology in alternative contexts can sensitize the researcher to people's needs and desires. While these study insights can be positive and negative, they all arise from a (hopefully) true account of how people engage with (or disengage from) the technology in everyday practice. This approach contrasts with methods, such as surveys, that ask people to predict how they might use future technologies. In contrast to problem- or user-driven approaches, the technology futures approach involves a broad exploration, potentially studying different users in different contexts with the same prototype to understand the opportunities and limitations of the explored design space.

4.2.3. Activity: Facilitating in-situ studies without directing

An in-situ deployment allows for the examination of people's technology appropriation. People can appropriate the novel technology in ways that suit their needs, rather than, for example, adhering to any preconceived ideas about the technology's function. For this activity, we aim to not steer participants in a particular direction but rather provide minimal instructions to them as a way to gain interesting insights around the emergence of practices, as guided by prior work (Sanches et al., 2019). The examinations of these appropriations often use ethnomethodological methods (Garfinkel, 1964). These methods allow researchers to produce "thick descriptions" of how the appropriation unfolds in the wild (Rogers, 2011), providing rich data that can help them understand if they had achieved the goal of facilitating awe-inspiring experiences with the future technology. By analyzing this rich data, a more vivid picture can be painted of the future technology's possible roles in people's lives.

4.3. Stage 3: Futuring

The goal of the futuring stage is to promote reflections on awe-some and awe-ful futures by engaging various people and communities in reflections on and discussions about the experiences the designers and users had with the future technology during stages 1 and 2. The stage's main activity is to seek dissemination venues for distributing user insights, and designer knowledge and ideas, as well as to stage debates with the public. Borrowing the term "futuring" from prior work around design and reflections (Sandjar et al., 2020), we aim to emphasize the continuous generation, examination, and evaluation of alternatives for the future. We expand on this prior work by not only theoretically hypothesizing, but also facilitating reflections on both awe-some and awe-ful futures that are grounded in the first-person accounts of users and designers who have first-hand engagements with the future technology.

4.3.1. Goal: Reflections on awe-some and awe-ful futures

The goal of the futuring stage is to facilitate reflections on awe-some and awe-ful futures. Again, we promote the idea of awe here because awe promotes critical thinking, learning, and ethical decision-making (Krogh-Jespersen et al., 2020), speaking nicely to our intention to facilitate a deeper engagement with future technology.

4.3.2. Objective: Engaging various people and communities in reflections and discussions

The reflections and discussions objective highlights the benefits of engaging in a dialogue with various stakeholders (such as the sellers of a future technology or owners of places where such technology will be installed), which can often include the general public, to discuss the future technology's implications for their lives. These discussions are often facilitated through presentations of the work outside academic publications: at public forums, via media interviews, and in social media posts. In addition, user insights can help inform the broader debate because others can hear such first-person accounts of how the novel technology contributed to their lives. Indeed, we believe that personal, intimate accounts can facilitate direct and impactful reflections on a future technology because they do not arise from what some might call an abstract, academic "navel-gazing" perspective. However, we also acknowledge that other approaches certainly exist, for example one could employ external documentary makers (Gaver, 2007, 2009) to engage additional communities. We find such approaches intriguing and therefore encourage future work around them, however, in our practice, we found them often cost prohibitive.

4.3.3. Activity: Seeking dissemination venues and staging debates

The activities in this stage include identifying appropriate venues at which the insights gained from the two previous stages can be disseminated. Circulating the insights widely can facilitate shared reflection and hopefully a broader and more informed debate about what role future technologies can (and should) play in people's lives. In addition, participants in these debates now have rich first-hand accounts of personal experiences to support the discussion, making the debate less abstract and more relatable, possibly even entertaining. Ultimately, we hope these more engaging debates will lead to better potential use insights, better designed future technologies, and more awe-inspiring experiences.

4.4. Iterative process

While the three stages run forward linearly and one stage informs the next, there can also be a looping-back to prior stages and to further and related studies. For example, the results from the concretizing stage can inspire the design of future awe-inspiring prototypes, and the reflections and discussions of the futuring stage can inform the design of additional studies involving alternative contexts. Furthermore, although academic papers about individual projects often end after completing the three stages, the design research lab work continues. Researchers could "loop" back to the beginning, investigate new technologies as part of other projects, derive additional insights, and close the iterative process. We agree with prior work, which proposes to consider how "looping" back can benefit the design process (Benford et al., 2013). For example, by going back to the first stage and starting with a new technology, it might be possible to use the previous findings from the futuring stage to guide the design of new prototypes.

5. Comparison of the case studies across the Technology Future's three stages

We now compare and critically discuss our three case studies in relation to our technology future's three stages (Table 1). We acknowledge that our three studies do not provide perfect instances across each stage, nor should they be seen as exemplary cases. Instead, as they arrived through practical design research within an academic context riddled with time, space and resource constraints, their descriptions should be seen as attempts to illustrate the abstract stages of our approach, aiming to make them more vivid and graspable for designers. To highlight that we, in hindsight, would have done particular aspects of those case studies differently, if we could conduct the research again, we provide a critical self-reflection on our work in regard to the technology future's three stages.

5. Challenges of technology Futures

Having discussed the technology futures approach, we now articulate its key challenges based on our experiences and use our three case studies to illustrate those challenges. We follow prior work, which suggested that identifying challenges can help progress a particular approach (Benford et al., 2013), and we build on the established academic practice of listing challenges to advance knowledge generation (Alexander et al., 2018). Through the approach of reflecting on our prior work, we propose that there are certain challenges associated with each stage that designers might benefit being aware of. To aid addressing these challenges, we also offer a set of strategies based on our design practice that designers might find useful when aiming to address these challenges. While these strategies are not the only way to address a challenge, they offer springboards for other researchers and practitioners to use.

5.1. Challenges of technology futures: envisioning challenges

Regarding the envisioning stage, we believe that there are, in particular, two challenges that designers might benefit from being aware of: identifying alternative and playful applications of the future technology; and documenting the envisioning process.

Table 1
Comparison of our three case studies.

	Joggobot	The Guts Game	CoMotion Bench
Envisioning	Our goal was to design an awe-inspiring experience that we hoped joggers would appreciate. We believed we reached our objective of exploring an interesting and novel design space, as demonstrated in the form of dimensions in a top tier publication (Mueller and Muirhead, 2015), however, this design space only partially captured awe. This was probably because our prototyping activity was severely hindered in terms of arriving at alternative and playful systems due to the limited capabilities of quadcopter hard- and software that prevented extensive tinkering activities.	We believe we achieved our goal of designing an awe-inspiring experience, including the exploration of a design space that came out of extensive prototyping activity. We acknowledge that this prototyping activity resulted in a rather traditional gamification experience; we believe that being able to more freely explore alternative system designs might have resulted in less gameful and more playful experiences. However, we were limited by health and safety considerations that limited the extent to which we were able to realize some of our intentions in relation to awe.	Our goal of designing an awe-inspiring technology through exploring the design space of actuating furniture was achieved, we believe; however, our prototyping was more limited than we wished as we could not implement all the interactivity we aimed for, limiting the number of alternative and playful systems we envisioned.
	JOGGOBOT	**THE GUTS GAME**	**COMOTION BENCH**
Concretizing	We hoped that our joggers would appreciate experiencing awe-inspiring technology. For that, we studied their appropriation in a park. We were proud to have achieved an in-the-wild study, however, acknowledge that if we would have been able to explore additional contexts, like jogger's own regular jogging paths, running tracks indoors, etc., we might have arrived at additional insights that could have spoken to aspects of awe beyond the immediate jogging scenario. Furthermore, we managed to not direct the joggers too much in the study. Nevertheless, we noted only during the study that	Extensive consultations with our ethics committee allowed us to realize an in-the-wild study, however, we had to provide more directions to participants than we wanted to, in order to ensure safety. Furthermore, although participants described indicators of awe in regard to their own, but also bystanders' experiences, the interviews we conducted could have been more focused on what exactly facilitated such awe experiences in order to arrive at a deeper understanding of the appropriation that occurred.	We are particularly proud of having been able to place the CoMotion bench in the various contexts beyond the initial university environment that would have been the default for many studies. In these in-the-wild studies, we were able to facilitate in-situ experiences without directing participants, much more than in the other studies where participants had to sign consent forms beforehand and therefore got to know the objectives of the research upfront. Participants who experienced the CoMotion bench certainly expressed indicators associated with awe experiences without us prompting for them, which might have been

(*continued on next page*)

Table 1 (*continued*)

	Joggobot	The Guts Game	CoMotion Bench
	interviewing bystanders to the jogging experience might have provided us with additional alternative context uses: a missed opportunity.		influenced by the fact that they experienced the bench often with many other people, however, we leave this hypothesis for future work.
	JOGGOBOT	**THE GUTS GAME**	**COMOTION BENCH**
Futuring	Our goal to facilitate reflections on awe-some and awe-ful futures was supported by our media department that helped with spreading the research results on social media, resulting in reflections and discussions by various people and communities. This facilitated interesting debates across stages we usually would not have had access to. However, we acknowledge that we were not always able to focus these debates on awe in relation to quadcopter technology, but often diverted to either technology-centric discussions or wider societal-focused conversations.	The Gust Game resulted in a diverse set of reflections and discussions that crossed the technical and medical community quite nicely, we believe. This was facilitated by external partners with expertise in seeking dissemination venues, resulting in interesting debates. However, we were limited in the extent to which we could discuss awe in these venues as the small number of participants resulted in not too many quotes that we could use in these debates to discuss the potential of awe of this future technology more broadly.	Although we were able to reflect on awe-some and awe-ful futures with not just participants but also the people responsible for the places we put the CoMotion bench in, we were not as successful in engaging various people and communities in reflections and discussions due to our, back then, limited expertise in how to seek dissemination venues and stage debates around awe and future technology. In hindsight, we might have benefited from a less local approach where we engaged with the people responsible the physical space, and instead put more effort into engaging with social media to reach more members of the public; however, we have yet to validate this presumption.

5.1.1. Identifying alternative and playful applications

While prototyping with future technology can help identify alternative and playful applications, this is not always easy, especially within the time constraints of many research projects. We present two strategies that worked for us and which might be useful for others: first, introducing the work to other projects, and second, to not let technical shortcomings hinder imagination.

5.1.1.1. Strategy: Introduce work to other projects. To arrive at alternative and playful applications, we found it useful to look at other projects going on in our design research labs and introduce them to each other so that they could inspire, inform and learn from each other, which led to new ideas. For example, the initial quadcopter project and our prior work with joggers helped identify alternative applications and ultimately led to our case study (Mueller et al., 2010, 2012).

5.1.1.2. Strategy: Do not let technical shortcomings hinder imagination. When aiming to identify alternative and playful applications for a future technology, we find it helpful to not let small, detailed limitations, such as technical shortcomings, hinder our imagination. This can be facilitated by reminders that fixing technical constraints is not the end goal, instead, small notes throughout the project could tell people that imagination is highly appreciated when it comes to the technology futures approach. Overall, we found that ideation is a complex process that requires an open mind, which can be difficult for a designer facing a novel, future technology with all its limitations.

5.1.2. Documenting the envisioning process

Unsurprisingly, documenting the envisioning process to help others arrive at functional prototypes is an ongoing challenge (Benford et al., 2013). We have experimented with desk-mounted action cameras, which captured some of the process but did not record the last-minute design decisions conducted in the field, nor those away from the desk. Furthermore, the video medium only captures the visual characteristics and consequences of some design decisions, while others are lost. In addition to the action cameras, we experimented with using iPads to record our envisioning process. We found the feedback provided through the iPad's large display very useful. The display allowed for an instant reflection on activities from a third-person perspective (Mueller et al., 2018). The display also provided a visual reminder of what was captured, highlighting what was in the shot (and what was not). While we attempted to use the think-aloud method when designing, we found this approach tiresome and felt that it hindered a flow experience (Csikszentmihalyi, 1990). We acknowledge that other approaches for documentation certainly exist, such as design workbooks (Gaver, 2011), however, we did not explore them in our case studies and therefore encourage future work to investigate if they might also be suitable here.

5.1.2.1. Strategy: Consider using visual recording technology. Based on our experiences above, we suggest that design researchers consider using visual recording technology to document the design process. The use of visual recording technology can complement any traditional methods such as daily notetaking. We found that visual recording, despite its shortcomings mentioned above, placed a light burden on the design researcher and was useful to capture details that notetaking might miss.

5.2. Challenges of technology futures: concretizing challenges

We believe that the concretizing stage can pose unique challenges that are exacerbated by the in-situ character of user appropriation. Based on our experiences, we highlight the challenges of how to capture and how to communicate the in-situ experience.

5.2.1. Capturing in-situ experience

Capturing the in-situ experience is challenging. The work of understanding users' appropriation via an in-situ deployment carries with it the imperative to avoid directly observing participants and introducing observer effects. While it would be preferable to capture the experience automatically (for example, through body-worn cameras, which raises privacy issues) or for the participants to capture it themselves, both are difficult alternatives.

5.2.1.1. Strategy: Consider utilizing data logging and discuss during interviews. We found it useful to log data from the system during the in-situ deployment, including logging when participants were not using the system (this data suggested times when users did not find the system useful). Consequently, we usually included a logging function into our systems that captured any events (and non-events) at a high frequency. Of course, considering log data is not new, however, we want to highlight that we found it particularly useful to show this log data to the participants during the interviews. We asked them about certain aspects of the data and what they thought had happened. We encouraged them to elaborate on those situations because this approach might provide insights into when and how the future technology elicited feelings of awe or other affective responses. Similar to explicitation interviews (Vermesch, 1994), this strategy can encourage participants to recall specific experience instances.

5.2.2. Communicating experience

To support concretizing, it is important to communicate the in-situ deployment experience so that the researchers and the participants undertaking the futuring work can understand it. However, communicating an experience is not easy. Conventional means of communication, like video recording, can fall short in capturing and conveying the nuances of an experience, such as haptic feedback (as was experienced by users of the CoMotion Bench).

5.2.2.1. Strategy: Consider asking participants to record their experiences. Although we acknowledge that video recording has limitations, we found that it offered the best compromise between feasibility and practicality. We asked participants to record their interactions and then play those recordings back to us, because this type of review can enrich the description of events. However, this request required participants to be very organized, and their compliance could interfere with (and change) any awe experience they might have. Awe is a very personal and intimate feeling. Recording the experience might take the participant "out of" this feeling and promote a more objective, third-person (Svanaes, 2019) view of their future technology experience. With this risk in mind, we recommend that researchers consider the use of video wisely, and we highlight its potential to easily capture their in-situ experience without the need for researchers to be nearby. However, we also point out that this capturing process might affect participants' experiences.

5.3. Challenges of technology futures: futuring challenges

We believe that futuring faces challenges in particular with the dissemination and implications of awe-inspiring experiences. Based on our experiences, we highlight the challenge of managing the researcher's limited control over the public exposure of their results.

5.3.1. Managing exposure with limited control

In undertaking our work, we normally engage actively with the media, contact media representatives, write press releases, and engage with our institutions' media departments and offices. This approach gives us some control over the way our research and associated findings are communicated. However, we have been surprised by how often the media independently rewrite and reinterpret our reports and do not confirm anything with the original authors or our respective institutions. These actions often led to overly simplistic summaries (especially when compressed to Tweets), slightly divergent information, and even patently incorrect and misleading representations of our work and findings. Our attempts to contact the writers of these articles and seek clarification have met with little success. Furthermore, our work is concerned with future technologies, which can, as we have noted, carry certain emotional connotations and can also be misrepresented by those wishing to pursue particular agendas. Because these risks are hard to avoid, we highlight the need for researchers to be aware that, during the futuring stage (and especially once a story is "out"), they will have only very limited control of the redistribution and interpretation of their results.

Our first encounter with limited control over the dissemination aspect of futuring was initially quite confronting. However, over time, and with more experience, we came to accept the nature of the media process. For example, we simply do not know how many articles have been generated based on our existing interviews and how many of them were done by algorithms that introduced errors that a human would probably not make. Simply accepting this fact helped to prepare for future occurrences in the future.

5.3.1.1. Strategy: Be prepared for limited control. We highlight to researchers that they will probably have limited control over dissemination in the futuring stage. The wider the news of their work spreads, the more likely it is that they might lose control of the story and become unable to do very much about it. One way to prepare for this outcome (albeit to a limited and often frustrating extent) is to anticipate it so that it does not come as a surprise, as we found that this can help manage any emotional response. Furthermore, we have found it helpful to engage with our public relations office that provided us with media training sessions that aided in being prepared for limited control.

6. Discussion

We now discuss our results in relation to prior work, articulating how we confirm, refute or extend previous approaches in HCI that concerned themselves with future technology.

We begin by acknowledging that HCI has previously engaged with future technology. Approaches such as Wizard of Oz experiments are popular in the interaction designer's toolbox that allow people to engage with future technology to an extent where the future technology might not even be available to the designer: The Wizard of Oz experiment is a research experiment in which people interact with a computer system that the research subject believes to be autonomous, but which is actually being operated by an unseen human being, the researcher (Bella and Hanington, 2012). This allows studying how people would engage with future technology, speaking to our approach. However, unlike Wizard of Oz, the technology futures approach focuses on the use of fully functional prototypes, not on speculations, hence researchers are much more restricted in terms of what they can offer to participants for their study. Nevertheless, we believe that the full functionality of the prototypes has the advantage that it allows for a more realistic account of what the future might hold. The researcher is more restricted in what they can study, however, this constraint can also be seen as guiding the designer in more fully engaging with the limitations and hence also the opportunities of the technology, facilitating a more intimate engagement with the future technology. Interesting for us is the fact that the Wizard of Oz experiment does not consider that future technology can facilitate awe. As such, a designer creating a Wizard of Oz experiment would have no guidance that would distinguish between creating an experiment with, for example, a decade old technology or a future technology. Therefore, we might say that the Wizard of Oz experiment is technology-age wise agnostic. This misses out on the opportunity to use the study to tease out opportunities enabled only through the novel aspect of a future technology, facilitating experiences not possible without it, such as awe. With our work, we hope that we have been able to provide designers with some structured guidance around how they can engage with such future technology and provide firsthand insights how to go about it.

Reeves' work (Reeves, 2012) around envisioning in ubiquitous computing in particular, and HCI more generally, highlighted that the field is often implicitly using future technology in designs without being clear about whether the resulting prototypes are meant to serve as fictions, forecasts or extrapolations. In consequence, Reeves suggests changing "the way we read, interpret and use envisionings" through taking into account other aspects such as context and intended audience. With our work, we have given designers a structured approach of how to engage with such future technology. By engaging with it in the field, we allow people to experience the technology firsthand, foregrounding the context of use. However, we acknowledge that we have not (yet) provided guidance for designers around how to engage with and analyze this context beyond the opportunity to study it. Furthermore, our case studies provided insights into the role of intended audiences for prototypes that engage with future technology, such as the use of joggers in Joggobot, however, our work does not (yet) provide guidance for designers on how to take these intended audiences into account. Nevertheless, we hope that our work make what Reeves describes as a confusing role of fiction, forecasting and extrapolation, clearer for envisioning within HCI by providing a set of stages and associated goals, objectives and activities that designers could use as handles when considering these different roles and researchers could use our framework as analytical lens to clarify such roles when encountering existing systems.

Our work also needs to be discussed in relation to research through design, as this approach is quite common in HCI and has demonstrated its potential to engage people with future technology over the years. The research through design approach highlights the role of the designer in the knowledge production process while appreciating the practice the designer engages with. As such, it aligns with our focus on the designer. Moreover, our three stages speak to common stages in the research through design approach. However, unlike existing articulations of the research through design approach that stop at the stages (Dow et al., 2013; Gaver, 2012; Zimmerman et al., 2007), our article provides further structure through the goals, objectives and activities, hopefully guiding designers in a useful way without restricting them. In particular, we hope that junior designers, who do not know where to start, would find our structure useful. Moreover, we find that research through design does not differentiate between future technology and existing technology, in contrast, we articulated the technology futures approach with future technology in mind, rising as a direct consequence of future technology being able to elicit awe (unlike old technology, that would probably fall short in this regard). Furthermore, we point out that Gaver called for more interaction design research that results in theory that is "provisional, contingent and aspirational" (Gaver, 2012). We believe that the results coming from the three stages of the technology futures approach can be provisional, as the technology it is concerned with is only emerging. This is also the reason why any resulting theory will most likely be contingent. Lastly, through our work, we hope that we are able to inspire designers to engage with future technology, where the outcome is unknown, hence we hope that the resulting theory is also aspirational.

Another key aspect of research through design that Gaver highlights is that the approach is "generative", meaning that research through design is not so much concerned with "what is", but rather, "what might be" (Gaver, 2012). This aligns well with the technology futures approach as our approach also focuses on "what might be", especially through the envisioning stage. Furthermore, Gaver proposes that research through design sets the condition for a feedback loop in which the development of a new design sets the scene for the development of variations, resulting in "new areas of reality" (Gaver, 2012). This aligns nicely with our iterative aspect of our approach.

Furthermore, we appreciate Gaver's statement that "one can imagine 'designing in the style of Dieter Rams' without the need for detailed formal theory to direct decisions" (Gaver, 2012) as we see the opportunity to design in the style of the technology futures approach. As such, one might even regard our article as a design portfolio, responding to the call to have more research through design projects presenting research through them (Gaver, 2012). We note, however, that Gaver makes a point that research through design does not need to "abstract regularities to design for the same domains", contrasting this with the commonly used design patterns often engaged with in HCI (Alexander, 1977). We do not see the same extent of a contrast in our approach, hence, unlike Gaver, we have articulated design strategies that, although not intended to ensure the same results in the same domains, could be regarded as belonging to the same school as design patterns. Time will tell if they can be useful for designers without being too restrictive.

In addition, we note that the research through design approach has also engaged with play as a way to facilitate better outcomes, hence aligns with technology futures from this perspective (Deen et al., 2014, Gaver, 2002). In particular, it speaks to our approach of facilitating playful engagement when it comes to future technology. We extend this prior theory by adding a set of practical insights and strategies on how designers can go about it, focusing on the particularities afforded by future technology.

7. Limitations and Future Work

Like most HCI design research methods work, our article also has limitations. We acknowledge these limitations and discuss how future work could address them. For example, we acknowledge that, so far, we have only considered technologies that researchers can get access to. The technologies we consider in the article need to be graspable by designers so they can engage with them at a granular level. Therefore, several future technologies appear to be out of reach for our envisioning stage, at least for now, and therefore other approaches might be more suitable. For example, Weisz et al. sought to facilitate an informed discourse around quantum computing. As quantum computers were not easily accessible at the time, the authors decided to create a board game around quantum computing concepts (Weisz et al., 2018). Future work might explore if it is possible to profitably combine our work with such approaches (by, for example, incorporating such a game in our "activities" during the concretizing stage).

We also acknowledge that further case studies could enrich our approach. We believe that future case studies, conceived and developed with the technology futures approach in mind, will complement ours and provide a more complete picture of how the technology futures approach can be implemented from the start of a project. Nevertheless, we hope that our three case studies, each of which has its strengths and weaknesses when implementing the technology futures approach, were able to provide an illustrative account of our approach.

Furthermore, we acknowledge that we have focused primarily on qualitative approaches, aligning with prior work that recommended qualitative methods for design research (Creswell and Creswell, 2017). However, this alignment does not exclude the use of quantitative data, which could complement our activities across the technology futures approach. For example, during stage 2, researchers might want to add measures of awe. Indeed, Krogh-Jespersen et al. suggested that experiences of awe can be operationalized into four facets: connection, oppression, physical reactions (such as chills and goosebumps), and a diminished sense of self in relation to the vastness of the world (Krogh-Jespersen et al., 2020). Future quantitative work could use these four facets to quantify any evoked sense of awe, allowing easier comparisons with other projects. Similarly, we have also not yet quantitatively examined to what extent the futuring stage led to substantive discussions. Instead, we have reported on our own qualitative assessment based on feedback from the media and study participants. The addition of quantitative measures could supplement our approach. Furthermore, we acknowledge that we have not yet examined the relationship between the novelty effect (Koch et al., 2018; Shavitt and Stellner, 2011; Shin et al., 2019) and awe, leaving future work to examine how awe is affected by repeated or frequent use.

We also wish to encourage future work around how sharpening our focus on awe could facilitate shared reflection and a more nuanced and enriched public debate. Addressing (and enhancing) the quality of public debates is a more complex and far-reaching challenge because we also need to understand how those debates inform future design decisions. We hope that our articulation of how designers can engage people with future technologies in a structured way can serve as a valuable springboard for such upcoming research.

Furthermore, we can also envision future work comparing designing for awe to some of the approaches mentioned above that aim for more monolithic user experiences such as "coolness" or "wow" (Sundar et al., 2014). The results of these different approaches could then be compared and possibly even quantitatively measure any differences. We hope that our qualitative account of the technology futures approach derived from drawing upon our own experiences provides a solid starting point for such future investigations. In particular, we hope that the reporting of our experiences offers a rich, practical perspective that hopefully makes such future work appealing to other design researchers.

We also acknowledge that our approach is untested by other designers so far and hence we can only speculate that the details we have given in this article are enough to reproduce our approach. We hope that our writing offers enough guidance so that other designers can engage with the approach successfully. The outcomes will hopefully align with our expectations. Future work could also investigate the value of our approach. For example, we can envision workshops in which half the group designs with future technology using our approach, the other half without our approach, and then compare results. Furthermore, we believe that future work would be beneficial to examine if our approach results in the same outcomes if engaged with by other designers, speaking to the replicability and reproducibility of our work. We hope that our article can serve as a useful starting point for such investigations and that they can become a useful springboard for developing a new understanding of how to engage with future technology.

Furthermore, we acknowledge that drawing on our own experiences to arrive at an articulation of an approach after having developed the case studies might be viewed as limitation, but there are also benefits. For example, our experiences offer a rich practical perspective that hopefully makes the work appealing and understandable for other design researchers who want to engage with our approach. Furthermore, we acknowledge that our approach needs to be further discussed, refuted, and refined so that it might mature and become a stable method that can be, for example, taught as part of an HCI curriculum. However, we acknowledge that building on our article by examining the approach with additional case studies could be an interesting avenue for future work.

In addition to the challenges we have identified at each stage of the technology futures approach, we are aware that we have not yet discussed several overarching challenges, such as ethics, conflict of interests, and various risks. We encourage future work around these overarching challenges and the identification of ways to mitigate them. Furthermore, another limitation of our work is that we assume that design researchers have access to future technologies and the resources and capabilities to engage with them. We acknowledge our privileged position relative to others in the HCI community. We have also not yet considered how different cultural, socioeconomic, and developmental contexts raise ethical issues (for such work, a good provocative starting point might be the paper by Brown et al. (2016)) and, at the same time, multiply the possibilities for creative envisioning, prototyping, in-situ studies, and shared reflection. Future work on the technology futures approach therefore might want to consider addressing the engagement of design researchers working in underprivileged circumstances.

8. Conclusions

As future technologies constantly emerge, design researchers have unique opportunities to inform the public discourse around those technologies, to attend more to the people who end up using them, to ensure that we listen to the stories those people tell about their experiences, and to consider those stories when developing future technologies for human use. To help design researchers take these opportunities, we have presented the technology futures approach to engage with novel technology, supplementing it with hands-on guidance we derived from our own experiences. Through its three stages of envisioning, concretizing and futuring, the technology futures approach builds on the belief that experiencing technology first-hand, in alternative and playful ways, can allow for a refined view of the potential for awe-inspiring futures.

Our work borrows from, combines with, and complements other design HCI approaches. While our approach is not a radical departure from existing practice, it offers a structured articulation of individual components, grounded in our focus on awe, and it provides a much-needed practical guide for future design research work. While we have offered a set of case study examples to demonstrate that our approach can be practical in everyday design practice, we also acknowledge that the use of case studies highlights that this approach is still emerging and will benefit from new examples, more theoretical scrutiny, and future refinements. Nevertheless, we are confident that our integrated and expansive approach can surface future technology uses that go beyond the technology's initial design intent and application domains, and that it can support further technological advancements. We hope that our work inspires designers, provides practitioners with a place to start when they encounter future technologies, supports researchers to investigate, analyze, and compare different HCI approaches, and equips teachers with a vocabulary that helps them share the approach with their students.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

Data Availability

No data was used for the research described in the article.

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