Moving on from Weiser's Vision of Calm Computing: Engaging UbiComp Experiences

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Abstract. A motivation behind much UbiComp research has been to make our lives convenient, comfortable and informed, following in the footsteps of Weiser's calm computing vision. Three themes that have dominated are context awareness, ambient intelligence and monitoring/tracking. While these avenues of research have been fruitful their accomplishments do not match up to anything like Weiser's world. This paper discusses why this is so and argues that is time for a change of direction in the field. An alternative agenda is outlined that focuses on engaging rather than calming people. Humans are very resourceful at exploiting their environments and extending their capabilities using existing strategies and tools. I describe how pervasive technologies can be added to the mix, outlining three areas of practice where there is much potential for professionals and laypeople alike to combine, adapt and use them in creative and constructive ways.

Keywords: calm computing, Weiser, user experiences, engaged living, UbiComp history, pervasive technologies, proactive computing.

1 Introduction

Mark Weiser's vision of ubiquitous computing has had an enormous impact on the directions that the nascent field of UbiComp has taken. A central thesis was that while "computers for personal use have focused on the excitement of interaction…the most potentially interesting, challenging and profound change implied by the ubiquitous computing era is a focus on calm." [46]. Given the likelihood that computers will be everywhere, in our environments and even embedded in our bodies, he argued that they better "stay out of the way" and not overburden us in our everyday lives. In contrast, his picture of calm technology portrayed a world of serenity, comfort and awareness, where we are kept perpetually informed of what is happening around us, what is going to happen and what has just happened. Information would appear in the centre of our attention when needed and effortlessly disappear into the periphery of our attention when not.

Now regarded as the forefather of UbiComp, Weiser has inspired governments, researchers and developers across the globe. Most prominent was the European Community's Disappearing Computer initiative in the late 90s and early 2000s, that funded a large number of research projects to investigate how information technology could be diffused into everyday objects and settings and to see how this could lead to

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new ways of supporting and enhancing people's lives that went above and beyond what was possible using desktop machines. Other ambitious and far-reaching projects included MIT's Oxygen, HP's CoolTown, IBM's BlueEyes, Philips Vision of the Future and attempts by various telecom companies and academia to create the ultimate 'smart home', e.g., Orange-at-Home and Aware Home. A central aspiration running through these early efforts was that the environment, the home, and our possessions would be aware, adapt and respond to our varying comfort needs, individual moods and information requirements. We would only have to walk into a room, make a gesture or speak aloud and the environment would bend to our will and respond or react as deemed appropriate for that point in time.

Considerable effort has gone into realizing Weiser's vision in terms of developing frameworks, technologies and infrastructures. Proactive computing was put forward as an approach to determine how to program computers to take the initiative to act on people's behalf [43]. The environment has been augmented with various computational resources to provide information and services, when and where desired, with the implicit goal of "assisting everyday life and not overwhelming it" [1]. An assortment of sensors have been experimented with in our homes, hospitals, public buildings, physical environments and even our bodies to detect trends and anomalies, providing a dizzying array of data about our health, movements, changes in the environment and so on. Algorithms have been developed to analyze the data in order for inferences to be made about what actions to take for people. In addition, sensed data is increasingly being used to automate mundane operations and actions that we would have done in our everyday worlds using conventional knobs, buttons and other physical controls. For example, our favorite kind of music or TV show that we like to exercise to will automatically play as we enter a gym. Sensed data is also being used to remind us of things we often forget to do at salient times, such as detecting the absence of milk in the fridge and messaging us to buy a carton when passing the grocery store.

But, as advanced and impressive as these endeavors have been they still do not match up to anything like a world of calm computing. There is an enormous gap between the dream of comfortable, informed and effortless living and the accomplishments of UbiComp research. As pointed out by Greenfield [20] "we simply don't do 'smart' very well yet" because it involves solving very hard artificial intelligence problems that in many ways are more challenging than creating an artificial human [26]. A fundamental stumbling block has been harnessing the huge variability in what people do, their motives for doing it, when they do it and how they do it. Ethnographic studies of how people manage their lives – ranging from those suffering from Alzheimer's Disease to high-powered professionals – have revealed that the specifics of the context surrounding people's day-to-day living are much more subtle, fluid and idiosyncratic than theories of context have led us to believe [40]. This makes it difficult, if not impossible, to try to implement context in any practical sense and from which to make sensible predictions about what someone is feeling, wanting or needing at a given moment. Hence, while it has been possible to develop a range of simple UbiComp systems that can offer relevant information at opportune moments (e.g., reminding and recommending to us things that are considered useful and important) it is proving to be much more difficult to build truly smart systems that can understand or accurately model people's behaviors, moods and intentions.

The very idea of calm computing has also raised a number of ethical and social concerns. Even if it was possible for Weiser's dream to be fulfilled would we want to live in such a world? In particular, is it desirable to depend on computers to take on our day-to-day decision-making and planning activities? Will our abilities to learn, remember and think for ourselves suffer if we begin to rely increasingly on the environment to do them for us? Furthermore, how do designers decide which activities should be left for humans to control and which are acceptable and valuable for the environment to take over responsibility for?

In this paper I argue that progress in UbiComp research has been hampered by intractable computational and ethical problems and that we need to begin taking stock of both the dream and developments in the field. In particular, we need to rethink the value and role of calm and proactive computing as main driving forces. It is without question that Weiser's enormous legacy will (and should) continue to have an impact on UbiComp developments. However, sufficient time has passed since his untimely death and it should be possible now for researchers to take a critical stance. As part of this exercise, I propose that the field needs to broaden its scope, setting and addressing other goals that are more attainable and down-to-earth. New agendas need also to be outlined that can guide, stimulate and challenge UbiComp (and other) researchers and developers, building upon the growing body of research in the field.

To this end, I propose one such alternative agenda which focuses on designing UbiComp technologies for engaging user experiences. It argues for a significant shift from *proactive computing* to *proactive people*; where UbiComp technologies are designed not to do things for people but to engage them more actively in what they currently do. Rather than calm living it promotes engaged living, where technology is designed to *enable* people to do what they want, need or never even considered before by acting in and upon the environment. Instead of embedding pervasive computing everywhere in the environment it considers how UbiComp technologies can be created as ensembles or ecologies of resources, that can be mobile and/or fixed, to serve specific purposes and be situated in particular places. Furthermore, it argues that people rather than computers should take the initiative to be constructive, creative and, ultimately, in control of their interactions with the world – in novel and extensive ways.

While this agenda might appear to be a regressive step and even an anathema to some ardent followers of Weiser's vision, I argue that it (and other agendas) will turn out to be more beneficial for society than persisting with following an unrealistic goal. Current technological developments together with emerging findings from user studies, showing how human activities have been positively extended by 'bounded' (as opposed to pervasive) technologies, suggest that much can be gained from reconceptualizing UbiComp in terms of designing user experiences that creatively, excitedly, and constructively extend what people currently do. This does not mean that the main tenet of Weiser's vision be discarded (i.e., computers appearing when needed and disappearing when not) but rather we begin to entertain other possibilities – besides calmness – for steering UbiComp research. Examples include extending and supporting personal, cognitive and social processes such as habit-changing, problem-solving, creating, analyzing, learning or performing a skill. Ultimately, research and development should be driven by a better understanding of human activity rather than what has tended to happen, namely, "daring to intervene, clumsily, in situations that already work reasonably well" [20, p231].

In the remainder of this paper I offer a constructive critique of Weiser's vision and the subsequent research that has followed in its footsteps. I then outline an alternative agenda for UbiComp, highlighting pertinent questions, concerns and illustrative examples of how it can be achieved.

2 Weiser's Vision Revisited and Early Research

To illustrate how his early vision of ubiquitous computing could work, Weiser [47] presented a detailed scenario about a day in the life of Sal, an executive single mother. The scenario describes what Sal gets up to, as she moves from her domestic world to her work place, during which she is perpetually informed of the goings on of her family, neighbors, fellow citizens and work colleagues. With this knowledge she is able to keep up-to-date, avoid obstacles, make the most of her time and conduct her work – all in smooth and effective ways. The scenario emphasizes coziness, comfort and effortlessness:

"Sal awakens: she smells coffee. A few minutes ago her alarm clock, alerted by her restless rolling before waking, had quietly asked "coffee?", and she had mumbled "yes." "Yes" and "no" are the only words it knows.

Sal looks out her windows at her neighborhood. Sunlight and a fence are visible through one, but through others she sees electronic trails that have been kept for her of neighbors' coming and going during the early morning. Privacy conventions and practical data rates prevent displaying video footage, but time markers electronic tracks on the neighborhood map let Sal feel cozy in her street."

In this small excerpt we see how the world evolves around Sal's assumed needs, where computers, cameras and sensors are embedded into her world to make her life super efficient, smooth and calm. It is as if she glides through life, where everything is done or laid out for her and whenever there is potential for frustration, such as a traffic jam or parking problem, the invisible computers come to her rescue and gently inform her of what to do and where to go. It is worth drawing an analogy here with the world of the landed aristocracy in Victorian England who's day-to-day live was supported by a raft of servants that were deemed to be invisible to them. This scenario also highlights the ethical issues that such an informed world needs to address, namely the importance of establishing appropriate levels of privacy that are considered acceptable by a community (e.g., having abstract digital trails rather than video footage to ensure anonymity).

The core topics raised in Weiser's seminal papers have motivated much subsequent UbiComp research. Most prominent themes are context-aware computing, ambient/ubiquitous intelligence and recording/tracking and monitoring. (N.B. It should be noted that these are not mutually exclusive but overlap in the aims and methods used.)

2.1 Context-Aware Computing

Context-aware computing focuses on detecting, identifying and locating people's movements, routines or actions with a view to using this information to provide relevant information that may augment or assist a person or persons. Many projects have been conducted under this heading to the extent that it has been noted that ubiquitous computing is sometimes called context-aware computing [12]. In a nutshell, context is viewed as something that can be sensed and measured using location, time, person, activity type and other dimensions. An example of an early context-sensitive application was comMotion that used location information and a speech output system to inform people when they were driving or cycling past a store to buy the groceries they needed [30].

A motivation behind much context-aware computing is to find ways of compensating for limitations in human cognition, e.g., attention, memory, learning, comprehension, and decision-making, through the use of sensor-based and computational tools. For example, augmented cognition – originating in military research – seeks to develop methods "to open bottlenecks and address the biases and deficits in human cognition" by continually sensing the ongoing context and inferring what strategies to employ to help people in their tasks [5].

Key questions in context-aware computing concern what to sense, what form and what kind of information to represent to augment ongoing activities. A number of location and tagging technologies have been developed, such as RFID, satellite, GPS and ultrasonics, to enable certain categories of information to be tracked and detected. Many of these, however, have been beset with detection and precision limitations, sometimes resulting in unreliable and inaccurate data. Recent advances in cognitive radio technology that is software defined (SDR), promises to be more powerful; wireless systems will be able to locate and link to locally unused radio frequency, based on the ability to sense and remember various factors, such as human behavior, making them more dependable and more aware of their surroundings [4]. The advocates of this new technology portray its potential for highly complex settings, such as combat war zones to help commanders from different friendly forces stay appraised of the latest situation, through voice, data and video links, thereby reducing collateral damage [4].

While newer technological developments may enable more accurate data to be detected and collected it is questionable as to how effectively it can be used. It still involves Herculean efforts to understand, interpret and act upon in real-time and in meaningful ways. Context-aware systems that attempt to guide a person through certain activities require models of human behavior and intentionality that are based on rationality and predictability [40]. However, as already mentioned, people often behave in unpredictable and subtle ways in their day-to-day contexts. Therefore, it is likely that context-aware systems will only ever be successful in highly constrained settings.

2.2 Ambient and Ubiquitous Intelligence

Another dominant theme that has emerged in the field of UbiComp is ubiquitous or ambient intelligence, i.e., computational intelligence that is part of both the physical and the digital worlds. This approach follows on from work in artificial intelligence. The phrase 'right place/right time/right means' has been sloganized with visions of smart worlds and smart things, embedded with intelligence, that will predict people's needs and react accordingly [25]. Instead of reaching for the remote to change the TV channel the smart entertainment system will do it for us, instead of browsing the web the smart internet will find the information we need and so on. Just as it is becoming increasingly common place for supermarkets to automatically open their doors as we walk towards them, toilets to flush when we stand up and taps to release water as we wave our hands under them it is envisioned that information will appear on our TVs, watches, walls, and other displays as and when needed (e.g., children will be alerted of dangers and tourists will be informed of points of interest when walking through an unfamiliar city).

However, similar to context-aware computing, ambient intelligence is proving to be a hard nut to crack. While there have been significant advances in computer vision, speech recognition and gesture-based detection, the reality of multimodal interfaces – that can predict and deliver with accuracy and sensitivity what is assumed people want or need – is a long way off. One of the most well known attempts at implementing ambient intelligence was IBM's BlueEyes project, that sought to develop computers that could "see" and "feel" like humans. Sensing technology was used to identify a person's actions and to extract key information that was then analyzed to determine the person's physical, emotional, or informational state. This was intended to be used to help make people "more productive by performing expected actions or by providing expected information." The success of the BlueEyes project, however, was limited; an example of an achievement that is posted on its website is of a television that would turn itself on when a person in the room made eye contact with it. To turn it off, the person could 'tell' it to switch off.

Such meager accomplishments in both context-aware computing and ambient intelligence reflect just how difficult it can be to get a machine to behave like a human. But it is essential that such systems be accurate for them to be accepted by humans in their everyday context. Reading, interpreting and acting upon people's moods, intentions, desires, etc, at any given moment in an appropriate way is a highly developed human skill that when humans get it wrong can lead to misunderstanding. When a ubiquitous computing system gets it wrong – which is likely to be considerably more frequent – it is likely to be more frustrating and we are likely to be less forgiving. For example, when the system decides to switch on the TV because we happen momentarily to stare into space while reading a book, it is likely to be unnerving and extremely annoying, especially if 'it' persistently gets it wrong.

2.3 Recording, Tracking and Monitoring

The push towards developing assistive applications through sensing and alerting has been most marked for vulnerable people; a number of UbiComp systems have been built to constantly check up on the elderly, the physically and mentally disabled [34]. The movements, habits, health and mishaps of such people are recorded, tracked and presented via remote monitors to the families, carers and other people responsible for them, who can then use the information to make decisions about whether to intervene or administer alternative forms of medical care or help. In particular, there has been a move towards developing ubiquitous computing systems to aid elderly people, who need to be cared for, by helping them take their medicines regularly, checking up on their physical health, monitoring their whereabouts and detecting when they have fallen over [e.g., 13].

A number of assisted living applications and services has also been developed to help people with loss of vision or deteriorating memory to be more independent in their lives. For example, Cyber Crumbs was designed to help people with progressive vision loss find their way around a building using a reader badge system that reads out directions and warns of obstacles, such as fire hydrants [39]. Cook's Collage was developed as an aid for people with memory loss. It replays a series of digital still images in a comic strip reel format depicting people's cooking actions *in situ*, intended to help them remember if they have forgotten a step (e.g., adding a particular ingredient) after being distracted [45].

A reason for there being so much interest in helping the less able in UbiComp is that explicit needs and benefits can be readily identified for these user groups. Moreover, there is an assumption that pervasive technologies offer more flexibility and scope for providing solutions compared with other computing technologies since they can sense, monitor and detect people's movements, bodily functions, etc., in ways not possible before. There is a danger, however, that such techniques may probe too far into the lives of less able people resulting in – albeit unintentionally – 'extreme' forms of recording, tracking and monitoring that these people may have no control over. For example, consider the extent to which a group of researchers went to in order to help with the care of old people in a residential care home [6]. A variety of monitoring devices were installed in the home, including badges on the patients and the caregivers and switches on the room doors that detected when they were open or closed. Load sensors were also used to measure and monitor weight changes of people while in their beds; the primary aim was to track trends in weight gain or loss over time. But the sensors could also be used to infer how well someone was sleeping. If significant movement was detected during the night this could enable a caregiver to see whether the person was having trouble sleeping (and if there was a huge increase in weight this could be inferred as someone else getting in or on the bed).

Such panopticon developments elicit a knee-jerk reaction of horror in us. While the motives behind such projects are altruistic they can also be naïve, overlooking how vulnerable people's privacy and self-respect may be being violated. Not surprisingly, there has been enormous concern by the media and other social scientists about the social implications of recording, tracking and re-representing people's movements, conversations, actions and transactions. Inevitably, a focus has been on the negative aspects, namely a person's right to privacy being breached. Is it right to be videoing and sensing people when sleeping, eating, etc., especially when they are not at their best [2]? Is it right to be providing information to other family members about their granny's sleeping habits, especially if it can be inferred from the sensed data that she might have got into bed with another patient, which none of the vested parties might want to share or let the others know about.

While most projects are sensitive to the privacy and ethical problems surrounding the monitoring of people, they are not easy to solve and have ended up overwhelming UbiComp research. Indeed, much of the discussion about the human aspects in the field has been primarily about the trade-offs between security and privacy, convenience and privacy, and informedness and privacy. This focus has often been at the expense of other human concerns receiving less airing, such as how recording, tracking and re-representing movements and other information can be used to facilitate social and cognitive processes.

My intention here is not to diminish the importance of awareness, ambience and monitoring to detect and inform people in their everyday lives, together with the ethical and social issues they raise. Rather, my overview of the projects in these areas has revealed how difficult it is to build calm computing systems and yet the attempts have largely dominated the field of UbiComp. Those that have tried have fallen short, resulting in prototype systems that can sometimes appear to be trivial or demeaning. Conversely, there has been less focus on other areas of research that could prove to be easier to achieve and potentially of more benefit to society. The time is ripe for other directions to take center stage in UbiComp. One such avenue promoted here is to consider how humankind's evolved practices of science, learning, health, work and play can be enhanced. This involves thinking about UbiComp not in terms of embedding the environment with all manner of pervasive technologies but instead as bounded ensembles of entities (e.g., tools, surfaces and lenses) that can be mobile, collaborative or remote, through which information, other people and the environment are viewed and interacted with when needed. Importantly, it argues for rethinking the nature of our relationship with the computer.

3 A New Agenda for UbiComp: Engaging User Experiences

I suggest here that it is highly profitable to recast UbiComp research in the context of a central motivation that computers were originally designed for, namely, as tools, devices and systems that can extend and engage people in their activities and pursuits. My reason for proposing this is based on the success of researchers who have started to take this approach. In particular, a number of user studies, exploring how UbiComp technologies are being appropriated, are revealing how the 'excitement of interaction' can be brought back in innovative ways; that is not frustrating and which is quite different from that experienced with desktop applications. For example, various mixed reality, physical-digital spaces and sensor-rich physical environments have been developed to enable people to engage and use multiple dynamic representations in novel ways: in scientific and working practices and in collaborative learning and experimental games. More extensive inquiries and decisions have been enabled *in situ*, e.g., determining the effects of deforestation in different continents and working out when is the best time to spray or pick grapes in a vineyard.

Recently, world famous computer scientist John Seely Brown put forward his updated vision of UbiComp[1] in a keynote, outlining 'a common sense' model that emphasizes how UbiComp can help to catalyze creativity [41]. He proposed that creating and learning be seen as integral to our work and leisure that are formed through recreation and appropriation activities. In a similar vein, I argue that it is timely to switch from a reactive view of people towards a more proactive one. Instead of augmenting the environment to reduce the need for humans to think for themselves about what to do, what to select, etc., and doing it for them, we should consider how UbiComp technologies can be designed to augment the human intellect so that people can perform ever greater feats, extending their ability to learn, make decisions, reason, create, solve complex problems and generate innovative ideas. Weiser's idea that

[1] John Seely Brown was a co-author of the paper written by Weiser on calm technology.

technologies be designed to be 'so embedded, so fitting and so natural' that we use them without thinking about them needs to be counter-balanced; we should also be designing them to be exciting, stimulating and even provocative – causing us to reflect upon and think about our interactions with them. While Weiser promoted the advantages of calm computing I advocate the benefits of engaging UbiComp experiences that provoke us to learn, understand and reflect more upon our interactions with technologies and each other.

A central concern of the engaging UbiComp experiences agenda is to fathom out how best to represent and present information that is accessible via different surfaces, devices and tools for the activity at hand. This requires determining how to make intelligible, usable and useful, the recordings of science, medicine, etc., that are streaming from an increasing array of sensors placed throughout the world. It also entails figuring out how to integrate and replay, in meaningful and powerful ways, the masses of digital recordings that are begin gathered and archived such that professionals and researchers can perform new forms of computation and problem-solving, leading to novel insights. In addition, it involves experimenting more with creative and constructive uses of UbiComp technologies and archived digital material that will excite and even make people feel uncomfortable.

In terms of who should benefit, it is useful to think of how UbiComp technologies can be developed not for the Sal's of the world, but for particular domains that can be set up and customized by an individual firm or organization, such as for agriculture production, environmental restoration or retailing. At a smaller scale, it is important to consider how suitable combinations of sensors, mobile devices, shared displays, and computational devices can be assembled by non-UbiComp experts (such as scientists, teachers, doctors) that they can learn, customize and 'mash' (i.e., combine together different components to create a new use). Such toolkits should not need an army of computer scientists to set up and maintain, rather the inhabitants of ubiquitous worlds should be able to take an active part in controlling their set up, evolution and destruction. Their benefits should be clear: enabling quite different forms of information flow (i.e., ways and means of accessing information) and information management (i.e., ways of storing, recording, and re-using information) from older technologies, making it possible for non-UbiCompers to begin to see how to and subsequently develop their own systems that can make a difference to their worlds. In so doing, there should be an emphasis on providing the means by which to augment and extend existing practices of working, learning and science.

As quoted by Bruner [10] "to assist the development of the powers of the mind is to provide amplification systems to which human beings, equipped with appropriate skills, can link themselves" (p.53). To enable this to happen requires a better understanding of existing human practices, be it learning, working, communicating, etc. Part of this reconceptualization should be to examine the interplay between technologies and their settings in terms of practice and appropriation [15]. "Practices develop around technologies, and technologies are adapted and incorporated into practices." (Dourish, 2001, p. 204). More studies are needed that examine what people do with their current tools and devices in their surrounding environments. In addition, more studies are needed of UbiComp technologies being used *in situ* or the wild – to help illuminate how people can construct, appropriate and use them [e.g., 16, 22, 23, 29].

With respect to interaction design issues, we need to consider how to represent and present data and information that will enable people to more extensively compute, analyze, integrate, inquire and make decisions; how to design appropriate kinds of interfaces and interaction styles for combinations of devices, displays and tools; and how to provide transparent systems that people can understand sufficiently to know how to control and interact with them. We also need to find ways of enabling professionals and laypeople alike to build, adapt and leverage UbiComp technologies in ways that extend and map onto their activities and identified needs.

A more engaging and bounded approach to UbiComp is beginning to happen but in a scattered way. Three of the most promising areas are described below: (i) playful and learning practices, (ii) scientific practices and (iii) persuasive practices. They show how UbiComp technologies can be developed to extend or change human activities together with the pertinent issues that need to be addressed. Quite different practices are covered, reflecting how the scope of UbiComp can be broad but at the same time targeted at specific users and uses.

3.1 Playful and Learning Practices

One promising approach is to develop small-scale toolkits and sandboxes, comprising interlinked tools, digital representations and physical artifacts that offer the means by which to facilitate creative authoring, designing, learning, thinking and playing. By a sandbox it is not meant the various senses it has been used in computing but more literally as a physical-digital place, kitted out with objects and tangibles to play and interact with. Importantly, these should allow different groups of people to participate in novel activities that will provoke and extend existing repertoires of technology-augmented learning, playing, improvising and creating. An example of a promising UbiComp technology toolkit is PicoCrickets, developed at MIT Media Lab, arising from the work of Mitch Resnick and his colleagues. The toolkit comprises sensors, motors, lights, microcomputers, and other physical and electrical devices that can be easily programmed and assembled to make them react, interact and communicate, enabling "musical sculptures, interactive jewelry, dancing creatures and other playful inventions" to be created by children and adults alike. An advantage of such light-weight, off-the-shelf tangible toolkits is that they offer many opportunities for different user groups (e.g., educators, consultants) to assemble and appropriate in a range of settings, such as schools, waiting rooms, playgrounds, national parks, and museums.

A nagging question, however, is how do the benefits of such UbiComp toolkits and sand boxes compare with those offered by more conventional ones – that are much cheaper and more practical to make? Is it not the case that children can be highly creative and imaginative when given simply a cardboard box to play with? If so, why go to such lengths to provide them with new tools? The debate is redolent of whether it is better for children to read a book or watch a 3D Imax movie. One is not necessarily better than the other: the two provide quite different experiences, triggering different forms of imagination, enjoyment and reflection. Likewise, UbiComp and physical toys can both provoke and stimulate, but promote different kinds of learning and collaboration among children. However, a benefit of UbiComp toolkits over physical artifacts is that they offer new opportunities to combine physical interaction, through manipulation of objects or tools or through physical body postural movement and location, with new ways of interacting, through digital technology. In particular, they provide different ways of thinking about the world than interacting solely with digital representations or solely with the physical world. In turn, this can encourage or even enhance further exploration, discovery, reflection and collaboration [35].

Examples of projects that have pioneered the design of novel physical-digital spaces to facilitate creativity and reflection include the Hunting of the Snark [32], Ambient Wood [36], RoomQuake [33] Savannah [17], Environmental Detectives [27], Drift Table [19] and Feeding Yoshi [7]. Each of these have experimented with the use of mobile, sensor and fixed technologies in combination with wireless infrastructures to encourage exploration, invention, and out of the box thinking.

The Hunting of the Snark adventure game provoked young children into observing, wondering, understanding, and integrating their fragmented experiences of novel physical-digital spaces that subsequently they reflected upon and shared as a narrative with each other. A combination of sensor-based, tangible, handheld and wireless technologies was used to create the physical-digital spaces, where an imaginary virtual creature was purported to be roaming around in. The children had to work out how to entice the creature to appear in them and then gather evidence about its personality, moods, etc, by walking with it, feeding it and flying with it. Similarly, Savannah was designed as a physical-digital game to encourage the development of children's conceptual understanding of animal behavior and interactions in an imaginary virtual world. The project used GPS and handheld computers to digitally overlay a school playing field with a virtual plain. Children took on the roles of lions, had to hunt animals in the virtual savannah and capture them to maintain energy levels. After the game, the children reflected on their experiences by interacting with a visualization on a large interactive whiteboard, that showed the trails they made in the Savannah and the sounds and images that they encountered at specific place.

The Ambient Wood project used an assortment of UbiComp technologies to encourage more self-initiation in inquiry and reflective learning. Various wireless and sensor technologies, devices and representational media were combined, designed and choreographed to appear and be used in an 'ambient' woodland. Several handcrafted listening, recording and viewing devices were created to present certain kinds of digital augmentations, such as sounds of biological processes, images of organisms, and video clips of life cycles. Some of these were triggered by the children's exploratory movements, others were collected by the children, while still others were aggregated and represented as composite information visualizations of their exploratory behavior. RoomQuake was designed to encourage children to practice scientific investigatory practices: an earthquake was simulated in a classroom using a combination of interconnected ambient media, string and physical styrofoam balls. The ambient media provided dynamic readings of the simulated earthquakes, which students then re-represented as physical models using the physical artifacts. The combination of computer-based simulations and physical-based artifacts enabled the whole class to take part in the measuring, modeling, interpreting, sparking much debate and reflection among the children about the seismic events.

As part of the Equator collaboration, a number of innovative 'seamful games' have been developed. The inherent limitations of ubiquitous technologies have been deliberately exploited to provoke the players into thinking about and acting upon their significance to the ongoing activity. Two examples are Treasure in which players had to move in and out of a wireless network connectivity to collect and then deposit gold tokens and Feeding Yoshi where the players were required to feed virtual creatures scattered around a city with virtual fruits that popped up on their displays as a result of their location and activity therein.

Evaluations of this emerging genre of physical-digital spaces for learning and playing have been positive, highlighting enhanced understanding and an immense sense of engagement. Children and adults have been able to step back and think about what they are doing when taking part in the game or learning experience, examining the rationale behind their choices when acting out and interacting with the UbiComp-based technologies in the space. However, many of the pioneering projects were technology, resource and researcher intensive. While guidance is now beginning to appear to help those wanting to design UbiComp-based learning and playing experiences [e.g., 9, 36] we need also to strive towards creating the next generation of physical-digital spaces and toolkits that will be as easy, cheap and popular to construct as Lego kits once were.

3.2 Scientific Practices

Another area where UbiComp has great potential for augmenting human activities is the practice of scientific inquiry and research. Currently, the sciences are going through a major transformation in terms of how they are studied and the computational tools that are used and needed. Microsoft's 2020 Science report – a comprehensive vision of science for the next 14 years written by a group of internationally distinguished scientists – outlines this paradigm shift [31]. It points out how new conceptual and technological tools are needed that scientists from different fields can "understand and learn from each other's solutions, and ultimately for scientists to acquire a set of widely applicable complex problem solving capabilities". These include new programming, computational, analysis and publication tools. There is much scope, too, for utilizing UbiComp technologies to enhance computation thinking, through integrating sensor-based instrumentation in the medical, environmental and chemical sciences. The ability to deliver multiple streams of dynamic data to scientists, however, needs to be matched by powerful interfaces that allow them to manipulate and share them in new ways, from any location whether in the lab or in the field.

Areas where there is likely to be obvious benefits to scientists through the integration of UbiComp and computational tools are environmental science and climate change. These involve collaborative visualization of scientific data, mobile access to data and capture of data from sensors deployed in the physical world. Being able to gain a bigger, better and more accurate picture of the environmental processes may help scientists make more accurate predictions and anticipate more effectively natural disasters, such as tsunamis, volcanoes, earthquakes and flooding. However, it may not simply be a case of more is more. New ways of managing the burgeoning datasets needs to be developed, that can be largely automated, but which also allows scientists to have effective windows, lenses etc., into so that they can interpret and make intelligible inferences from them at relevant times.

The 2020 report notes how tomorrow's scientists will need to make sense of the masses of data by becoming more computationally literate – in the sense of knowing how to make inferences from the emerging patterns and anomalies that the new generation of software analysis tools provide. To this end, a quite different mindset is needed in schools for how science is taught. The design of new learning experiences that utilize UbiComp technologies, both indoors and outdoors, need to be developed to seed in young children the sense of what is involved in practicing new forms of complex, computational science. An example of how this can be achieved is the embedded phenomena approach; scientific phenomena are simulated using UbiComp technologies, for long periods of time, to create opportunities for groups of students to explore 'patient' science [32]. Essentially, this involves the accumulation, analysis and representation of data collected from multiple computational devices over extended periods of observation in the classroom or other sites. In so doing, it allows students to engage in the collaborative practice of scientific investigation that requires hard computational thinking but which is also exciting, creative and authentic. A core challenge, therefore, is to find ways of designing novel science learning experiences that capitalize on the benefits of combining UbiComp and PC technologies that can be used over extended periods.

3.3 Persuasive Practices

The third area where there is much potential for using UbiComp technologies to engage people is as part of self-monitoring and behavioral change programs. While a range of persuasive technologies (e.g., adverts, websites, posters) has already been developed to change people's attitudes and behaviors, based on models of social learning [18], UbiComp technologies provide opportunities for new techniques. Specifically, mobile devices, such as PDAs coupled with on-body sensors, can be designed to enable people to take control and change their habits or lifestyles to be healthier by taking account of and acting upon dynamically updated information provided by them. For example, Intille and his group are exploring how mobile computational tools for assessing behavioral change, based on social psychology models, can be developed to motivate physical activity and healthy eating.

A key question that needs to be addressed is whether UbiComp technologies are more (or less) effective compared with other technologies in changing behavior. A diversity of media-based techniques (e.g., pop-up warning messages, reminders, prompts, personalized messages) has been previously used to draw people's attention to certain kinds of information to change what they do or think at a given point. In terms of helping people give up habits (e.g., smoking, excessive eating) they have had mixed results since people often relapse. It is in the long-term context that UbiComp technologies may prove to be most effective, being able to monitor certain aspects of people's behavior and represent this information at critically weak moments in a cajoling way. A constant but gentle 'nagging' mechanism may also be effective at persuading people to do something they might not have otherwise done or to not to do something they are tempted to do. For example, a collaborative cell phone application integrated with a pedometer was used to encourage cliques of teenage girls to monitor their levels of exercise and learn more about nutrition in the context of their everyday activities [44]. The software was designed to present the monitored process (e.g., walking) in a way that made it easy for the girls to compute and make inferences of how well they were doing in terms of the number of steps taken relative to each other. A preliminary study showed that such a collaborative self-monitoring system was effective at increasing the girl's awareness of their diet, level of exercise and enabling them to understand the computations involved in burning food during different kinds of exercise. But most significantly, it enabled the girls to share and discuss this information with each other in their private clique, capitalizing on both the persuasive technology and peer pressure.

Incorporating fun into the interface can also be an effective strategy; for example, Nintendo's Pocket Pikachu with pedometer attached was designed to motivate children into being more physically active on a consistent basis. The owner of the digital pet that 'lives' in the device is required to walk, run or jump each day to keep it alive. If the owner does not exercise for a week the virtual pet becomes unhappy and eventually dies. This can be a powerful means of persuasion given that children often become emotionally attached to their virtual pets, especially when they start to care for them.

UbiComp technologies can also be used to reduce bad habits through explicitly providing dynamic information that someone would not have been aware of otherwise. In so doing, it can make them actively think about their behavior and modify it accordingly. The WaterBot system was developed using a special monitoring and feedback device to reduce householder's usage of water in their homes – based on the premise that many people are simply unaware of how wasteful they are [3]. A sensor-based system was developed that provided positive auditory messages and chimes when the tap was turned off. A central idea was to encourage members of the household to talk to one another about their relative levels of water usage provided by the display and to try to out do one another in the amount of water used.

But to what extent do UbiComp technologies, designed for persuasive uses, differ from the other forms of monitoring that were critiqued earlier in the paper? A main difference is that there is more active involvement of those being monitored in attaining their desired behavior change compared with those who were being monitored and assisted in care homes. The objective is to enable people, themselves, to engage with the collected information, by monitoring, understanding, interpreting and acting upon it – and not the environment or others to act upon their behalf. Much of the research to date in UbiComp and healthcare has focussed on automated bio-monitoring of physiological processes, such as EEGs and heart rate, which others, i.e., specialists, examine and use to monitor their patient's health. In contrast, persuasive technologies are intended to provide dynamic information about a behavioral process that will encourage people from doing or not doing something, by being alerted and/or made aware of the consequences of what they are about to do. Moreover, designing a device to be solely in the control of the users (and their social group) enables them to be the owners of the collected data. This circumvents the need to be centrally concerned with privacy issues, allowing the focus of the research to be more oriented towards considering how best to design dynamically updated information to support cognitive and social change. A challenge, however, in this area is for long term studies to be conducted that can convincingly show that it is the perpetual and time-sensitive nature of the sensed data and the type of feedback provided that contributes to behavioral modification.

4 Conclusions

Many of the research projects that have followed in the footsteps of Weiser's vision of calm computing have been disappointing; their achievements being limited by the extent to which they have been able to program computers to act on behalf of humans. Just as 'strong' AI failed to achieve its goals – where it was assumed that "the computer is not merely a tool in the study of the mind; rather, the appropriately programmed computer really is a mind" [41], it appears that 'strong' UbiComp is suffering from the same fate. And just as 'weak' AI[2] revived AI's fortunes, so, too, can 'weak' UbiComp bring success to the field. This will involve pursuing more practical goals and addressing less ambitious challenges; where ensembles of technologies are designed for specific activities to be used by people in bounded locations. To make this happen, however, requires moving from a mindset that wants to make the environment smart and proactive to one that enables people, themselves, to be smarter and proactive in their everyday and working practices. Three areas of research were suggested as to how this could be achieved; but, equally, there are others where there is much potential for enhancing and extending human activities (e.g., vineyard computing [11], firefighting [24] and sports). As part of the expansion of UbiComp, a wider range of human aspects should be considered, drawing upon alternative theory, guiding frameworks and metaphors [c.f. 8, 15]. To enable other human concerns to become more prominent, however, requires the hefty weight of privacy and other related ethical issues on UbiComp's shoulders to be lessoned.

The 'excitement of interaction' that Weiser suggested forsaking in the pursuit of a vision of calm living should be embraced again, enabling users, designers and researchers to participate in the creation of a new generation of user experiences that go beyond what is currently possible with our existing bricolage of tools and media. We should be provoking people in their scientific, learning, analytic, creative, playing and personal activities and pursuit. Finally, while we have been privileged to have had such a great visionary, whose legacy has done so much to help shape the field, it is timely for a new set of ideas, challenges and goals to come to the fore and open up the field.

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[2] Weak AI refers to the development of software programs to perform specific problem-solving or reasoning tasks that do not have to match the way humans do them.

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