Creativity in Ubiquitous Computing Research

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ABSTRACT

This paper is concerned with the process of creating and designing research prototypes for augmented objects and applications in ubiquitous computing. We present a range of descriptions and reflections from personal experience in building prototypes for ubiquitous computing research, while students were introduced and guided in this process. This is linked to a rationale of the process as well as the way it affects built-in experience and knowledge and its needs to transform teaching and learning in these domains.

Author Keywords

Creativity, Ubiquitous Computing, Prototyping, Problem-Solving, Design, Interaction, HCI.

ACM Classification Keywords

H5.m. Information interfaces and presentation: Miscellaneous.

INTRODUCTION

Ubiquitous computing (ubicomp) was first mentioned by Mark Weiser in the late eighties. This term refers to the drift that we, as humans, no longer interact with only one computer at a time, but with a dynamic set of small networked computers, often invisible and embodied in everyday objects spread over the environment.

The emergence of ubicomp resulted in an inevitable shift from the constricted desktop reality to the broader surrounding environments [7]. Ubicomp involves physical environments that often relate to incidental and low-intention interaction.

According to Dix, Finlay, Aboud and Beale [7] there are three main theories that focus on the "in the world " nature of knowledge being explored within the ubicomp community: i) activity theory, ii) situated action and iii) distributed cognition.

Activity theory recognises concepts such as goals ("objects"), actions and operations that fluidly take place. Also, it includes the transformational properties of artefacts that implicitly carry knowledge and traditions.

Situated action emphasises the improvisational aspects of human-behaviour and de-emphasises *a priori* execution plans, not requiring or anticipating user actions.

Finally, *distributed cognition* also de-emphasises internal human cognition, but in this case, humans are just part of a larger system. This theory takes larger attention to the knowledge in the world and as much information that is needed to accomplish a systems' goal is encoded in the individual objects.

Nature of Ubicomp

Ubiquitous computing has grown in the last decade into a vast multi-disciplinary research domain in which the importance of innovation is privileged and vital. It often embeds technology into familiar artefacts or personal devices that are considered as common tools. This results in augmented objects that are more powerful and more intelligent and that bring a qualitative benefit to the user's life. Another characteristic is that many times the interaction with these objects is less direct, and can be even incidental or accidental from the user's point of view. Additionally, ubicomp inherently tends to utilise concepts grabbed from our reference world.

The "in the world" nature of ubicomp systems also dictates that their design requires implementations in both physical and virtual concepts. Novel kinds of augmented, tangible and technology-embedded objects are commonplace in ubicomp research, and more and more present in our everyday life, think for instance of the "house of the future", nowadays being developed and researched around the world.

Scope: Prototyping in Ubicomp

The scope of this paper includes the process of creating and designing applications and prototypes for augmented, tangible or embedded objects. It is rarely the intention of ubicomp research to develop new products for mass consumption markets, but rather to develop prototypes that serve as a proof-of-concept. This typically ranges from testing the feasibility of new ideas, to experiments that study user acceptance of particular technologies. It is also interesting to note that development of these prototypes seldom has any constraints beyond these research goals.

Unlike other domains, ubicomp research rarely develops objects from scratch. In fact, it often revolves around using existing technologies that are already available, and combining these in completely different contexts, with small modifications.

In short, concerning the presence of constraints, we identify three levels of strength: i) the first, in which there are no constraints at all and the ubicomp researchers are free to create whichever idea they can think of; ii) second, in which constraints are associated with the object(s) being used as a starting point for the development of a novel idea (in this case, there is a moderate level of constraints related with an object that, from the beginning, the team wants and decides to include in the final design); iii) and, finally, the level in which the presence of constraints is high, although it rarely occurs as it is related with a specific project that is introduced by an external company or entity aiming at a specific goal or application.

From the second author's experience, the second level is undoubtedly the most frequent as we can conclude from the description provided in this section, but these go along with the permanent need for novelty and scientific impact of the technology proposed.

BACKGROUND: CREATIVITY AND PROBLEM SOLVING

Design team members (in which ubicomp researchers are included) often benefit from stepping back and rethink their projects, or even to think out-of-the-box in order to create new ones. There are several creativity and problem solving techniques [1] to promote these tasks, from where we detach the deBono six thinking hats [3] or Dix' BadIdeas [6]. Amongst others, these encourage critical and divergent thinking. This process often involves two important activities that occur in subsequent phases, one divergent and another convergent; one of exploration of ideas and another of implementation of one selected idea. These aspects have already been mentioned in some studies [6, 8].

As in the BadIdeas technique, thinking of the potential uses of materials to apply them in new forms or domains implies a deep analysis and understanding of its properties, characteristics and affordances. This can be done by simply questioning what materials are available and are potentially usable, why, when and how or... why not, when not or how not to use them?

We highlight two examples of how ideas can be reconstructed and generated through processes, in which materials and its detailed comprehension is essential.

A first example is the application of virtual crackers, which came out of Dix's [4, 5] research regarding the importance of deconstruction and reconstruction as a technique for understanding interactive experience and then applying it to the redesign and recreation of experience on new media.

Figure 1 shows the features of both real and virtual crackers and its mapping. As we can observe, each relevant property of the experience with the real crackers has its (possible) correspondence in the virtual version.

	real cracker	virtual cracker
shared	offered to another	sent by email, message
co-experience	pulled together	{ sender can't see content until opened by recipient
design	cheap and cheerful	simple page/graphics
hiddenness	contents inside	first page - no contents
excitement	cultural connotations	recruited expectation
suspense	pulling cracker	slow ... page change
surprise	bang (when it works)	WAV file (when it works)
play	plastic toy and joke	web toy and joke
dressing up	paper hat	mask to cut out

Figure 1: Crackers features

Figure 2 illustrates with a schema how the virtual crackers work, reflecting the deconstruction of the experience of real Christmas crackers and its reconstruction in a web version. The recreation process of the crackers experience in a new medium demanded a deep understanding of the materials involved, in both reference and virtual world.

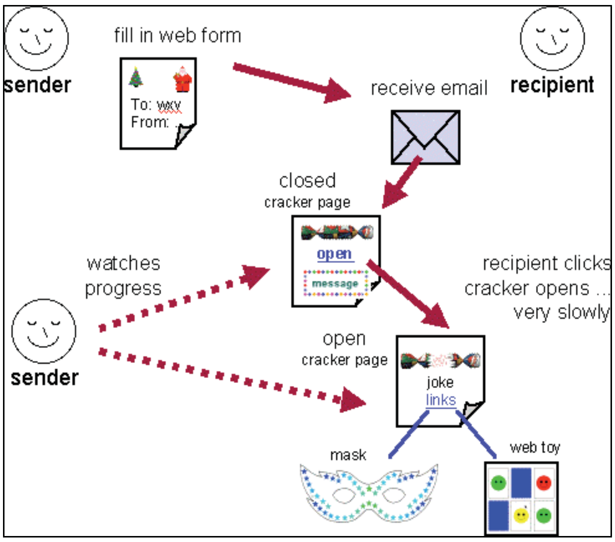

Figure 2: How virtual crackers work

A second example comes from the results of the Chindogu Scrapheap Challenge, an event that was held as part of a LeonardoNet Workshop in November 2005 [9] and that was used as an 'opportunity experiment' to study creative groups at work. During the workshop, 16 of the 20 participants were divided in three groups and given HCI themes. Within a day, they had to create a design and prototype, and implement solutions using materials either provided by the organising committee or found by the groups.

In this context, one of the groups proposed a low-power, one-second call-time, static mobile phone charger for use in ‘the wild’ (see Figure 3). Static electricity is generated from a nylon carpet and would be enough to charge the mobile phone for one second of connectivity.

Figure 3: Static mobile phone charger

The nature of the exercise did not require a fully working prototype, but the understanding of characteristics and functions of the materials used to implement the prototype is clear. For instance, in the list of used materials, there is a capacitor, needed to transform the static energy in energy that can be used by the mobile phone which is essential for the implementation of the idea.

This example may sound weird or/and impracticable, but it did solve a problem and creates an opportunity of development. Additionally, the "creation" process was found to produce a great sense of achievement as well as enthusiasm and fun.

In the next sections, we will particularly focus on ubicomp design processes. In an initial phase, researchers aim at finding innovative ubiquitous computing concepts[1] and, therefore, highlight the need for creative processes in the generation and/or emergence of new ideas. In a second stage, problem solving and creativity in prototyping are discussed, as we need to address individual challenges, find the right components to implement the prototype and combine them into a working prototype.

CREATIVE DESIGN IN UBIQUITOUS COMPUTING

We identify the two levels of the design process in ubiquitous computing research, where creativity plays a crucial role: i) the generation and/or emergence of ideas, and ii) the actual implementation of a prototype.

[1] Concepts are usually materialised in augmented as well as tangible technologies, objects and/or materials.

Generation and/or Emergence of Ideas

Since part of the ubiquitous computing aspiration is to steer away from the traditional desktop computing paradigm, it is paramount that novel ways of using and interacting with technology are explored. This purposefully implies the generation and/or emergence of novel ideas, demanding creative thinking.

The researcher(s) often come up with an idea to implement out of need or practical use, sometimes they are asked by a third party to research a certain concept or technology. Other times their work is driven more by new technologies that emerge in the research field.

As an example of creative thinking and the remoteness from conventional computing science development and research, we have the Pin&Play project [8], which was conceived by combining two existing technologies - conductive textiles and connectors in the shape of sharp pins - into a method to network small pushpin-like computers by ‘pinning’ them into the same surface. By combining two completely different technologies, an idea that exploited strengths from both concepts emerged and positioned itself as a solution to a problem.

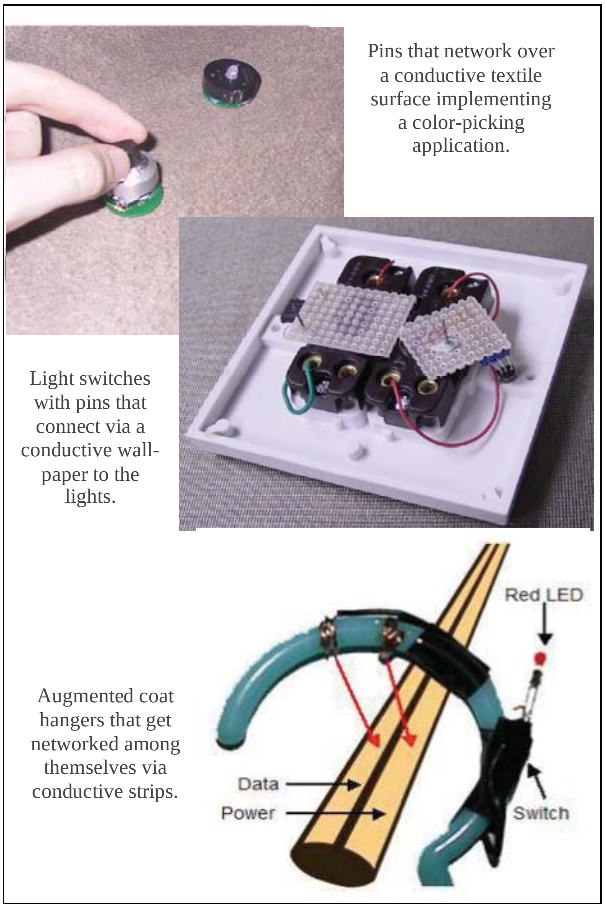

Figure 4: Several applications of the Pin&Play project, where conductive layered materials are used to connect objects.

Figure 4 shows several implementations using the same idea, where unusual connectors and conductive surfaces are used to address certain problems. It is important to stress that each of these prototype demonstrators worked along a similar principle: conductors for which normally cables are used.

Creativity During the Prototyping

Once an idea has emerged, creativity is also needed for the implementation of its prototype (and eventually anything beyond the prototype). But, in this stage, it has more to do with problem-solving emerging from joining and mixing components. This often encompasses a variety of design processes, most notably user interface design, software design, microelectronics, and even design of the casings.

The process has two perspectives: i) what do we have and what can we create from what we have; and ii) what do we need to accomplish a certain goal and what do we have available that allow us to pursue it.

We make a distinction here between finding creative solutions to employ and combine the best materials and components for the job at hand, and using creativity to see beyond regular usage of components.

Understanding of Basic Components and Materials

Many prototypes in ubiquitous computing research consist of physical components. The understanding of the properties, skills, and affordances of objects and components is not just important but crucial, as well as the ability to identify required components so that the most suitable components or materials are applied.

A particularly reoccurring challenge in ubiquitous computing is the need to package the prototype in such a way that its shape, texture, and affordance are as close as possible to what the real device would look like. Due to time and money constraints, it is often not possible to create specifically engineered casings or industrial-quality base components. Figure 5, Figure 6, and Figure 7 show examples where readily available materials were employed to encase computing components.

For instance, in the TEA project [11], which main goal was to augment mobile devices with environmental sensors, batteries were removed from an enlarged mobile phone battery pack and replaced with a custom-made sensor board and smaller battery module (see Figure 5). This allowed the project team to quickly construct a mobile phone that could change its ringing profile (ringing tone, volume, vibration intensity, etc.) according to what was being sensed in the environment. For example, the mobile would play a loud ringtone when carried outside, whereas if the phone was in the user’s hand it would just vibrate.

Concerning the Cubicle project [13], after early experiments with plastic cubical boxes (Figure 6), the team opted for custom-prepared wooden boxes that were constructed out of old massive table legs. This allowed the encapsulation of motion sensors in a cube-shaped object that could serve as an input device. Users were found to be much more comfortable with this heavier but more robust wooden exterior than with the various plastic casings tried previously. A follow-up project experimented with smaller wireless motion sensors encased in a mixture of epoxy resin and hardener, an insulating coating material.

Figure 5: Modifying large battery pack cases allowed the TEA project to quickly prototype a mobile phone add-on.

Figure 6: Various casing solutions in the Cubicle project.

As a final example of the significance of materials, its understanding, properties, skills, affordances, etc and the forms in which these can be applied, we have wearable sensors. Styrofoam, Velcro and FIMO (a crude toy clay which can be baked) were used to create protective cases for watch-like body-sensors (Figure 7). This is another example of how materials can be used in unpredictable contexts for unintended purposes and of how such crude and apparently unusable materials can represent extraordinary solutions.

Figure 7: Sensors encased in FIMO-styled and Styrofoam containers, and attached to Velcro straps, were used to quickly create a body-worn sensor prototype.

Understanding Context

In the examples of the previous section, the materials and components that were used in the prototyping were serving a purpose that was almost always close to their intended use. Sometimes, however, it is required to think about changing the context of the building components, and reapplying them in a totally different context. In many cases, prototypes are built with materials that are used beyond their regular purpose, out of context.

The earlier discussed Pin&Play project [12] for instance utilized nails, sewing needles, electronics wrapping material, medical syringes and miniature model paint (see Figure 8). None of these materials and components can be found in a standard 'prototyping toolbox', and finding out that these products are most suitable for the prototypes took several iterations and a high dose of out-of-the-box thinking.

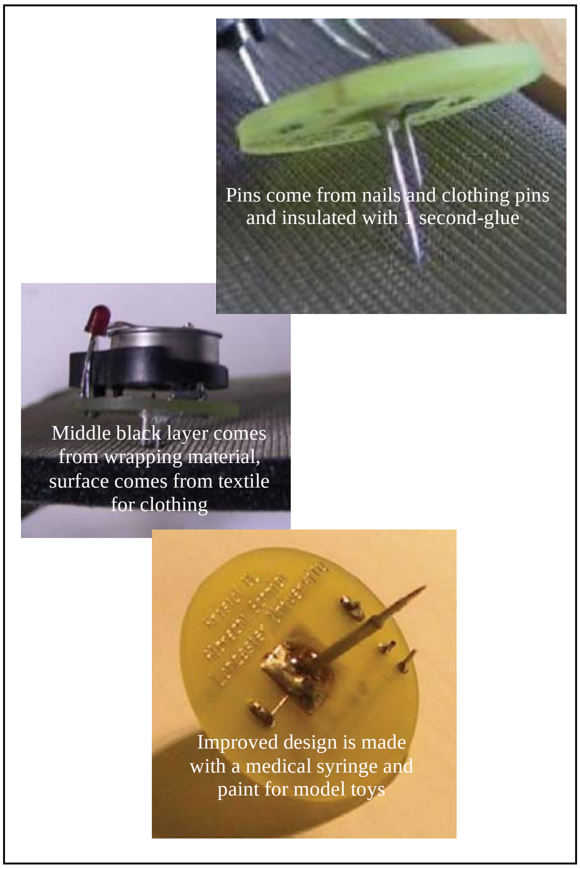

Figure 8: Pin&Play materials that were taken out of their usual context and re-applied for prototyping.

TEACHING AND LEARNING IN UBIQUITOUS COMPUTING

The examples shown in the previous section were implemented by students and researchers with engineering and computer science backgrounds. From a technological point-of-view, this makes perfect sense, since most of the prototyping involves writing microcontroller software and designing efficient electronic circuit boards. Although, from an overall point-of-view, it is surprising how these students, traditionally used to a very modular, defined and structured methodologies were able to apply lateral thinking and embrace novelty with such competence. This section will focus on teaching and guiding these students while making such prototypes and efforts to develop their creativity skills.

It is important to stress here that the following exposes only the second author's personal experiences and reflection in guiding and observing students. In effect, we do not intend to present *de facto* solutions for any type of research or teaching process, not even ubicomp-specific.

The process of guiding and teaching these students and creating and implementing such prototypes is distinct from normal coursework. Those are described next, as a reflection of how, in many of these projects, students were familiarized and guided while creating these prototypes.

The Development Process - Step-by-Step Description

In many of the specific examples mentioned in the previous section, students were most comfortable with designing software. This is to be expected, since that is what they have been taught for several years, as well as a rigid and well-known (and, therefore, very comfortable) process. The initial step of gaining familiarity with programming microcontrollers was therefore short and resembled a traditional programming exercise.

The design of the hardware was seen as a bigger challenge. Usually this consisted of a basic microcontroller-based design, for which the circuit board was designed by the student, but produced by a company, and to which the student then had to manually solder the components (IC chips, sensors, connectors, etc.). Since this part of the process is still within the realms of engineering, this process was usually learned quite fast as well. Typically, many new skills had to be taught as the process went on, such as soldering particularly small components, using a hotglue-gun, or shrink-wrapping wires and connectors. These were shown by example as the prototype progressed.

But the stage which required by far the most effort and dedication from the students was the integration of the technology into a usable physical device or object. In fact, the need for physical creative solutions to make technology work in the real world was, in most cases, underestimated. This crucial part of the design process required the usage of physical components and materials, sometimes used in a completely different manner than that which it was designed for[2]; i.e.: something the designers of these prototypes were never explicitly prepared for in their education. As a result, we observed the largest variability in the performance from student to student and an extension on the time needed to perform this phase of the process.

Wisely and perspicuously, some students realized early on that this was not going to be solved by using and combining basic components already present in a toolbox (as in software and hardware development) and went to flee-markets, clothing shops, and through drawers of abandoned hardware, looking for ideal solutions.

We argue that this type of design process is very different from that of other designers, such as industrial or product designers. It has less constraints, as the prototypes are made for a particular research purpose only. In some cases the prototypes are constructed as a proof-of-concept of a novel idea, rather than to solve a particular need or problem. In many cases it was sufficient that the prototypes worked flawlessly for an afternoon to facilitate user studies. Development costs are another factor that generally are far less important during these prototyping studies.

[2] The application of medical syringes or short nails as connectors in the Pin&Play project are good examples.

The Importance of Experience

A first observation we make here is that experiencing things makes a substantial difference. Information transmitted from teacher to student can be transformed into knowledge if the student experiences and engages in the process and naturally absorbs it, in incremental steps. This allows the students to have a big jump in their learning process.

Figure 9: Old prototypes boxes with cables, packaging material, in lab environment, where prototypes are built.

Figure 10: Stressing that the students need to try out their own designs themselves early on (here: wearing their own body-sensors for longer times).

To encourage students to this mindset, it was found helpful to have boxes of scraps and old prototypes in the lab (see Figure 9), and introduce them to their use in small steps and by providing examples. When for example a cable or connector was added that might (or, as often was the case, would) break, the student was shown techniques to secure them and make the prototype more robust. As the student was introduced to increasingly more examples, often from scrapped gear around the lab, they would get more explorative in finding design solutions, many times beyond the lab environment.

A second method that proved to be beneficial to the student's involvement and adjustment to the prototyping work was to make them use it, even in early stages when it was not sufficiently ready. This tends to confront them with obvious design faults by themselves, and also gives a stronger motivation why a certain aspect of their design should be altered. Figure 10 shows an example of a wearable activity sensor prototype where, by wearing the system extensively, the student found increasingly optimized solutions to protect the electronics from outside shocks, dust and humidity.

DISCUSSION AND FUTURE WORK

As we can infer from the previous section the most significant challenge to ubicomp students occurs when they are invited to explore the boundaries outside their academic knowledge domain and consider it together with all the possible knowledge and experience they have from their reference world. Or, in other words: innovate, create, and think of objects and relations between objects in a form that might have never been considered yet.

This demands creative and lateral thinking that, as we mentioned before in this paper, can be fostered by the appliance of numerous techniques, conventionally used in creativity and problem-solving research. But, for the purpose of this paper, we bring special attention to the BadIdeas technique [6], whose aim is to encourage creative technical thinking, individually or in group. This is supported by stimulating divergent thinking and pulling the thinker outside his or her established design space and facilitating a more structured analysis of the problem.

Creativity and/or innovation can also be promoted, as Csikszentmihalyi [2] states, by the environment in which the researcher is integrated, what in ubicomp consists of a significant advantage since ubicomp groups hardly are constrained by any aspect.

As to what concerns the student's development, and from our experience, we believe that a significant development happens when students: i) realize that their initial expectations of a conventional organized, modular, sequential and oriented working method does not have to be followed or present in their current work; and ii) understand that a working pattern no longer exists and if so it may need to be relegated to a second plan, giving priority to the randomness and exploration of real experience.

It is hard to obtain an objective measure of the student's development while he or she is creating the prototype. Sometimes a promising initial model is implemented within a day and is only replaced by a complete redesign much later, because of certain problems arising at a later stage. Other times, a student can get stuck for a long time over the first hurdles and then increases progress rapidly as they are finally cleared.

Finally as a proposal for potential future work, we ask: How do we assess creativity? And how do we assess ubicomp prototypes? By its nature creativity and ubicomp are hard to define and evaluate. The process of creating ubiquitous computing prototypes does not allow traditional methods of evaluation. As it is a dynamic and young field, there is still a lack of guidelines and clear goals.

Additionally, it would be interesting to apply the BadIdeas technique in ubicomp teams, not only to verify its results on the overall development process (checking if this technique constitutes a significant improvement in the students' development), but also to help specifically on the evaluation and (re)design of ubicomp prototypes.

CONCLUSIONS

We presented in this paper some observations on the process of developing prototypes in the field of ubiquitous computing research. By nature, this research aims at investigating highly innovative ways of human-computer interaction, away from the classic desktop environment. We have shown through a variety of examples from our own research that this prototyping process contains many opportunities for creativity, but is also far from well-understood.

Gaining the experience of designing these prototypes is also a difficult task to integrate in education. Some methods were identified that encourage students to think beyond structured development processes they are accustomed to, and re-assess their ideas. We also observed, however, that exploring the design space in ubicomp prototyping is still an open field with many potential areas where creativity research in education can contribute.

As future work, we have pointed out the current lack of evaluation techniques for stimulating creativity in these processes, and have suggested methods to improve and support the creative development of ubiquitous computing research prototypes in particular.

ACKNOWLEDGMENTS

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