Gaming Media and Social Effects

Anton Nijholt *Editor*

More Playful User Interfaces

Interfaces that Invite Social and Physical Interaction

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Preface

This is the second book on playful user interfaces. The first book, "Playful User Interfaces: Interfaces that Invite Social and Physical Interaction," also published by Springer, introduced playful interfaces and focused on an already-existing culture of designing and implementing playful user interfaces. The book also contained many examples of users creating interfaces and interaction tools, following the assumption that creating a game or an interactive installation can be play, and creating them can be just as satisfying as using the result. This is especially true for children, enabling them to create their own games, using tabletops and tools such as Arduino, Makey Makey and, for example, Scratch programming. Making games or entertainment applications also introduces users to the wonders of digital technologies and how to use them to design other applications.

In this book, we continue this exploration of playful user interfaces, whether they are for educational purposes, for example, introducing children to digital technology, for creating awareness, for changing behavior, for artistic expression, or for entertainment. But, we will extend the application domains of playful user interfaces. Among the many new topics are the playful use of the Internet of Things, organizing participatory design workshops, for the design of connected toys, physical games, and storytelling. How to use smart materials in order to realize interactive artistic installations has been explored in workshops with young artists. Organizing workshops for kids to make game controllers and involving young children and children with special needs in the design process of tabletop games are other topics that are investigated in the chapters of this book. It is not possible to play digital games or enjoy digital entertainment in some countries without daily electric power interruptions. Can we design games with power and no-power conditions, where a hybrid game, that is, a game with digital and physical elements, can be continued using physical elements only in the no-power condition and change again to the hybrid form in its power condition?

Learning about new domains, improving awareness of sustainability issues, and persuading behavior change through playful user interfaces are the other new issues that also appear in this book. There are chapters about having interactions with ecosystems, plants, and pets. Hence, computer-mediated human–nature interaction, experiencing the biosphere through digital technology, and having wearables that allows us to experience forests are the topics that are investigated. How can we design interfaces that allow playful interaction with our dogs, cats, or other pets and animals? What kinds of digital tools or smart environments can be offered to them? Playful remote interaction with pets staying at home while we are away at work has become a research issue in computer-mediated human–animal interaction. Well-being and safety need to be addressed in this kind of research.

In this book, there are also reports of research on shared experiences and on facilitating and creating shared experiences. Obviously, this already happens and is an important aspect of workshops where children, artists, or other creators of digital technology are involved in designing, making, and evaluating playful products and interfaces. Sharing experiences can also be done during public events such as sport events, political meetings, school meetings, demonstrations, open air or theater performances, or traffic and public transport disturbances. For example, an issue addressed in this book, can we contribute to enhancing the experiences of sports spectators, whether they are attending the live event or whether they are remote spectators? Can we, as a remote spectator, enjoy a sport event more by receiving multimedia information from fans in a stadium about their enthusiasm at certain moments and can we use mobile devices to share our experience with them and other remote spectators? Similar aims, with completely different technology can be recognized in research, also reported in this book,on playful music installations that take as input EEG-measured changing brain activity of two or more participants using the interface and turning it into a joint performance.

In the first chapter of this book, we discuss some views on leisure and developments in leisure activities and technologies in the twentieth-century literature and in movies. In particular, we look at viewpoints on passive and active leisure consumption and activity. After that, the book consists of three parts in which the chapters of this book are categorized. These parts are (I) Designing Interactions for and by Children, (II) Designing Interactions with Nature, Animals, and Things, and (III) Designing Interactions for Arts, Performances, and Sports.

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More Playful User Interfaces: An Introduction

Anton Nijholt

Abstract In this chapter, we embed recent research advances in creating playful user interfaces in a historical context. We have observations on spending leisure time, in particular predictions from previous decades and views expressed in science fiction (SF) novels. We confront these views and predictions with what has really happened since the advent of computers, the Internet, World Wide Web and sensors and actuators that are increasingly becoming integrated in our environments and in devices that are with us 24/7, not only with us, but also connected to networks of nodes that represent people, institutions, and companies. Playful user interfaces are not only interesting for entertainment applications. Educational or behavior change supporting systems can also profit from a playful approach. This chapter concludes with a meta-level review of the chapters in this book. In this review, we distinguish three views on research and application domains for playful user interfaces: (1) Designing Interactions for and by Children, (2) Designing Interactions with Nature, Animals, and Things, and (3) Designing Interactions for Arts, Performances, and Sports.

Keywords Human–computer interaction · Animal–computer interaction · Child–computer interaction · Human–ecosystem interaction · Tangible interfaces · Entertainment computing · Constructionist gaming · Video games · Internet of Things · Pervasive computing · Urban games · Brain–computer interfaces

1 Introduction

Usually, playfulness and efficiency are considered to be opposing concepts. However, also in the past, we could see that playful approaches to education, behavior change, health, and rehabilitation could improve efficiency, that is, could

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decrease the time to achieve the results that were aimed at. It is only nowadays, when we have control of smart sensors and actuators, that we can tune this digital technology to applications that are playful, useful, and efficient. Or, maybe we can use digital technology to provide every application with playful aspects. Introducing playful and gamelike elements into our daily life is not only about particular applications. It addresses our daily activities, whether at home, in transport, in office and public environments, and in our digitally enhanced physical or real-world environments (Nijholt 2014a).

We will not receive a message telling us that the Internet of Things has been realized. Incrementally, our world will change and newly introduced technology is meant to make us happier, not only by offering us new and maybe more efficient ways to deal with cumbersome home, office, and urban situations, but also by giving us positive emotional experiences that follow from the introduction of 'playfulness' into the design of such environments. 'Playfulness' assumes an active role of the human that is a node in the Internet of Things.

In the 1920s of the previous century, we saw a growing interest among scientific and literary intelligentsia in what could be the consequences of the increasing role of machines in society and its effects on work and leisure. In 1920, the writer Karel Čapek wrote about artificial humans (robots). In a 1926 interview, electrical engineer Nikola Tesla told his interviewer (Kennedy 1926):

> When wireless is perfectly applied the whole earth will be converted into a huge brain, which in fact it is, all things being particles of a real and rhythmic whole. We shall be able to communicate with one another instantly, irrespective of distance. Not only this, but through television and telephony we shall see and hear one another as perfectly as though we were face to face, despite intervening distances of thousands of miles; and the instruments through which we shall be able to do this will be amazingly simple compared with our present telephone. A man will be able to carry one in his vest pocket.

And in 1928, in 'The Conquest of Ubiquity,' French poet and philosopher Valéry (1928) wrote:

> Just as we are accustomed, if not enslaved, to the various forms of energy that pour into our homes, we shall find it perfectly natural to receive the ultrarapid variations or oscillations that our sense organs gather in and integrate to form all we know. I do not know whether a philosopher has ever dreamed of a company engaged in the home delivery of Sensory Reality.

At that time, this enthusiasm was caused by inventions that made it possible to reproduce art such as photography, motion pictures and phonograph recordings, and the possibility to manipulate pictures and recordings. It does not seem to be the case that Valéry predicted that this multimedia information would enter our homes through water pipes or electrical power lines.

1.1 Leisure and Views on the Future of Leisure

Leisure was not really an issue in the early movies that introduced robots or robotlike machines. In *Metropolis* (1927), Fritz Lang introduced a mechanical woman. Monitoring behavior and giving warning messages using big 'television' screens was already present in Charley Chaplin's *Modern Times* (1936) and in Orwell's 1984. Rather than looking at possible leisure applications, attention went to efficiency aspects, for example, the 'feeding machine' in *Modern Times* that was meant to reduce factory workers' lunch time.

Writing or making predictions about the role of technology in leisure activities was hardly done by scientists and was left to science fiction (SF) writers who, of course, did not yet know about digital technology but knew about machines, robots, telephone, films, and television and used that knowledge to predict future developments, including that technology would liberate us from boring tasks, having robots do our work for us, and leaving us with lots of time for leisure. How society had to deal with this increasing time for leisure was considered to be a serious problem, and rather than being positive about it, the negative aspects were emphasized. Aldous Huxley's *Brave New World* (Huxley 1932) presented a rather pessimistic view on a future society. Leisure time is filled with electronic games and sports where nobody ever loses and where constantly new equipment is required and has to be bought in order to deal with improvements in the game. There is no love; instead, there are 'erotic games.' Huxley also introduces a new form of cinema. That is, after the silent movies and the 'talkies,' there should be the 'feelies,' where the theater audience, sitting in pneumatic chairs, experience smell and touch in addition to the visual and auditory experiences when watching a movie. And, of course, *Brave New World* inhabitants have their 'soma,' a drug that releases them from emotional stress and negative emotions. In Huxley's perspective, people would turn into 'robotlike' creatures held in control by drugs and mass entertainment.

Huxley's view is not really that different from what is presented in SF author Ray Bradbury's book *Fahrenheit 451* from 1951. He predicted that all books would be burned and more controlled entertainment would be provided on the TV walls in our home environments (Bradbury 1951).

> "What's on this afternoon?" he asked tiredly. She didn't look up from her script again. "Well, this is a play comes on the wall-to-wall circuit in 10 min. They mailed me my part this morning. I sent in some box-tops. They write the script with one part missing. It's a new idea. The home-maker, that's me, is the missing part. When it comes time for the missing lines, they all look at me out of the three walls and I say the lines: Here, for instance, the man says, 'What do you think of this whole idea, Helen?' And he looks at me sitting here centre stage, see? And I say, I say –" She paused and ran her finger under a line in the script. "'I think that's fine!' And then they go on with the play until he says, 'Do you agree to that, Helen!' and I say, 'I sure do!' Isn't that fun …'?"

Obviously, machines, assembly lines, robots, telephone, automation, radio, and especially television with its communication of moving images to whatever location spurred the imagination. In 1957, the Dutch futurologist Fred Polak introduced the view that a Ministry of Leisure Activities would be the most important governmental department in the year 2000 (Polak 1957). His ideas included the replacement of military conscription by leisure conscription so that youngsters could learn how to deal with leisure time. Maybe in agreement with Huxley, Polak mentions that we need to be aware that humans can become passive, consuming, robotlike creatures, not interested in self-reflection, initiative, and autonomy, if they live in a world controlled by robots and machines.

In 1962, Marshall McLuhan introduced the notion of the Global Village (McLuhan 1962). While Valéry's view focused on information entering our home, where we are 'passive' consumers, McLuhan focused on distributing and sharing information (as had been made possible by writing and book printing in earlier years) all over the world, reaching all corners of the Global Village and, in fact, getting rid of such corners, seamlessly integrating them in the Global Village. No particular role for computers was assumed in McLuhan's views, but having the means, whether it is through telephone, radio or television, and journals or books, to reach people 'everywhere' and to share views and information, is required when we want to speak of a Global Village. Obviously, sharing views and information does not necessarily assume a converging of views, rather an increase of awareness that there is a natural diversity of such views. Everybody everywhere was predicted to become a villager in such a Global Village. In 1962, there were not that many computers. They were used for scientific computations, simple and repeating administrative calculations, and industrial process control (Nijholt 1994). Although telephone companies were among the first companies that established computer research laboratories, knowledge about the role computers and networks of computers could play in distributing information or mediating human–human interaction still had to emerge.

McLuhan introduced his views in 1962, long before the prosperous part of the world learned about what computer technology would offer them in the years to come. That is, long before, Internet and World Wide Web technology allowed people living in this prosperous part of the world to communicate with friends, relatives, colleagues, and their community members. Also, long before, they were not only passive consumers of information, but also actively selecting, searching, and producing multimedia information and making that information available to others. In McLuhan's time, an important role for digital technology in leisure activities was not foreseen. The ideas of computers outshining human chess or other game players were not elaborated to an extent that a possible impact on leisure activities or mass entertainment came into view.

At that time, television provided mass entertainment. But, as mentioned by Neil Postman in *Amusing Ourselves to Death* (Postman 1985), 'by ushering in the Age of Television, America has given the world the clearest available glimpse of the Huxleyan future.' In Postman's view, at least at that time, television played the role of 'Happy Medium.' And in the Foreword to his book, he mentioned that Huxley made the following distinction between Orwell's 1984 view and his own view:

In 1984, people are controlled by inflicting pain. In *Brave New World*, they are controlled by inflicting pleasure.

In later SF books or in movies that pay attention to new technology, we now see a zooming in on human behavioral and emotional aspects, such as the ‘mood organ’ and the ‘empathy box’ in Philip K. Dick’s SF novel *Do Androids Dream of Electric Sheep* (1963), the artificial intelligence in William Gibson’s *Neuromancer* (1984), and the humanoid *Data* in the *Star Trek* series (*Star Trek: The Next Generation*, 1987) that tries to understand emotions—with the help of an emotion chip—and humor, that is, trying to understand kinds of irrational behavior, rather than behavior that is aimed at efficient operation. In later SF books or movies, playfulness, pleasure, humor, and leisure activities seem to disappear into the background. In Neal Stephenson’s *Snow Crash* (Stephenson 1992), we have a virtual reality-based Internet called *Metaverse* that includes some restricted environments where the elite can have some nightclub fun, but otherwise it is not clear what makes the world attractive to live in. Another icon of SF is of course *The Matrix* (Wachowski and Wachowski 1999). In *The Matrix*, computers have taken over, and they live off bioenergy extracted from billions of people whose minds are trapped in a shared simulated reality of the year 1999. SF does not usually provide us with a positive view on a future society. It will not make a nice story. Hence, we can also not expect that in the SF literature, leisure activities escape from the control of the rulers of the society, whether they are humans, robots, or computer programs.

1.2 Digitally Supported Leisure Activities

In the 1980s and 1990s, we saw the computer being used for game and leisure activities, at first by researchers and university students exploring new computer applications—making use of networked university facilities—such as text-based multiuser applications. The first home or garage-built personal computers were also mainly used for games and making games. Before video games, there were already arcade games. Arcades provided electronic and kinetic entertainment, sometimes requiring or enforcing application-dependent realistic bodily interaction movements. Steering a car or a spaceship, playing in a simulated sports environment, or taking part in a digitally enhanced dance competition are examples of digitally supported game environments that aim at providing users as realistic as possible an experience. Many hobbyists or small companies involved in building simple computers for personal use did so in order to provide users with games and in the early years of video games arcadelike physical behavior to interact with a game using peripherals such as touch and pressure controllers, was no exception. Moreover, toolkits were offered so that computer hobbyists could build their own computer, similar to what happened when in the 1930s radio enthusiasts got the opportunity to build their own radio receivers. As mentioned in (Swalwell 2012), many of these users were involved in games. They did not only build their own computers, but they had to make their own software too. So they learned machine code or a simple programming language and wrote a game or tinkered around with game code written by others. It was the start of a physical and digital tinkering movement that in later years turned into an educational movement, inspired by the constructivist learning theory of Papert (1980). At that time, Papert had already developed the child-friendly computer language Logo. In an early version of this language, virtual and physical (including touch sensors) 'turtles' could be programmed to move and draw shapes and pictures ('turtle graphics').

With the advent of the Internet, or more particular its graphical form in the 1990s, the World Wide Web, games, and entertainment in general could be distributed and shared, and it allowed multiuser cooperative and competitive participation in leisure activities, that is, participation from users in remote locations, from users on the move using mobile devices, and from users guided by sensors and actuators in their physical environments. Apart from spending time on video games and digitally supported physical entertainment, people now spend lots of time creating, sharing, and exchanging non-work-related information on social media, usually using mobile devices, intertwining work with leisure.

Unlike watching television, video games and socializing using social media require interaction with virtual or real people. Video games require keyboard, mouse, and/or joystick interaction. While initially, in the 1980s, there were examples of game computers that also aimed at having physical effort or even physiological information as input, in the years that followed all interest changed from expensive and not always reliable physical equipment, to graphical 2D, 3D, and virtual game environments that are expensive to design, implement, and test, but where development costs can be on the back of millions of consumers. Only after the development of smart sensors and actuators in the early 2000s, we see that interaction devices such as the Wii remote game controller and computer vision devices such as the Kinect allowed the development of games that again require bodily interaction rather than clicking arrow keys on the keyboard. From a social interaction point of view, it should be mentioned that (massively) multiplayer online role-playing games (MMORG) require interactions between team players, for example to discuss a strategy, and also audience members sometimes have the possibility to share comments on the game, often leading to humorous interactions. However, these interactions do not take place in a physical environment. But there are also game parties and game competitions, maybe not that different from a dance–dance competition, where video gamers, for some period of time, share a physical environment, comment on and ridicule the actions of other competing and cooperating players, and have lots of social fun.

Nevertheless, this is different from a situation where in a domestic situation family members and a family audience engage in an entertainment or sports game, requiring physical effort and interaction, and being monitored by smart sensors and supported by smart actuators. Moreover, it is different from a situation in a public or urban environment where we can have smart and large public displays and where our behavior is monitored and we have the possibility to use this environment for game and entertainment applications using smart devices and meaningful bodily interactions. Whatever the developments are called, disappearing computer, ambient intelligence, pervasive computing, or Internet of Things, they all have in common that they allow leisure activities, whether it is about sports, games, entertainment, or socializing, in environments that not only provide digital support to traditional ways of physical interaction, but also provide new methods of virtual and mediated interaction, including interactions in dedicated digitally enhanced physical game and entertainment environments or fully virtual environments.

1.3 Changing Leisure Activities?

We can certainly recognize a mainstream research activity that follows a way of reasoning that assumes that billions of users of future entertainment technology are indeed interested in non-keyboard, non-joystick, and non-Xbox or non-PlayStation digital entertainment. At this moment, it is quite unclear, despite some success of Nintendo's Wii home and similar video games, whether in the long term such entertainment will be successful. But clearly, we can assume that there will be a variety of digital entertainment and playful user interfaces for training, serious gaming, rehabilitation, education, and domestic and sports applications where the environment and its sensors, also reading our wearables, assigns a role to our bodily activity according to the aims of the playful environment.

We can compare research efforts aiming at active involvement of a user in game and entertainment applications rather than having him or her 'passively' consume entertainment with observations on trends in spending time on leisure activities. Clearly, there is no reason for research to follow consumer trends; there can be many societal and health-related reasons why it is useful to have research that aims at making it possible to change consumer trends and behavior. In previous sections, we mentioned the role TV or TV-screen-supported environments played in SF literature and also in observations made by Marshal McLuhan on its positive aspects, leading to a 'Global Village' and its negative aspects ('amusing ourselves to death') emphasized by Neil Postman. Neither of these authors was able to foresee the advent of personal computers, the Internet, the World Wide Web, wearable smart devices, and the digitalizing of physical environments and objects. Nevertheless, despite wearables, smartphones, and social media, it seems that according to US reports (Nielsen Company 2014), passive consumption of TV content is not decreasing. One reason might be the possibility to watch TV on Internet and mobile phone and watching time shifted TV. According to the same reports, the time spent on playing video games is rising. Increase is certainly due to the possibility of playing games on portable tablets and smartphones, rather than on console systems only. Leisure activity also includes socializing. Social media usage has invaded our daily lives. And our digital daily life activities are no longer restricted by the keyboard and computer on our desk. Rather than assuming that gaming activity will increase, we can also assume that it will decrease. That is, due to increasing possibilities to use our devices to communicate, socialize, and consume, we can also access digital entertainment content everywhere and access TV-like or otherwise digitally created and accessible content whenever we want it.

We already alluded to the physical and digital tinkering interest in the late 1970s and the 1980s of the previous century and the inspiring ideas of Seymour Papert. In the 1990s, this led to constructionist gaming, giving children the opportunity to create their own games; that is game making to develop programming and design skills, and to become familiar with digital technology in general, including sensors and actuators. Nowadays, there are many more opportunities to create interactive games and digital entertainment using commercially available and reasonably priced toolkits, sensors, and actuators. Moreover, universities have developed attractive visual programming environments that allow children to design algorithms in an intuitive way and also allow them to use algorithm building blocks that have been created by others or are available as examples from the programming environment.

1.4 Leisure Technologies and Emerging Worlds

Not all households in the world have access to Internet. There are billions of Internet users and their number is growing. But there are also billions of people that do not have home access to Internet, do not know about tablets, and do not use mobile phones. We may expect that this situation will change. Obviously, when this situation changes, whether it is in areas in Central Asia or Africa, information and communication technology (ICT) will bring conditions that can help these countries to build an infrastructure that is necessary to improve life and working conditions and make them part of Marshall McLuhan's Global Village. This is not yet what has happened. Information produced by people from the prosperous world can be seen everywhere, but it is certainly not the case that this information production and pushing is balanced by information production and pushing made possible by ICT that displays ideas, needs, and preferences coming from the less prosperous and developing countries. Rather, we see a need for political stability and economic development, health care, and education.

Public Internet access sites such as Internet cafes, NGO-sponsored telecenters, and public gaming centers allowed many people to get acquainted with ICT, and as argued in (Kolko and Putnam 2009), based on surveys of four countries in Central Asia: Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan, games and game playing often provide the pathway to ICT use. That is, in the developing world context, games provide user's first 'touch' of a computer. In their study, they conclude that games motivated to gain technical expertise. One example they mention is that gamers in Bishkek developed a LAN connecting players in a flat as a cheaper solution than going to a game café. On the other hand, these gamers also enjoyed gathering in public spaces to share their knowledge and compete in public.

It is certainly not true for all gamers, but gamers have a tradition of being creative with exploring the possibilities that (multiplayer) games offer, how bugs or weaknesses can be exploited, and how games can be hacked. Interest to tinker with hardware and software has probably always been there, but for decades, software, hardware, and game companies offered expensive products that had to be accepted as they were, not allowing modifications and even introducing punishments (temporarily ending a subscription to an online game) when a gamer in the Global Village did not follow the rules laid out by the game company. Gamers share their experiences with games, including how to profit from weaknesses in design or enjoy unusual and humoristic game behavior made possible by such weaknesses. Maybe 'weakness' is not the right word. Complex software can be compared with designing and building a bridge. Any bridge can be destroyed; any complex software that can interact with humans or in addition gets input from a non-predictable (natural and physical) environment can react in a way that has not been anticipated by the designers of the smart environment. When designing a bridge, civil engineers need to embed safety coefficients in their calculations. Games do not always have 'safety coefficients' that prevent you from taking certain actions.

Gamers share knowledge about games and supporting software and hardware. They discuss new games, and in multiplayer games, they discuss strategies with their team members or with game audience members. More than any other computer users, they know about the characteristics of their software, their hardware, and peripheral devices. Presently, we are seeing the rise of a community of digital tinkerers that have access to open-source software, libraries with program examples, and visual programming environments that allow them to create their own game and entertainment applications. But, in contrast to the video game communities, they create interactive entertainment by tinkering with off-the-shelf digital–physical technology. Among these physical–digital technologies are low-cost sensors and actuators and open-source computing platforms that control such sensors and actuators. They allow the design of interactive entertainment. Designing such entertainment can be as much fun as consuming entertainment, in particular when there is a community of like-minded tinkerers. In addition, as we argued in (Cheok et al. 2014), low-cost prototyping tools for game and entertainment design offer opportunities for youngsters in developing countries to start companies to develop and distribute their digital entertainment on the markets of our Global Village.

1.5 Access and Control of Leisure Activities

Sensors and actuators in our domestic, office, urban, and recreation environments can make our environments more supportive and increase efficiency when having to perform certain tasks. They can be proactive, anticipate our actions, and act autonomously. Particularly in the latter case, one has to ask whose interests are being served by the smart environment. These sensors and actuators also support our leisure activities. They monitor our playful behavior and what they monitor and what they support is not necessarily controlled by us. So, when we are talking about future leisure activities, it may well be the case that our future smart environments, how, when, and however smart they may be, will be controlled by those who own and control these environments. Do we ourselves control the devices in our own smart environments or is it the owner of the smart environments we need to pay for our use of the environment? Or is 'smartness' something like the air we breathe and available for everybody? In Nijholt (2008), we assumed that companies like Google would enter our daily life activities and would be our companion with whatever we do and want. In Nijholt (2014b), we introduced the role of humor in smart environments. This led to the question (Morozow 2014) who will control the sense of humor in our future smart environments and their smart devices? Or more generally, will interactive entertainment enter our homes as we saw it described in *Fahrenheit 451*, or do we have the freedom to design our own entertainment or interact with entertainment offered by others in our network or community? Although we have no chapters in this book that address these questions explicitly, in many chapters, we should accept the implicit invitation to think about these matters. That is, looking at the future, who will then control our leisure activities?

1.6 About This Book

Research activities in the area of playful user interfaces aim at inviting users to take part in playful social and physical interaction with digital or digitally supported applications. There may be other users, there may be socializing, there may be cooperation, and there may be competition. Physical behavior and physical efforts play a role as well. In order to be playful, we can also accept that these interfaces and their environments display humorous, irrational, clumsy, and magic behavior. In addition, we see an active role of users in the (iterative) design process of playful user interfaces or have the users design their own interfaces, games, or interaction tools. We certainly see these aspects emerging in the topics that are discussed in the chapters of this book.

In this book, we distinguish three parts. After this introduction, we have a Part I that is concerned with **Designing Interactions for and by Children**. It contains three chapters.

In the first chapter, Javier Marco, Eva Cerezo, and Sandra Baldassarri discuss the design of tangible tabletop games for very young children. Toys that are manipulated on the tabletop are tracked using visual recognition software, and these manipulations are integrated with visual elements in a virtual world. The authors report about their iterative design and their experiences with 3-to-4-year-old children in a nursery and 4-to-5-year-old children in a school classroom. They also tested the game they developed with cognitively disabled older children.

In the second chapter, Yoram Chisik, Monchu Chen, and Jesus Ibanez look at the design of games that take into account that there may be disruptions in power supply, that is, an electricity-dependent game should be designed in such a way that it can be continued even if electricity is cut off and it should allow smoothless continuation when being back in a state where electricity has returned. This is a situation that is not unusual in emerging countries and it triggers interesting design observations that are not only useful for this particular setting, but also useful for situations where we have mixed reality games that include not only virtual worlds, but also physical objects and tangibles that play a role in the game. Field studies with children (aged 10–14) were done in Kathmandu (Nepal) and in Funchal (Portugal).

The third chapter in this section, written by Gabriela T. Richard and Yasmin B. Kafai, is on constructionist gaming for children aged 10–15. However, rather than having children program their own video game, as is usually done, these authors build on previous work where they had kids design game controllers. In the current chapter, they report about their experiences with kids designing responsive wearable controllers. These controllers are bidirectional, for example, by responding to on-screen game cues. The authors discuss the children's learning experiences during a design workshop and how they became familiar with sensors and actuators, tangible construction kits, and visual programming environments.

Part II of this book is on **Designing Interactions with Nature, Animals, and Things**. It contains three chapters.

The first chapter in this section is by Hill Hiroki Kobayashi. He introduces the concept of human–computer–biosphere interaction, that is, sustainable interaction with ecosystems, such as a subtropical forest, by having sensors in such environments and also allowing users not only to experience a forest soundscape (birdsong, buzzing insects) but also to interact with wildlife by transferring prerecorded sounds of wildlife to speakers in the forest. One example he mentions is the playback of the croaking of frogs through the remote speakers in the forest in order to invite actual frogs to start croaking. A wearable forest clothing system with audiovisual communication possibilities was developed to increase telepresence of the ecological system and to facilitate interaction.

The next chapter in this section is by Patricia Pons, Javier Jaen, and Alejandro Catala is about playful interactive environments for animals and animal–computer interaction (ACI). Motivating physical activity and therefore improving an animal's welfare is one reason to design animal–computer interfaces or computer-mediated human–animal interaction. Playful training of dogs or just having cooperative fun with cats, hamsters, and pigs are other aims of this kind of research. Understanding animal behavior is a requirement. The authors survey the issues that need to be addressed when designing smart playful environments for animals.

The third contribution to this section is a chapter on playful and gameful design for the Internet of Things by Paul Coulton. This chapter provides a broad overview of the possibilities an Internet of Things offers to design playful user interfaces, whether it is with humans, robots, or animals. Living beings are part of this network, they do not visit the network, rather the network should be considered as an augmented reality place they live in. In this context of an Internet of Things, the author discusses the role of affordances and participatory design issues and introduces some playful Internet of Things applications, such as a storytelling system that uses interactive and connected toys and an interactive digitally enhanced scarecrow that took part in a yearly village festival.

Part III of this book is devoted to **Designing Interactions for Arts, Performances, and Sports**. Again, we have three chapters.

The first chapter in this section by Andrea Minuto and Fabio Pittarello is on creating interactive artistic installations with the help of smart materials. Smart material interfaces are physical interfaces that are responsive to environmental changes by changing their appearance and interaction abilities. The authors present their experiences during a workshop where they presented the possibilities of smart materials to art school students (students of the Fine Arts Academy of Venice) and where these art students were to learn about smart materials and use them in their art projects. With some exceptions, students were between 22 and 25. Apart from learning about smart materials, in particular memory shape alloys such as NiTiNOL, students had to learn about Arduino and how to activate their smart materials using Arduino. Various student projects are described, including students' opinions about their use of smart materials.

The second chapter in this section is on playful and social installations at the interface between music and the brain, written by Tim Mullen and many coauthors. The chapter provides descriptions and discussions of recently displayed musical installations at the annual Mozart and The Mind festival in San Diego. The installations are for entertainment and require interaction with users, sometimes inviting participation and interaction between multiple individuals. Real-time visualization of joint activity makes it possible to make performers aware of synchronization, to 'play' with it, improve it, or explore rhythmic relationships. In some installations, brain activity is translated into an audiovisual representation, or it is used to generate musical patterns that are blended with improvisations by players of musical instruments.

The third chapter in this section is on enhancing the 'live' experience of sports fans not attending the sports event in the stadium, but watching real time and listening through a television broadcast. The authors investigate the use of mobile devices as a 'second screen' to interact with content that compliments the TV broadcast. In particular, they look at possibilities to increase emotional involvement of remote spectators while watching a live sports event. Examples of implemented systems are discussed that allow virtual synchronous applauding, sharing opinions, predictions, and, using emotion buttons, emotions with friends and family members.

The three sections and their chapters provide the reader with a state-of-the-art view of advanced research on playful user interfaces and their application domains.

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Part I
Designing Interactions for and by Children

Hybrid Games: Designing Tangible Interfaces for Very Young Children and Children with Special Needs

Eva Cerezo, Javier Marco and Sandra Baldassarri

Abstract During recent years, our group has been combining tabletop devices and Tangible Interaction in several experiments in nurseries, schools and special education schools. The development of tangible tabletop games for children involves the integration of physical, virtual and social aspects, thus introducing new challenges to their design, implementation and evaluation processes. This chapter describes the complete process of creating a tangible tabletop game for kindergarten children. The role of the children in every step of the process is discussed, and the different evaluation methods used are shown. The frequent evaluation sessions have provided us with valuable information such as the kind of gestures to be recognized, the benefits of using an additional monitor, or the convenience of using a virtual agent to guide the game. These and other lessons extracted from our experience are presented and discussed in the chapter. An evaluation of the game in a special education environment is also described. Owing to the particular social and cognitive characteristics of these children, conventional well-known usability and user-experience evaluation methodologies are not suitable. Findings from these evaluations are also shared and discussed in order to help in the challenging task of designing tangible tabletop games for all.

Keywords Tangible interfaces · Children-centered design · Tabletop hybrid games · Children with special needs

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1 Introduction

One of the emerging research fields in human–computer interaction (HCI) is concerned with innovative interaction techniques that aim to provide a more seamless bridge between the physical and digital worlds. Tangible user interfaces (TUI) aim to give physical form to digital information by coupling physical manipulations of conventional objects with computational systems (Ishii and Ullmer 1997). TUI are envisioned as an alternative to conventional desktop computers (monitor + keyboard + mouse) that would bring some of the intuitiveness of the interaction with conventional objects back into our interaction with digital content.

Games and entertainment computer applications are especially prolific in putting into practice the TUI paradigm, giving rise to a new generation of hybrid games which combine traditional physical playing based on the manipulation of toys and playing pieces, with the new possibilities of digitally augmenting the player's area with computer images and audio feedback.

Large horizontal interactive surfaces (or tabletop devices) are emerging as an ideal environment for these innovative hybrid games (Heijboer and van den Hoven 2008; Leitner et al. 2010). Tabletop devices are of particular interest for reinforcing face-to-face social relations (Rogers and Rodden 2003) and group activities (Morris et al. 2005). However, most current child-oriented applications for tabletops are based on tactile interaction. This poses important problems when applied to very young children or children with physical and cognitive disabilities since this kind of interaction requires fine muscle coordination. This problem can be avoided in the Tangible Interaction approach, investigating how objects and digital content could be more intuitively coupled and how to better apply TUI to children. Recent studies carried out by Marshall et al. (2003) and Zuckerman et al. (2005) proved that applying the Tangible Interaction approach to young children can take advantage of the same pedagogical values as learning with materials. TUI enable children to interact with the physical world, while augmenting it with relevant digital information used to facilitate and reinforce active learning (Price and Rogers 2004). However, there is a lack of studies about the impact of Tangible Interaction with very young children (3–6 years of age). Moreover, the application of alternative ways of interacting with digital contents has also recently revealed important benefits for special needs children (Bevan 2003; Piper et al. 2006). New interactive devices are not only more physically accessible but also offer a more direct and flexible form of showing digital information to the child. However, the lack of specific studies in this area is particularly noticeable.

In recent years, our group (the AffectiveLab at the University of Zaragoza, Spain) has been combining tabletop devices and Tangible Interaction in several experiments in nurseries, schools and special education schools. Our approach is that an appropriate combination of a tabletop computer device with Tangible Interaction can bridge the gap between digital- and physical-based activities for young children and/or children with cognitive disabilities. The objective of our work is to explore the benefits that this kind of technology offers to these children in terms of usability, user experience and physical co-located playing. In this context, we decided to create the NIKVision system, which consists of a tabletop device and a set of tangible games (Marco et al. 2010a) designed to support co-located gaming around the table with a Tangible Interaction approach based on toy manipulation. To achieve an optimal design for the NIKVision tabletop and games, the development process was undertaken with the active involvement of children right from the very early conceptual stage (Marco et al. 2010b, 2013a). The participation of children in the technological design of products oriented to them is always desirable, but it involves many challenges (Raisamo et al. 2006). The very considerable variation in their needs and social skills depending on their age and even among children of the same age has to be taken into account as well as the ethical questions involved (Farrel 2005). Even though useful guidelines have been provided by researchers such as Read et al. (2002), Markopoulos (2008) and Druin and Hanna (1999), the best way of selecting the role of children in a project and the most suitable testing method in every step still remains an open question. Besides, the consideration of children with special needs, in particular, with cognitive disabilities makes the evaluation issue even more difficult but opens the door to the challenge of designing TUIs for all.

This chapter is organized as follows. Section 2 describes the state of the art. Section 3 presents our tabletop NIKVision. Section 4 describes the complete process of developing a tangible game for kindergarten children from the creation of the concept to the final evaluation, as well as the lessons learned. In Sect. 5, an evaluation of the game with special needs children is presented. Finally, Sect. 6 is devoted to the conclusions.

2 Related Work

The work described in this chapter relates to two main research areas: computer-augmented surfaces for very young and special needs children and the evaluation of interactive applications with children. The most relevant works in both areas are summarized below.

2.1 New Technologies for Very Young and Special Needs Children

In recent years, classrooms have been digitally augmented by replacing conventional blackboards and tables with computer-augmented surfaces provided with image projection and multitouch interaction. The educational community is taking a special interest in creating pedagogical content for multitouch-based tables (or tabletops) (Utani 2012). Many tabletop-based projects have focused on the new possibilities that multitouch active surfaces offer for co-located learning (Scott et al. 2003; Cappelletti et al. 2004; Morris et al. 2005). Nevertheless, some researchers have claimed that many problems emerge when tabletop devices based on multi-touch interaction are used by very young children on the grounds that their fine motor skills are not sufficiently developed (Mansor et al. 2008; Harris et al. 2009). Alternatives have appeared based on hybrid physical board games and computer-augmented surfaces, keeping playing pieces in the players' physical environment (Mandryk and Maranan 2002; Heijboer and van den Hoven 2008), and thus reinforcing the emotional impact of the game (Magerkurth et al. 2005; Hengeveld et al. 2009). This way, traditional play activities and board games meet with video games, combining the benefits of co-located gaming and face-to-face social relations (Iwata et al. 2010). The handling of conventional toys on an interactive surface may also open new horizons in interaction design for children. Hendrix et al. (2009) proposed the use of miniature construction toys on an interactive surface to help shy children aged 9–10 to reinforce collaborative behaviour and the sharing of ideas. Also, tangible educative materials such as cards have been used on computer-augmented tabletop surfaces to reinforce the learning of reading skills (Sluis et al. 2004) and maths (Khandelwal and Mazalek 2007) for 5-to-7-year-old children. Expanding tabletop applications with Tangible Interaction can make computers accessible to children with cerebral palsy (Li et al. 2008) and to children with social disorders (Pipper et al. 2006; Battocchi et al. 2010; van Veen 2009). These studies have provided promising results about the accessibility and benefits of this technology. However, studies that combine tabletop devices and Tangible Interaction applied to children with cognitive disabilities remain scarce and of a preliminary nature (Hengeveld et al. 2009; Pontual Falcão 2010).

In the light of the state of the art, it can be seen that there is a lack of works that adapt tabletop devices to very young and special needs children using Tangible Interaction with the aim of achieving the seamless integration of computers with conventional physical games and activities.

2.2 Evaluating with Children

Young children are users of technology and are thus entitled to be involved in user-centred design projects. However, many products for children are still analytically evaluated only by adult experts (Buckleitner 1999), but it is not easy for an adult to step into a child's world, and therefore, expert evaluation can miss important problems that could emerge when the final product is used by children (Druin and Hanna 1999).

Well-known evaluation methods for adult users are also applied in evaluations with children, but the special characteristics of the child's development stage may require substantial adaptations of these methods. Some such methods may even need to be discarded when working for children belonging to specific age groups (Rounding et al. 2013). It should be remembered that young children are less able to read, verbalize, concentrate and perform abstract logical thinking than adults (Markopoulos and Bekker 2002). Their undeveloped ability for translating experiences into verbal statements and for formulating compound and abstract tasks could pose problems, as their abstract and logical thinking abilities are not yet fully developed and they are not skilled in keeping multiple concepts simultaneously in mind. Inquiry methods which rely on these skills are therefore not suitable for very young children.

Observational methods seem to be the most appropriate for product evaluation involving children, although some techniques of observational evaluation that work with adults may not necessarily work with children. Hanna et al. (1997) suggest that children's frowns and yawns are more reliable indicators of lack of engagement than their responses to questions. Read et al. (2002) propose that children's engagement could be measured by observing the occurrence of a set of behaviours including smiles, laughing, signs of concentration, excitable bouncing and positive vocalization, while lack of engagement could be measured through frowns, signs of boredom (ear playing, fiddling), shrugs and negative verbalization. Formative evaluation methods of children's products must look not only for usability problems, but also for positive factors such as magic (Xu et al. 2009) and fun (Pagulayan 2003; Sim et al. 2006). Usability and fun are closely linked. If the game has a goal too easy to achieve, children might get bored; but if it is too difficult, children may get frustrated. Usability and fun problems will occur during the test and will influence each other, but after the test, it may be necessary to distinguish between them as they may require different solutions.

In the case of children with cognitive disabilities, all the aforementioned problems become even more marked so that observational methods and expert evaluation are the only possibilities (Lepisto and Ovaska 2004). But even these methods should take into account such children's difficulties in adapting themselves to a testing environment, interacting with the facilitator, following some procedures and, in general, contributing to the evaluation by reporting on their experiences. Methods based on the structured analysis of video sequences captured during test sessions may be carried out without requiring active participation in the evaluation process, leaving the children to interact in a natural way (Van Kesteren et al. 2003). These methods may be adapted to the consideration of usability issues such as fun and user experience (Barendregt 2006) and accessibility matters that go beyond hardware concerns, incorporating broader concepts such as children's understanding, digital feedback and adult support during the interaction (Hasselbring and Glaser 2000).

In conclusion, the evaluation of applications with very young children still remains an open question. In the case of testing with cognitive disabled children, the difficulties and challenges markedly increase and require specific efforts and studies.

3 The "NIKVision" Tabletop

The NIKVision tabletop (Marco et al. 2009) uses well-known techniques for multitouch active surfaces (Schöning et al. 2010), but its design is mainly focussed on Tangible Interaction and therefore in the handling of physical objects on the table surface. It is easily mountable and dismountable and, because it is oriented to kindergarten children, robust and safe (Fig. 1).

Children use NIKVision by manipulating conventional toys on the surface (Fig. 2a). A USB video camera is placed inside the table, capturing the surface from below (Fig. 2b). Visual recognition software runs in a computer station (Fig. 2c) which also handles the game software and the tabletop active image provided by a video projector under the table (Fig. 2d) through a mirror inside the table (Fig. 2e). The image output is also shown on a conventional computer monitor (Fig. 2f)

Fig. 1 NIKVision tabletop

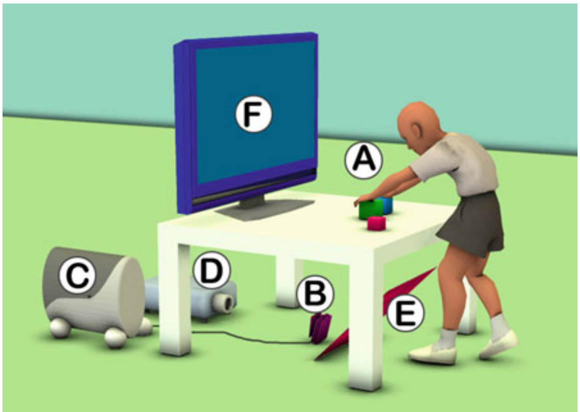


Fig. 2 NIKVision sketched components

Fig. 3 Toys with printed marker attached to base

adjacent to the table; this is a distinguishing factor of NIKVision. Visual recognition and tracking of objects manipulated on the table is provided by the reacTIVision framework (Kaltenbrunner and Bencina 2007). A printed marker attached to the base gives each toy a digital "*Name*" (Fig. 3).

The Tangible Interaction is achieved by manipulating the toys on the table surface. During play, children move the toys over the translucent surface of the table, putting the base of the toys in contact with the table to enable the camera to see the markers located under the base. The manipulations that visual recognition software is able to track are:

- Movements over the surface: children can grab the toys and drag them over the surface. The software tracks the position and velocity of the toy over the table.
- Rotate toy: the toys can be rotated on the surface, and so long as the base with the marker remains on the table, the software can track their orientation. Thus, toys that have a distinguishable front and back can be oriented by the child during the game; e.g., a toy car is moved on the tabletop and a virtual 3D car on the monitor will move in the same way as in the game.

Several games have been designed and developed for the NIKVision tabletop, with the involvement of children (Marco et al. 2010a). In the next section, the complete process of developing a game for NIKVision is presented. Children involvement techniques, evaluation strategies and the difficulties encountered are discussed.

4 Getting Down to Work: Developing a Farm Game for Nikvision

The engineering life cycle adopted for developing NIKVision games (Marco et al. 2013a) starts out from the Mayhew (1999) usability life cycle. This cycle takes users into account and reflects the iterative nature of the design of interactive

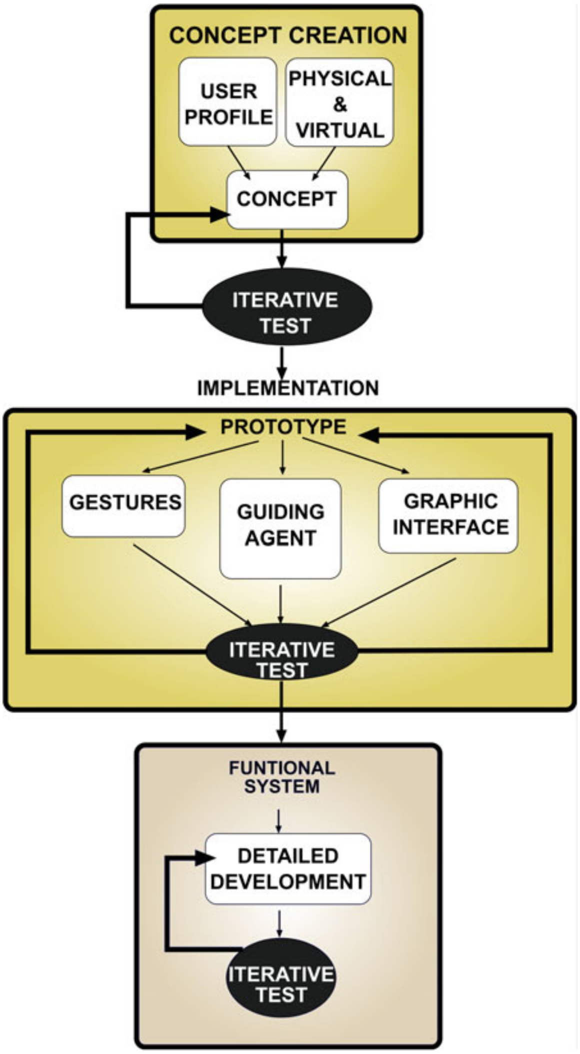


Fig. 4 Usability engineering life cycle used in NIKVision adapted from Mayhew (1999)

technologies. We have adapted the Mayhew engineering life cycle to reflect the dual character of tangible interactive applications (Fig. 4), combining virtual and physical design when working on ideation and during the prototyping of both physical and logical aspects of the games.

During *concept creation*, designers need to create concepts according to the *user profile* and considering the best combination of *physical and virtual* aspects. When users are young children, the key at this stage is to possess knowledge of their mental and psychomotor development, as well as to know their needs, desires and expectations in relation to the kind of product designers are working on. Once the concept is ideated, designers start working with developers. In tangible interfaces, *implementation* is not only software coding, but also physical building. Thus, the *prototype phase* requires to implement gesture recognition to identify children's manipulations of objects and provide feedback through a graphic interface and other virtual elements, such as a virtual agent in charge of providing guidance to children through the game. Developed by successive iterations, the prototype evolves into a product with all its functionalities implemented. During *the functional system* stage, the product is iteratively refined and fixed in order to achieve an error-free finished product ready to be commercialized or installed in its intended environment. In our case, life cycle iterations are guided by *test sessions* with the involvement of children. This means that from the concept creation through to the prototyping and functional system stages, the design of games for the NIKVision tabletop involves children at every step. The following sections describe the various stages and discuss the specific situations and methods used to capture and analyse information from the test sessions during the design of a specific NIKVision game.

4.1 Concept Creation

At the beginning of the NIKVision project, the question to be answered was how technologies based on tabletop and Tangible Interaction could be used in preschool children's education. In order to start researching this question, we first needed to know our users, the children. Then, we had to originate new concepts of tangible applications suitable for the NIKVision tabletop, adapting usual nursery and school activities to the new interaction paradigm.

4.1.1 User Profile

When intending to create a new product for users with very particular characteristics, such as 3-to-6-year-old children, it is important to have a detailed user profile in relation to the benefits that the new product can offer them. As described by Piaget (1952), children between 3 and 6 years are in the preoperational stage in which they begin to develop the symbolic function (language, symbolic games, mental image, imitations), while using manipulation and handling to build their mental image of the world. Use of physical manipulation in children's education has been seen as beneficial by Montessori (1936) and Alibali and diRusso (1999) who came to the conclusion that children can solve problems better by handling materials than by using pictures only. Chao et al. (1999) called this concept the "tool of mental sight". The physical nature of Tangible Technologies fits this user profile.

Inspiration to create new concepts in tabletop games can be derived from observing children playing with non-technological and technological toys. First of all, many non-computerized children's toys are played on horizontal surfaces such as a table or floor (Fig. 5). In fact, these are "non-computer-enriched" tabletop games.

Fig. 5 **a** MB Lucky Ducks™, **b** Goula Domino™ and **c** Playmobil™

On the other hand, nurseries and schools have computer stations among their facilities and children use them to play multimedia games from the age of 3. The observation of children playing computer games in their nurseries shows that they usually play in little groups around the computer station. However, as there is only one mouse and keyboard for one child to use, the others spend their time looking at the back or touching the screen to encourage their friend to act. This is where tabletop technologies overcome the limitations of keyboard and mouse, offering children collaborative playing and social experiences.

4.1.2 Physical Versus Virtual

Tangible tabletop concept ideation should be based on an appropriate combination of the "*physical versus virtual*" nature of tangible interfaces. In this way, designers can start from a virtual concept (pre-existing multimedia game based on keyboard or mouse) and enrich it with physical embodiment, or designers can start from a purely physical game concept, and think about how computer augmentation could enrich it with virtual environments. When creating NIKVision, the designers observed in nurseries how children love to play with wooden farm toys (Fig. 6a). A tabletop game concept was thus created based on a virtual farm, where the animals

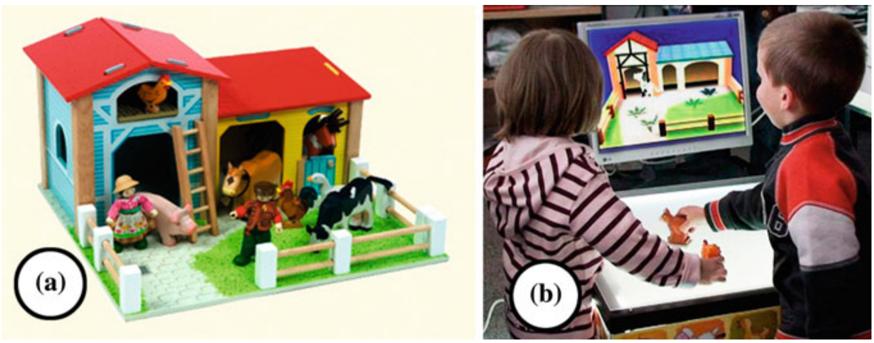


Fig. 6 **a** "Le Toy Van"™ wooden farm toy and **b** tabletop concept for farm game

were physical toys interacting with each other and with virtual elements in a 3D farm scene (Fig. 6b).

During the *concept creation* stage, children act as informants for designers. Adults can ask their opinions about the toys and games they like most and assess their potential expectations (Scaife and Rogers 1999). Even if their verbal skills are not sufficiently developed, designers can retrieve a lot of useful information by observing them playing. Although this is not a development stage, sometimes implementing a very simple initial prototype might help to obtain more information from the children about the ideas designers are working on. In the above-mentioned tabletop farm concept, a very simple conceptual farm game prototype was implemented. Children could play by placing rubber animal toys on the tabletop surface, and virtual animals appeared on a 3D farm on the monitor. No further interaction was implemented. A pair of children participated in some tests relating to this ideation. Their reactions were observed while they played. While child and parent were playing together, their conversations provided valuable subjective reporting of the child's impressions of the concept, and this was the base for developing a prototype of a more interactive farm game.

4.2 Prototype

At the end of the *concept creation*, designers need to draw up the specification of the concept game so that developers can start coding. At this point, it is important to mitigate the risk of spending too much time and effort on developing design decisions that might prove to be unviable in later user evaluations. This is why test sessions must be planned with very early prototype designs. However, prototyping with physical interaction (such as tabletop interaction) implies prototyping the *graphical interface* (images, animations, sounds, feedback, etc.) in a similar way to any conventional game, but also *gesture recognition* for physical interactions must be prototyped and the guidelines to be given by the *virtual agent* must be specified.

4.2.1 Gesture Prototyping

Algorithms to robustly detect user gestures and manipulations on the tabletop are hard to code, and at this stage, designers do not yet know if their decisions will be wasted after being tested by users. In prototyping, it is common to ask the user to "figure" or "imagine" that some system functionalities are working; but this is not a good idea with children (Sluis-Thiescheffer et al. 2007). It is important to remember that children are not really "testing" our prototypes; they are in fact playing, and they will only do so for fun. In this situation, a Wizard of Oz (Höysniemi et al. 2004) method would enable a prototype with simulated functionalities to be developed while children remain unaware of the fact.

Fig. 7 Farm game in NIKVision tabletop

In the tabletop farm concept, the “Wizard of Oz” approach was adopted to capture how children would naturally manipulate the toys to interact with the virtual elements of the game.

The farm game prototype consisted of a virtual 3D farm to be shown on the monitor and a 2D yard to be shown on the table surface. A set of virtual objects was placed in the 3D virtual farm scene and in the 2D table surface yard: plants, animal feeders, a nest, a barn, a bucket, etc. and a virtual farmer character that collected the objects gathered by the animals (Fig. 7).

By using a keyboard placed beside the NIKVision table, adult evaluators were able to change the state and appearance of these objects: to pick a strawberry, lay eggs in the nest, give milk, eat, give wool, etc.

A test session was planned in a school with 4-to-5-year-old children who were brought into play in pairs with the farm prototype. Three pair of children participated in the session. They were asked to feed the animals with strawberries (Fig. 8a), to use the toy hen to lay eggs (Fig. 8b), or to give milk or wool with the cow and sheep, respectively, but it was not known how the children would physically perform each action. Their gestures with the toys were observed by an adult designer who played the role of “Wizard of Oz”, triggering the game events using a keyboard beside the tabletop (Fig. 9). In this way, the children were really receiving feedback from the game that motivated and encouraged them to continue playing. By observing how the children manipulated the toys to perform the game tasks, valuable information was retrieved about how they performed actions while having fun with the game.

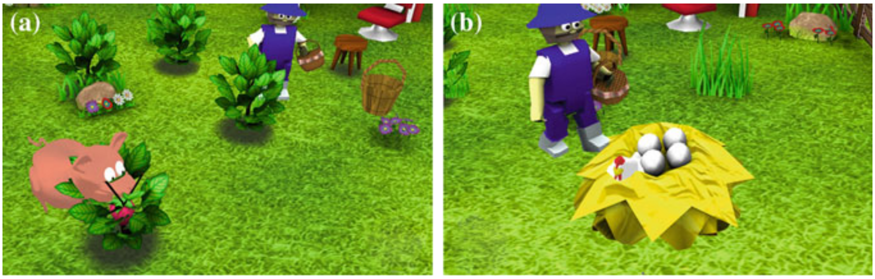


Fig. 8 **a** Virtual pig looking for strawberries and **b** Virtual hen laying eggs

Fig. 9 Adult “Wizard of Oz” observes children playing and triggers game events with a keyboard

The first couple of children started playing with the game without using the toys. They touched with their fingers on the different areas of the tabletop surface. Obviously, they understood the tabletop device as a tactile tablet device. We needed to explain them that the game has to be played handling the toys on the table surface. After that, they stated to manipulate the toys, but they played in turns; i.e., they did not tried to play with two toys at the same time. First, they tried to feed the animals with strawberries. They used a tilt gesture to lower the toy head until it touched the table surface, simulating the toy was eating the virtual strawberry. Then, they handled the hen on the nest. To simulate the hen putting eggs, they slowly jumped up and down the toy on the nest.

The second couple understood the game as a competition. They simultaneously handled and moved the toys on the surface with lots of energy. They used a very quick “shake” gesture to pick up the hidden strawberries from the plants. Once the strawberries task was completed, they stopped competing and carried out the other tasks in turns. They also used a jump gesture to put eggs with the hen, but they perform it more strongly compared to the previous couple.

The third couple took different roles to play the game; one handled the toys, and the other helped her partner by pointing on the table surface where she should place the toys. This child also simulate the toys were eating the strawberries by tilting the toys on the table surface, and they also used the jump gesture to put eggs with the hen.

After the session, we coded these gestures to be recognized by the NIKVision software, and they proved to be very viable actions in later test sessions. However, not all the actions proposed by the children were finally used. For example, the tilt gesture used to "feed the animals" task could not be implemented because the system cannot technically detect this gesture and consequently the feed gesture was discarded from the game.

Thanks to this Wizard of Oz approach, the children were again playing the role of informants in the design process of the tabletop game.

4.2.2 Guiding Agent

The developers implemented algorithms to automatically recognize the shake and jump gestures. After this implementation, the farm game was composed of three activities:

- Collecting strawberries: triggered with any animal using the shake gesture.
- Laying eggs: triggered with the hen using the jump gesture.
- Giving milk: triggered with the cow using the jump gesture.

The next step was to evaluate the activities with children. At the time, an adult assistant was in charge of asking the children to trigger the activities. However, our aim was to have an autonomous game without adult human intervention. Thus, this was the moment to develop the role of the farmer in order to turn him into an autonomous talking agent, able to perform the task of asking and guiding the children to carry out all the activities. The question that emerged at this point was "how detailed should the farmer's instructions be?"

To involve the children in this decision, we developed three different behaviours for the autonomous agent:

- "What to do": the farmer only gives the instruction of what to do (to find strawberries, to lay eggs, to give milk, to give wool).
- "What and where": the farmer also specifies where the toy has to be manipulated (on the plants, nest, bucket, barber's chair), using verbal instructions and moving near the object in the virtual scene.
- "What, where, who, and how": the farmer specifies what to do, with what animal, where and how to do the manipulation (shake, jump, etc.).

In the next school test session, the children played the farm game in pairs. Each pair played with only one of the three roles of the farmer. During a full-day test session in the school, seven pairs of children tested the game, so each version was tested at least twice. The trials were video recorded. Also, observation notes were taken down during the trials in order to assist designers in matching the videos and the times.

It was observed that all the children completed all the activities from the beginning to the end in the order of the three farmer roles described above. First, the children listened to the farmer's instructions and then tried to achieve that goal only (although the game still enabled them to do all the tasks in any order independently of what the farmer was asking for). Only a few children needed help with some tasks using behaviour "What to do" as they did not always know how to complete the task after hearing the instructions. Nevertheless, all the children were able to complete the task with behaviours "what and where" and "what, where, who, and how" without adult intervention. In conclusion, it was found that the "what and where" behaviour retained some exploration and challenge in the game without increasing its difficulty, and this was the behaviour finally implemented for the autonomous agent figure represented by the farmer.

Next, another design question about the farmer emerged: which were the most appropriate verbal expressions to be used? In which situations in the game should the farmer help?

Again, the children were involved in these decisions as informants, adopting a "peer tutoring" (Höysniemi et al. 2003) approach. In a test session held in a school, designers worked with a class of 4-to-5-year-old children, taking them in groups of three but letting one of them learn how to play before the other two. It was explained to the first child that later he/she would help other children to play the game. The child was given a farmer's hat to encourage him/her in the role of the farmer (Fig. 10).

The sessions were video recorded and later analysed in order to design the verbal expressions to be used by the virtual farmer and to see at which points help was required. New expressions and terms emerged from this session that were different

Fig. 10 Farmer child guiding his friends in the farm game

from those used by the adult designers; e.g., the children described the “jump” gesture using the verb “stomp”, and this was the term finally verbalized by the autonomous virtual farmer.

4.3 Functional System and Final Evaluation

The iterative nature of the prototype stage helped us to take all the design decisions needed to complete the farm game as a totally functional product to be used as a ludic activity. The work in this stage focussed on achieving a complete product, aimed to be used in early-year education environments and to provide fun and playful physical and co-located activities for young children. It was decided to integrate the collecting strawberries, eggs and milk activities in a game with one objective: to help the farmer to find the ingredients needed to make a cake.

The fully functional game prototype was evaluated in nurseries and schools. The evaluation was aimed at collecting a wide range of summative data from the tangible game, focusing on the following usability issues:

- Those related with a video game application: game task completion, paying special attention to the influence of the autonomous character.
- Those related with the tabletop tangible device: promotion of physical activity through toy manipulation, and co-located gaming through groups of children actively playing with the game.
- Those related with user experience: engagement of children in a playful and fun activity.

Next, the tools used to evaluate the functional game are described, and the summative analysis of the recovered data is presented.

4.3.1 Evaluation Tools

The plan for the final evaluation was to install the tabletop and the farm game in nurseries and schools to recover data relating to their use by children, minimizing the adult evaluator’s intervention. In order to do this, evaluation methods based on usability testing were used with children involved as mere users, playing freely with the game. Data were retrieved from video recording and automatic log files. Summative data were extracted by software tools that analysed all the log files and gave statistical measures of:

- Task completion: percentage of tasks completed related to the total number of trials of the tasks.
- Influence of the autonomous character: percentage of tasks completed in the order given by the farmer character compared to the total number of tasks completed; and percentage of tasks in which children gave greater quantities of

the ingredients (eggs or milk) than the amount requested by the farmer compared to the total number of tasks completed.

- Physical activity and co-located gaming: measured by the number of manipulations and different toys used on the table during a time unit and graphically represented during the time of the trial.

To capture the degree of fun and the children's engagement, the sessions were video recorded by two cameras. One camera was placed under the monitor to capture the children's faces. This video stream allows the children's gestures and verbal expressions while interacting with each other to be transcribed, as well as showing to what degree the game caught the children's attention. The other camera was placed so as to capture all the area surrounding the tabletop. By placing the camera high up on a tripod, a view of the tabletop surface and the children's manipulations on it can be captured. This video stream helps to identify usability problems during the game (problems in carrying out a task, difficulties in performing the physical gestures, etc.) that log analysis is not able to detect. The interaction between children was also retrieved with the camera (to see if children played independently or helped each other, or if some child stopped playing to watch his/her partner).

In the analysis phase, both video streams were synchronized together with a graphical animated representation of the log file. The complete video-stream composed of the three views (Fig. 11) was used to relate all game events to the degree of fun and the engagement experienced by the groups of children during the game.

4.3.2 Summative Analysis

The data of the final evaluation were retrieved from two sessions: one carried out in a nursery with 3-to-4-year-old children and the other in a school classroom with 4-to-5-year-old children. The initial plan was to analyse both sessions together but, even with this small age gap, there are significant differences in cognitive and motor skills in children (Piaget 1936). Moreover, there were differences between the nursery and school environments that may influence the results. In the nursery,

Fig. 11 Three video streams synchronized. **a** face camera, **b** tabletop camera and **c** log video-stream

NIKVision was available simultaneously with the rest of the activities. Toddlers came in groups of three to play freely with the game. However, in the school, NIKVision was installed in the library, not in a classroom. Adult intervention was not as minimized as in the nursery, since the teacher brought groups of two or three children to play with the game and adult assistants introduced the game and encouraged the children to start playing. It can be deduced that children in the nursery did not feel that they were being tested and they played completely uninhibited, whereas in the school, the children had the feeling of being tested. They were shy when entering the library and sometimes even asked for permission to start playing. For this reason, the analysis is separated according to the origin of the data: nursery or school.

The “Making a cake” game starts with the farmer asking the animals to help him to make a birthday cake. For this purpose, he first asks for 5 strawberries which appear randomly within the plants: the children can use any animal toy to pick strawberries. Then, the farmer asks for 4 eggs, which can only be provided by the hen toy. Finally, the farmer asks for milk, which is obtained by jumping the cow four times on the bucket. When one of these tasks is completed, the farmer announces that he does not need more and asks for the next ingredient. In any case, the children can continue laying eggs and giving milk if they want to.

Ten trials of the “Making a cake” game were obtained from the nursery session and twenty from the school.

In the school test, nearly all groups finished all the game goals (98 %), in contrast with the nursery where most of the children did not finish the tasks (only 36 % finished the tasks). The video analysis of the nursery data showed that carrying out the tasks did not seem too challenging for the toddlers. They were able to shake the bushes and to stomp with the cow and the hen to give milk and eggs without any difficulty. But their motivation was merely exploration, so they did not worry about the amount of strawberries, eggs and milk needed to complete the task. The toddlers explored the yard freely, not paying attention to the farmer’s verbal instructions. Indeed, the chaotic and noisy environment of the nursery did not help the farmer to be heard. This is confirmed by analysing the order in which the tasks were carried out: while in the school, most of the children carried out the tasks in the order asked by the farmer (65 %), hardly any trials in the nursery were carried out following the farmer’s instructions (10 %). Also, in most of the nursery trials, the toddlers laid more eggs and gave more milk than the amounts asked for by the farmer (75 %). Therefore, it can be concluded that the farmer had almost no influence during the nursery test. In contrast, in the quiet environment of the school library, the farmer was easily heard and the children played mostly following the order proposed by the farmer. However, the school measurements show that nearly half of the groups that had already finished the eggs and milk tasks continued repeating them as if there were no limit to the eggs and milk they could produce, indicating that the children in the school wished to carry out the activities beyond the farmer’s commands.

Regarding the game performance in promoting physical and co-located gaming, Fig. 12 shows the graphs of the evolution of these measurements during a trial of

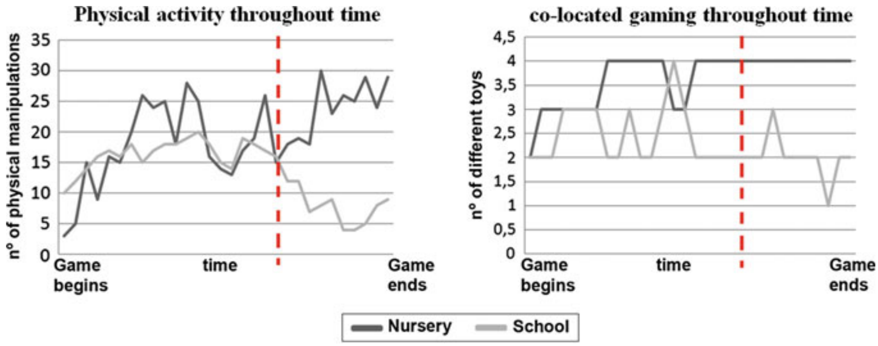


Fig. 12 "Making a cake" game: physical and co-located gaming

the game comparing the nursery and school sessions. As each trial game has a different time length, all the game trials were divided into 30 time segments to obtain the statistics.

The school trials show active physical and co-located gaming during the first two-thirds of the game (until the red line in the graphs), decreasing to the end of the trial. The school trial was more task driven, and it can be seen that the strawberry task (the first task requested by the farmer) engaged the children in a more intense physical and co-located activity than the eggs and milk tasks which can only be carried out by one toy (hen and cow, respectively). This was confirmed by the video streams, where more than one child could be seen trying to find strawberries on the bushes at the beginning of the game but, when the strawberries task had finished, only one child carried out the eggs and milk tasks, while the other partners looked away. In contrast, in the nursery, physical and co-located gaming measurements show almost the opposite results: these rates increased continuously during the trials and were higher than in the school. Looking at the videos, it can be observed that the toddlers were rather shy at the beginning of the game, not knowing how to play. But they soon discovered how to interact with the yard elements, and physical and co-located gaming increased to a maximum until the end of the game, even with one child manipulating two toys at the same time.

The degree of fun and the engagement of the children in the game were extracted from the video streams. The children's attention was attracted to the monitor most of the time. Laughs and expressions of fun were always related with 3D animations and sounds. The children only looked at image projections on the table surface during very short periods of time when they needed to locate the strawberries in the plants and the nest and bucket. But once they had placed the toy on the spot, they performed the gesture looking at the monitor and laughed when the strawberries were dropped, the eggs were laid and the milk filled the bucket (Fig. 13).

This evaluation shows results relating not only to the impact on usability of a guiding autonomous agent, but also to the influence that the design of tangible tabletop activities and toy roles have in promoting physical and co-located gaming in young children.

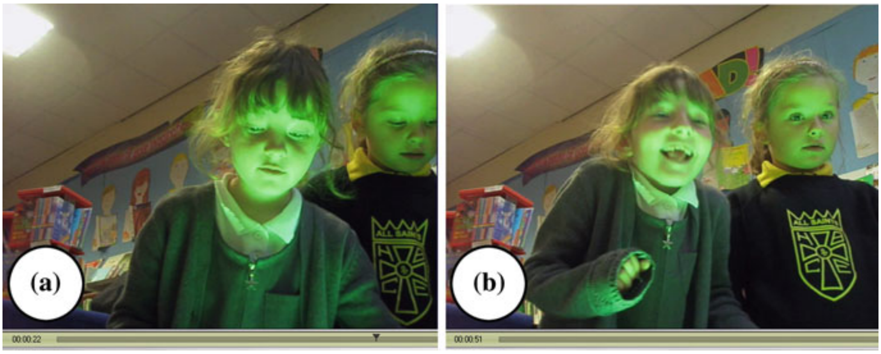


Fig. 13 Four-year-old girls playing, **a** seriously manipulating toys on table surface, **b** having great fun seeing animations on monitor

4.4 Discussion: Designing Tabletop Games for Young Children

From the experience gained during the design process and the final evaluation of the farm game developed for our tangible tabletop device, some lessons might be extracted that could be useful for developing future tabletop games for very young children.

- Analysis of the video recordings showed children expressed their sense of fun and engagement in the game while looking at the virtual characters and animations running at the conventional monitor. This benefit should be exploited with an appropriate distribution of visual feedback between monitor and tabletop projection. While the first should be responsible for engaging children in the game, using attractive scenery, funny animations and autonomous characters, the second should provide visual feedback about task completion and guide children to locate the interactive spots where toys are to be manipulated. As a consequence, children attention during the game is divided in two different locations. Feedback events should be wisely distributed in different moments, providing children with guidance on the tabletop surface while carrying on the task and, once the task has been completed, rewarding them with funny animations on the conventional monitor.
- The inclusion of a virtual character and its role in the game must be carefully considered depending on the game objectives. In games where children need to perform all the tasks so that pedagogical content is transmitted, the use of an autonomous character to provide instructions and precise commands is essential. In a task-driven approach with a guiding character imposing the order of task completion, children gain a clear understanding of the objectives and end conditions of each task. However, interaction with the game may become rigid,

with less fun and fewer spontaneous moments. In contrast, a free game with no autonomous character giving instructions may encourage greater exploratory behaviour in children, enhancing physical and co-located gaming. The use of a virtual character in this kind of scheme may still have benefits in engaging children, if its behaviour is oriented to informing children of their progress through positive and negative feedback.

- Guidelines extracted from previous literature about video games and children (Malone 1984) may be useful, but designers should consider new methods of TUI interaction closer to non-digital toys and gaming. In other words, the potential of a tangible tabletop to promote physical playing is better exploited when the classical video game model (with tasks and objectives to be sequentially achieved) is avoided, and children are left to freely explore and discover how to activate sound and animations. In such a scheme, a guiding virtual character could help to engage children in the exploration of the game.
- A tabletop device which supports co-located gaming does not in itself produce such gaming. The design of the game tasks is decisive for engaging groups of children to actively play with the toys. By giving balanced roles to each toy throughout the game, children can take any toy at any moment and start exploring its interactions in the virtual environment of the game, and thus, co-located gaming is encouraged.
- Psychomotor and cognitive development of children should always be considered when designing any game task: for example, when children are asked to shake or stomp with the toys, will they all perform the gesture in the same way? Observation of children playing with the games helps to solve these kinds of questions, and with an iterative design process, the game can be refined and adapted to children's capabilities.

There are some important considerations that designers and developers interested in receiving help from young children have to take into account during the process of creating new technology applications:

- The most important decision is to define the role of the children in the project from the beginning. Roles requiring a high degree of involvement, such as design partners and informants, may be very useful for detecting children's needs and preferences, but they are not suitable for very young children whose social and cognitive development is not sufficiently developed for a natural relation with adult evaluators. Furthermore, these roles require more structured evaluation sessions, which can compromise the value of the data obtained. In fact, our experience during the evaluation sessions with very young children shows that the more structured the session, the less useful the data obtained. One possible explanation would be that the large number of instructions that have to be given before they start reduced the children's naturalness and spontaneity when playing. An additional risk in this kind of structured session is that the child may have the impression of being tested. In contrast, those sessions in which the game is just one more classroom activity among others provide more reliable, honest and valuable data to evaluators. Additionally, the use of log files and video streams allows the evaluation to be conducted in an objective and exhaustive manner.

- As regards the most appropriate places to carry out the evaluation sessions, nurseries and schools are very versatile environments for developing projects involving adult designers and children. Toddlers have difficulties in adapting to new environments and new people. Therefore, children may have unpredictable reactions in laboratory test sessions, added to which it is difficult to arrange frequent visits to the laboratory and usually only small groups of children can enter the laboratory at a time. On the other hand, many teachers are willing to collaborate with researchers by offering their classrooms and time provided, of course, that all ethical questions about testing with children have been carefully considered and permission from parents has been granted. For designers, classrooms provide a sufficient number of users for formative and summative evaluation, as well as being a favourable environment for inspiration and creativity. To conclude, the most important thing to consider when planning a test session is that children are using the product just for fun.

5 Tangible Tabletops for All? Evaluating the Farm Game with Children with Special Needs

The principles of universal accessibility have made possible a great advance in the application of digital technologies to the learning of disabled children. In the case of physical disabilities, accessibility is achieved with specific hardware and software to allow access to digital contents. In the case of children with cognitive disabilities, accessibility problems come from the difficulty of understanding the information given by the computer application.

Thanks to a collaboration project with a special education school, we were given the opportunity to test the NIKVision tabletop and games with children with cognitive disabilities (Marco et al. 2013b). As stated in the introduction, studies focusing on Tangible Interaction applied to children with cognitive disabilities are still very scarce. The aim of our tests was to investigate the suitability of our tangible tabletop for this kind of child. Would they understand how to play? What should be the role of the virtual character? What role should the teacher assume during the game? In fact, studies carried out to analyse the use of computers in classrooms with cognitively disadvantaged children have shown a strong dependence on teacher intervention (Bunninga et al. 2010). Studying these issues in depth required a more meticulous video analysis of the data retrieved during the test session, as explained in the following sections.

5.1 Testing Sessions and First Results

The test sessions took place in one of the school classrooms with the participation of three pairs:

- Pair 1: one multidisabled boy aged 8 and a girl aged 6 with West syndrome.
- Pair 2: two boys aged 9 and 11 with Down syndrome.
- Pair 3: a boy aged 7 with attention deficit and a boy aged 8 with autism.

During the sessions, the pair of children, two school teachers and two evaluators were present in the classroom. The game was briefly presented to the children, and they were encouraged to play, but they were not told exactly how to do this. The teachers only intervened when the children became blocked and did not know how to advance the game. Each pair played twice so that every child could carry out all the tasks (the laying eggs and giving milk tasks can only be done with one of the animals), and therefore, six “Making a cake” games were played in total.

In this case, besides the video recordings and the logs, a usability test was conducted by the evaluators with the aid of the teachers who answered at the end of the test a simple questionnaire with opinions and suggestions about the performance of the game. After the session, the video and log files were recovered and paired up (Fig. 14). The log files were exported as video sequences and synchronized with the recordings of the children playing. In this way, a complete reconstruction of every game carried out in the classroom was achieved.

The first analyses were similar to those carried out in the regular school tests, examining task completion, task order (an indicator of the impact of the virtual farmer), physical activity (through the number of manipulations over time) and co-located playing (through the number of toys manipulated).

As regards task completion, results are very similar to those obtained from the previous school tests. The tasks were completed in all trials (100 %), the task order followed the instructions given by the farmer in most trials (65 %), and nearly half of the children continued the egg and milk tasks after completion. The explanation may lie in the similarities of both environments: in both cases, the children had the feeling of being tested which pushes them to follow instructions and complete the

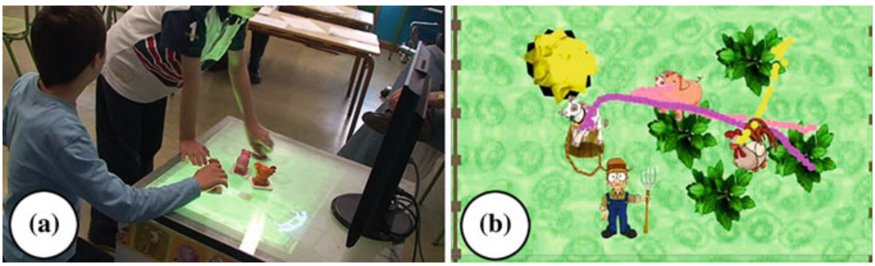


Fig. 14 **a** Video sequence captured in the classroom and **b** graphical reconstruction from the log file

tasks. But the way this behaviour is achieved is quite different in both environments. In the regular school, the farmer's instructions are sufficient to ensure task completion and task order. In the case of the special education school, the farmer's instructions are often not enough: many children have difficulties in paying attention to the farmer's instruction even if they are periodically repeated. On many occasions, it is necessary for the teacher to intervene to ensure that children continue with the task. In spite of the teacher's interventions, there were some shifts in the task order and some tasks were continued after having been completed. The shift in order always occurred in the pair's second game: thanks to the knowledge gained during the first game, the children went directly to the tasks they liked most.

Besides comments referring to the farmer's role, the questionnaire filled out by the teachers revealed a new problem. The children did not really know whether they had completed a task or not, because they did not know how many eggs or how much milk was needed. This explains why they so frequently persisted with the tasks. Therefore, more attention should be paid by game developers to ensure children understand the game. Appropriate feedback should be added to motivate children to continue, rewarding them when the task is finished. In fact, educators suggested using the virtual farmer to reinforce positive feedback by means of laughs, applause, dancing, etc. and not only by spoken words.

As regards physical activity and co-located playing (Fig. 15), the analysis shows results very similar to those obtained in the nursery tests. Physical activity shows an ascending tendency during the game. Again, at the beginning, children behaved very shyly and appeared reluctant to play. The teachers' motivation and explanations encouraged the children to start playing. Co-located playing also shows very high ratios, with all the toys being used all the time. Analysing the videos, it was realized that the children loved to have all the toys on the table and while one child was carrying out the task, the other took advantage to explore the environment with the other toys. In the second game of the same pair, the roles were reversed, and the tasks were then performed by the child who had devoted the previous game to exploring. Therefore, it can be concluded that special needs children like to actively explore the farm with the toys, similar to toddlers in the nursery environment, but

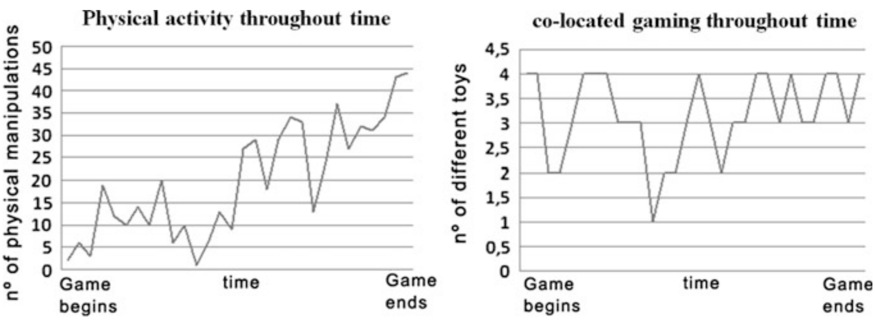


Fig. 15 Evaluating the "making a cake" minigame: physical and co-located gaming with special needs children

they still need the support of educators to begin playing and to continue moving the game forward.

From these results, it was clear to teachers and evaluators that the children's comprehension of the game needed to be studied in more detail. The impact and usefulness of feedback in the application and educators' interventions during the test sessions also required further examination. A more detailed video analysis of the games was therefore carried out, as explained in the following section.

5.2 Detailed Video Analysis

To perform a more detailed analysis, the DEVAN (DEtailed Video ANalysis) method proposed by Vermeeren et al. (2002) was chosen and adapted. The DEVAN method is based on the structured analysis of video material captured during user tests and was developed to detect usability problems in task-based products for adults. When used for evaluation with children, this method can be adjusted for the detection of usability and fun problems (Barendregt 2006) in computer games. It is a very time-consuming method: the interaction is analysed in detail to locate events that indicate an occurrence of a problem, i.e. the evaluators have to detect and code the behaviours that may indicate a problem, which are called "breakdown indications". The breakdown indications have to be grouped into problems, as there can be multiple indicators for the occurrence of one problem. The result of this stage of the analysis is a list of pairs of time stamps and behavioural categories.

In our case, the aim of the video analysis was to relate the usability breakdowns found during the sessions with the children's comprehension problems and their relationship with game feedback and adult interventions. A graphic dictionary of indicators (Table 1) was drawn up. The indicators were grouped in two categories:

- Child **behaviour indicators** that mark game moments in which the child's action is *correct* (allowing moving forward to task achievement), *incorrect* (the child shows the intention of achieving the task, but the action performed is not correct), *exploratory* (the child does not show any intention of completing the task but has a good time exploring the virtual farm scenario) and *system problem* (the action is correct but the system misses it).
- **Feedback indicators** that mark those game moments when information is given to the child through the **virtual farmer** (asking the child to complete a task and giving instructions on how to do it), through **graphics and animations** visualized in the farm scenery that indicate the degree of task achievement (egg laid, bucket filled, etc.) and through **teacher intervention** at those moments when the child becomes blocked and is not able to continue with the task.

The indicator icons are used to label, by means of a video editing tool, those moments when the evaluator observes the appearance of one of the events defined in the dictionary (Fig. 16).

Table 1 Dictionary of indicators used to label the test session video recordings

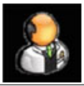
Child behaviour			
			
Correct	Incorrect	Exploratory	Correct action but system problem
Feedback			
			
Verbal indications given by virtual farmer	Visual feedback	Adult intervention	

Fig. 16 Different labels on video streams, **a** a child discovers how to lay eggs while exploring the game, **b** a child tries to collect strawberries when the task has already ended and **c** a child is making a jump gesture which the system does not recognize

After the labelling process, each game is graphically shown as a timeline where the children's actions are related to feedback events (Figs. 17 and 18). Each event is depicted as a rectangle of the corresponding indicator colour and with a width proportional to the duration of the event. These time graphs are of great help when trying to correlate children's behaviour with system or adult feedback. For example, Fig. 17 shows a child carrying out a milk task. At the beginning, the farmer gives instructions about how to perform the task (Fig. 17a). The child tries it, but he has not really understood the farmer's instruction and makes the wrong action. Afterwards, an adult intervenes, and consequently, the child succeeds (Fig. 17b) in partly filling the bucket with milk. Nevertheless, the child has not fully understood the task and keeps repeating it incorrectly in spite of the adult's interventions (Fig. 17c). Finally, there is a longer teacher intervention explaining how to perform the task (Fig. 17d), and the child correctly completes it, completely filling the bucket.

In the laying eggs task, the same child shows a very different behaviour (see Fig. 18). The timeline shows that the child has definitely understood the task: after listening to the farmer's instructions, he lays an egg correctly (Fig. 18a). Subsequently, his actions are exploratory and he has fun playing with another toy

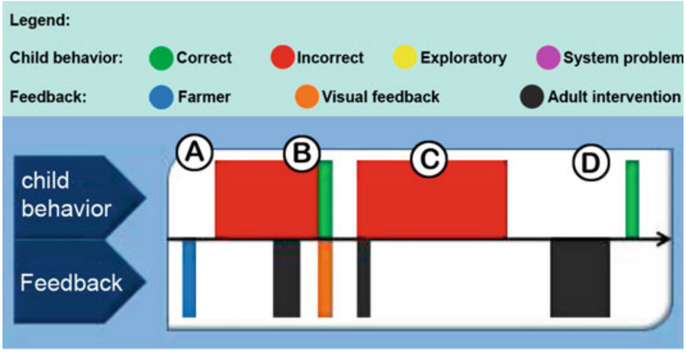


Fig. 17 "Giving milk" task timeline

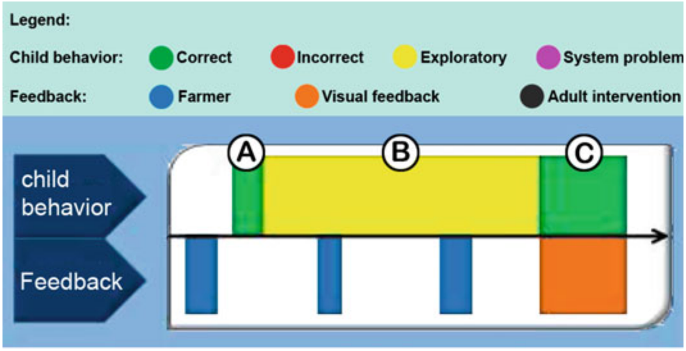


Fig. 18 "Laying eggs" task timeline

without realizing that he has to lay three more eggs to successfully complete the task. Meanwhile, the farmer keeps telling him to finish the task (Fig. 18b), and finally, the child realizes and correctly lays the rest of the eggs (Fig. 18c).

The results from the video analysis show the intrinsic difficulty of designing computer feedback for children with cognitive disabilities. Figures 17 and 18 reflect two very similar game activities carried out by the same child, resulting in very different adult interventions and child understanding.

These tests have highlighted important issues to be taken into account in our future work, as discussed in the next section.

5.3 Discussion: Designing Tabletop Games for All

The evaluation of the farm game in the special education school has resulted in some findings similar to those found in the school and nursery environments:

children have fun playing with the tabletop and have no problems in interacting with it. However, specific issues have arisen related to the autonomy of children in special education environments:

- In these environments, children's activities strongly depend on teacher support. Virtual characters, which can be very effective in regular educational environments, should not be developed as a substitute for motivating and guiding role of teachers. This has to be taken into account not only when developing the game but also when assessing it. Evaluations in nurseries and schools have to be planned minimizing adult intervention in order to observe children's natural interaction. In a special education classroom, however, educators should have an important role in encouraging and helping children during the test and supporting evaluators with their perceptions and opinions about the performance of the technology after the test.
- Virtual characters may have an important role giving positive and negative feedback to children's actions and rewarding the children after fulfilling the tasks. Feedback should be emotional: that is, appearing sad for negative feedback, and laughing and dancing for positive feedback.

6 Conclusions

The feasibility and impact of developing digital technologies based on Tangible Interaction for young children and those with special needs have been shown. In particular, our NIKVision system with its combination of tabletop and manipulative toys has considerable potential for collaborative computer gaming. During the testing of the games, children played together and engaged in a high degree of physical activity, thus overcoming one of the most controversial aspects of computer video games (i.e. lack of social and physical activity).

Child-centred design methods have to be used to capture usability and user-experience data from children playing with the game prototypes. The methods used during each test session must be selected according to the kind of data to be captured. However, due to their young age, methods based on children's expressions or verbalizations of their thoughts should be avoided. Instead, usability testing methods are a good option, for example observation notes, automatic logging and video recording. These methods have proved to be very useful for comparing different versions of our prototype and have been combined with other methods of child involvement such as Wizard of Oz techniques in order to capture their natural gestures for implementation in the game.

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The Power to Play When There is No Power

Yoram Chisik, Monchu Chen and Jesus Ibanez

Abstract Electrical power is the lifeblood of digital play. Without electricity, the devices on which digital play depends cease to function and thus disrupt the engagement of the player with game. While such disruptions are normally disruptive to the "flow" of a game, they can be quite constructive when taken into account in the design of the game. In this chapter, we discuss the notion of power/no power games, that is, games specifically designed to provide engaging play experiences under power and no power conditions. We provide an initial blue print for the design of such games and present early findings from play tests conducted with the proof of concept games we have developed to explore this notion.

Keywords Game design · Interaction design with children · Hybrid games · Physical and digital play · Child play

1 Introduction

When it comes to digital games, there are two kinds of power at play, the power of electricity, i.e., the current that drives the devices that facilitate digital play; and the power of play, i.e., the spark of engagement that fuels the desire of the player to continue playing the game.

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Digital devices are dependent on a constant flow of electricity for their operation, and players require a constant flow of experiences to engage them with the game and to make them to want to continue to play it. Most digital game designers assume the availability of a constant supply of electricity in the same way that they assume their game will capture the attention of one or more players. While this is quite a reasonable assumption to make in large parts of the world, it ignores the sad fact that for many people living in parts of the world where the infrastructure is less developed, the supply of electricity is anything, but constant and frequent power interruptions are a part and parcel of everyday life.

One may argue that as players and electricity are exogenous entities, i.e., they do not come in the "box" with the rest of the game elements, their absence or availability should be resolved outside the game as well. However, this argument ignores the distinction between *game*, which following Aarseth (2007), we define as a set of facilitators comprised of physical (and in the case of digital games also virtual) structures, rules, and mechanics that structure player behavior, and *play* which we simply define as a phenomenon in which a person engages with a game.

The decision of whether to play a game, as opposed to doing something else, is external to the game as is the decision of which game to play; however, once the decision has been made and play has commenced, the actions of the player and the supply of electricity (in the case of digital games) are as fundamental to the game as any of the other elements which facilitate play and thus cannot be externalized.

Therefore, if we look at what makes a person wish to continue playing a game as opposed to what makes them want to play in the first place, any interruption to the power supply is not merely disruptive but down-right destructive, for without the power of electricity an Xbox is nothing more than a box, a Wiimote is nothing but a mote and the player is left holding the controller with little if any recourse and no way forward.

In *Flow*: *The Psychology of Optimal Experience*, Csikszentmihalyi (2008) notes that in order to maintain a flow state, i.e., a state of engagement with an activity (which in our case is playing a game), one must have perceptible ability to continue with the activity. It is obvious that without the power of electricity, it is impossible to maintain the "flow" of a game on a digital platform. But is it possible to maintain the player in a state of flow during a power failure? We believe it is. We believe that by incorporating physical and digital elements and intertwining digital and physical modes of play, it is possible to provide a high enough level of engagement with the game that will maintain the player in a state of flow.

2 Playability and Electricity

Players engage in a game by manipulating the game structures within the limits set by the game rules and mechanics. The engagement may take the form of direct physical manipulation as in the case of moving a chess piece on a board or kicking a football on a field, or indirect manipulation of a virtual object on a screen via the physical manipulation of a game controller, or the performance of certain eye, hand, or body motion that are picked by a motion sensor.

Playability is an intrinsic element of the design of a game; it refers to the ease and the duration in which play is sustained. Some games may be more playable than others, and the level of playability may fluctuate over time. The reasons will vary from player to player as well as from game to game and context to context. We illustrate this via the following four potential playability scenarios represented as four separate plots in Fig. 1:

(a) A very easy to learn game in which players can gain a high level of proficiency very quickly. These games offer a high level of playability which can be sustained over a long period of time as players may play them as a source of diversion and entertainment as opposed to a challenge.
(b) A slightly more difficult to learn game thus requiring more time and effort for players to acquire proficiency. This type of game also offers high levels of playability that can be maintained over long periods of time, but some players may loose interest depending on whether their engagement with the game derived from enjoyment they got from playing the game or the challenged they experienced while learning and gaining proficiency in playing the game.
(c) A game with a fairly complex set of rules and/or a complex gameworld which may be difficult to learn at first but which offers a satisfying challenge to a player thus sustaining play through skill development and emotional attachment. The playability of such a game will vary greatly from player to player and from game to game based on the way in which the game was designed the satisfaction, enjoyment, or frustration experienced by the player and the level of accomplishment they have achieved or the proportion of the gameworld they have explored. Most games fall into this category.
(d) A game with an overly complex set of rules, an overly complex gameworld, or an ill defined and unintuitive interface resulting in low playability that will stymie the most determined of players.

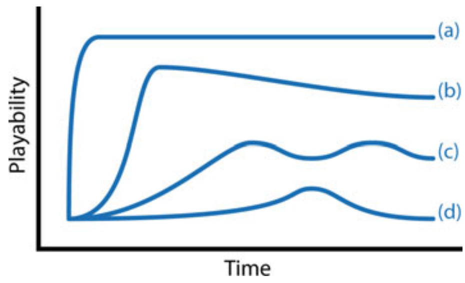

Fig. 1 Four potential playability scenarios

3 Power and Play

For "traditional" games, i.e., games composed solely of physical structures, the *power to play* is all that is required to continue to play the game as the physical elements of the game, i.e., the tokens, cards, and balls are moved around by the players themselves, and thus, their own motivation and energy is all that is required to play the game.

However, digital games are dependent on a constant supply of electricity to maintain playability as without it the elements that facilitate digital play, screens, consoles, and controllers cease to work and thus the games become unplayable (Fig. 2).

Playability will suffer a serious blow even if the supply of electricity is restored within a short period of time (Fig. 3) as the players will in most cases have to start a new session of the game as opposed to continue from where they left off.

Games that combine elements of traditional games with digital elements such as *Lego Mindstorms* can maintain a certain level of playability after the loss of electrical power (Fig. 4); for while the motors, sensors, and software that make up the digital part of the game cease to work, the bricks and anything assembled with them do not lose any of their functionality, and thus, a *Lego Mindstorms* truck will offer a certain level of playability to the player when the electrical power in its battery runs out, while an Xbox controller will offer close to none.

Our ultimate goal is to create games that maintain their playability after a power failure, i.e., design a game that will offer the player an equal level of playability with power and without power (Fig. 5).

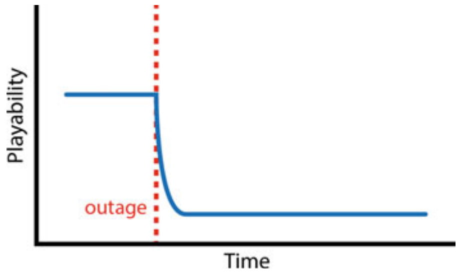

Fig. 2 Playability drops suddenly and the game becomes unplayable

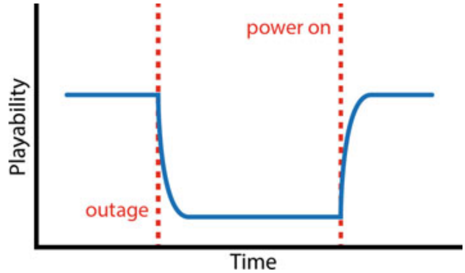

Fig. 3 Disrupted playability during power outage

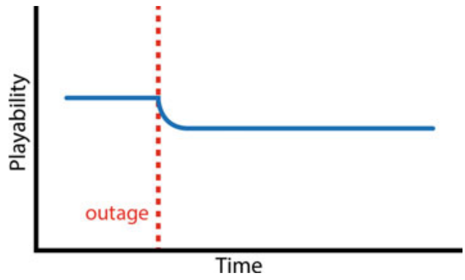

Fig. 4 Some games may retain certainly degree of playability after power outage

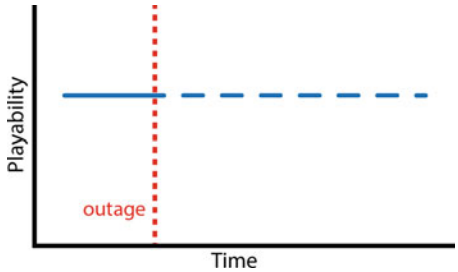

Fig. 5 Maintaining the same playability after the power outage

4 Maintaining the Power to Play

Schoenau-Fog (2011) describes the player engagement with a game as a process of objectives, activities, accomplishments, and affect each driving one another to sustain engagement with the game (Fig. 6).

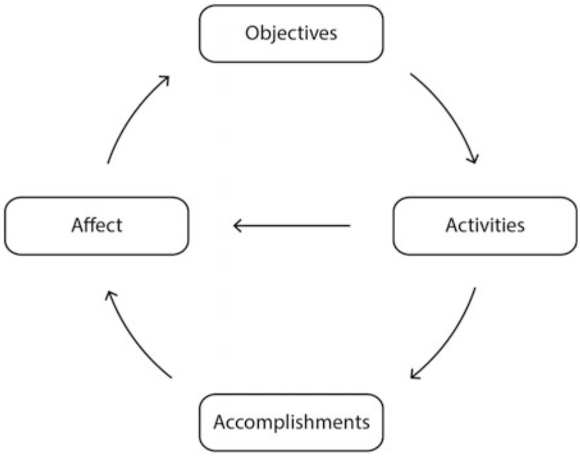

Fig. 6 Relations between objectives, accomplishments, activities, and affect (The OA3 framework), Schoenau-Fog (2011)

According to this framework, once the player has started playing the game:

- "…Either the game sets up an objective (e.g., to win a race) or the player makes up a self-defined objective (e.g., to visit all locations in a game world).
- The objectives trigger activities that the player performs (e.g., experimentation) in order to accomplish the objective (e.g., optimize a racing car).
- An engaged player can have the desire to continue performing activities as long as the objective is not reached, in order to experience accomplishment as a result of successfully performing the activity (e.g., completing a level through solving puzzles).
- Players can experience affect of some sort as the result of performing an activity (e.g., relaxation after moving the body in an "exergame"), through the accomplishment of an objective (e.g., satisfaction through achieving special equipment) or if the objective is not accomplished (e.g., frustration because of an unbalanced game).
- If the affect is experienced as positive, player engagement can be sustained and a new cycle can begin with new objectives or by returning to play the same game later."

Looking at digital game play from this perspective, the activities part of the framework will suffer a mortal blow as practically all activities in a say a console or tablet game require electricity in order to be completed. Thus, for a game to maintain playability through a power failure, it would need to offer alternative activities for any of its objectives, so whenever a power outage happens before an activity is finished, the players can adopt any alternative activities and continue to reach the original objective.

This requires thinking of the game not in terms of platforms or technologies but in terms of challenges and opportunities. Caillois (1961) defined gameplay as an activity, which is non-obligatory, governed by rules, is uncertain, and involves a certain level of make-believe. If we incorporate the notion of an uncertain supply of electricity into the design of the game in a way that equally engages players via both digital and non-digital activities and accomplishments building on their imagination and capacity of make believe, their motivation to play the game should remain the same regardless of the power condition (Fig. 7).

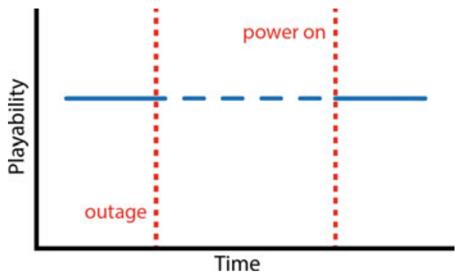

Fig. 7 Playability is maintained at the same level before, during and after a power outage

There remains the question of how we can put this to practice. In order to derive the player engagement framework described above, Schoenau-Fog (2011) conducted a series of surveys, which queried players about which parts of a game engaged them the most. The responses show five key aspects of player engagement: *Experiencing the Story* (18 %, in *Activity* component); *Completion* (16 %, in *Accomplishment* component); *Progression* (13 %, in *Accomplishment* component); *Socializing* (10 %, in *Activity* component); and *Sensing* (9 %, in *Activity* component).

Applying these five aspects to our uncertain power supply condition, we get the following five guidelines, which we believe to be essential to designing a game, which will supply sufficient power to play regardless of whether the electrical power is on or off.

1. *Experiencing the Story*, it is imperative that the narrative of the game incorporates the notion of an uncertain power supply so that the players will be motivated to explore aspects of the game in both the power-on and power-off conditions regardless of whether the power-off condition was forced upon them (power supply failure) or whether they opted to play in the no power condition to begin with.
2. *Completion*, the no power condition should not be a stopgap measure to sustain the interest of the players until the power is back on but should be fully workable on its own, i.e., players can complete the game in the no power condition. Perseverance and closure are important aspects of motivation and gameplay; if the game will not offer the potential for completion with no power, there will be less or no incentive to continue playing the game once the power of electricity runs out.
3. *Progression*, the game should be designed so in the power-off condition; players will not lose their desire and momentum to improve and advance to a higher level. During a power outage, the non-digital component of the game may become more predictable and less varied than its digital counterpart. As a result, players may feel there is less of a chance for progression and become disengaged. By designing and balancing the game to offer equally perceivable opportunities for progression within and between the digital and non-digital components, can prevent players from losing their momentum and encourage them to continue playing the game.
4. *Socializing*, assuming the players are colocated this condition will be relatively easy to maintain across power conditions as the cooperative aspect of the non-digital component of the game are bound to keep players engaged during the power outage.
5. *Sensing*, this component of player engagement equation will be somewhat challenging to keep during the no power condition as the variety of visual and aural special effects cannot be easily mimicked by other means if at all. However, the design can still strive for an equally engaging sensory experience as exemplified by the visually and audibly compelling no digital games available on the market. We believe balancing the sensory experience for both

power-on and power-off conditions will be more important than increasing the sensory engagement for the non-digital component of the game.

In the following two sections, we provide examples of projects in which we began exploring these principals.

5 Puppets Duets

Puppets Duets was our first foray into the realm of equally engaging games. We designed *Puppets Duets* as a simple game consisting of physical and digital elements for which we provided no explicit rules. The design was deliberately simple leaving out many of the components mentioned in the guidelines we outlined above, as we wanted to test a worst-case scenario.

Our goal was to see how children would react to the game, whether they would discover the game rules and mechanisms by themselves and whether they would be engaged by the game with the power on and whether they would continue to play when the power was cut down? We presumed that if we could get a certain level of playability from such a simple design, then we could surely get better results as we further develop our ideas.

Puppets Duets consisted of two screen avatars, a singer and a conductor (Fig. 8, left), that were controlled by two corresponding sock puppets operated by two players (Fig. 8, right) and governed by two self-discoverable rules.

The game has a simple set of mechanics. When the singer sock puppet opens his mouth, the singer avatar starts singing, and when the conductor puppet opens his mouth, the conductor avatar waves his baton. In addition, if the conductor avatar waves his baton at the same time the singer avatar is singing, the singer will change his tune.

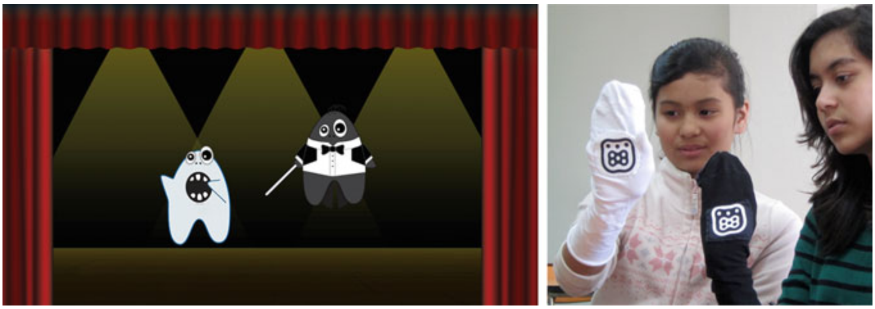

Fig. 8 The avatars (on the *left*) and the sock puppets (on the *right*)

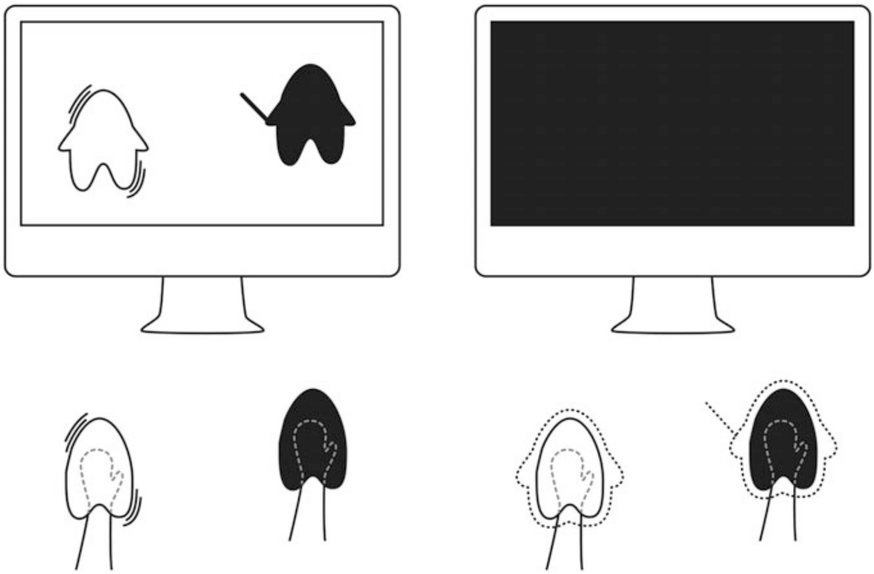

Fig. 9 The relationships between sock puppets, avatars, and imaginary avatars

The game is governed by a set of two rules:

> The first rule is that the puppet (operated by a player) controls the avatar appearing on the screen. To enact this rule, the player has to interact with the computer.
> The second rule is that the player/puppet/avatar control each other. To enact this rule, the players have to interact with each other.

We hypothesized that if the children can discover/learn these rules in the digital game (Fig. 9, left), they would be more likely to enact them when the electricity supply fails and the computer ceases to function (Fig. 9, Right) and that the sock puppets coupled with the learned rules and a sense of play would provide an engaging (and hopefully an equally engaging) experience.

The game was developed using Quartz Composer[1] and reacTIVision.[2] The motion of the sock puppets and the evaluation of the open/close mouth events were detected using a webcam connected to a computer and fiducial markers affixed to the sock puppets (Fig. 8, right).

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[1]https://developer.apple.com/technologies/mac/graphics-and-animation.html.

[2]http://reactivision.sourceforge.net/.

5.1 Putting the Puppets to the Test

To put the game to the test, we conducted a number of field studies in schools. Our aim in these studies was not to conduct a formal evaluation of the game but to gauge the overall concept and its reception. We primarily wanted to see whether the children found the overall experience fun and engaging; how they related to the avatars and whether they would be able to discover/learn the rules of the game and what they would do when the computer ceased to function due to a simulated power failure.

Initially, we had planned to conduct two field studies: one in Nepal, a country with severe infrastructure challenges where the population is hampered by frequent power failures which we had an opportunity to visit while attending the 9th Advances in Computer Entertainment Conference (Nijholt et al. 2012), and one in Portugal (our home base) so that we cannot only investigate the ways in which the game is being played but also see whether there are any differences in the ways Nepalese and Portuguese children engaged with the game given the huge disparity in terms of culture, geography, and economic well-being between them. However, in light of the great socioeconomic disparity between different schools in Nepal, we decided to conduct two field studies in Nepal, one in a private school catering to the children of the well to do and the other in a public school catering to village children so that we can gain a more representative image of the child population of Nepal.

5.2 Discovering the Rules

The field studies, which are described more fully in Chisik et al. (2013a, b), showed that all of the children easily discovered the first rule (the puppet controls the avatar) although there were some minor differences in the speed in which the children came to these realizations, all did so within the first minutes of playing the game.

The second rule (the player/puppet/avatar control each other) was easily discovered if there was a highly distinct difference between events, i.e., high tonal difference between the song sung by the singer when operating alone and the song sung when directed by the conductor. When there was not a significant difference, most of the children had a problem making the association between the actions of the conductor and their effects on the singer.

5.3 Interacting with the Avatars

All the children reacted warmly to the avatars on the screen and to their reaction to the movement and actions of the puppets.

In some cases, the relationship between the child and the avatar was more personal in both Kathmandu and Funchal we observed children talking to the avatars by saying “hello” to the conductor at the beginning of the game or telling the singer to “shut up” when he was singing his warm-up song. Some of the children also tried to guide the avatars by placing their sock puppet next to the avatar on the screen and trying to nudge him in the direction they wanted him to go.

As was hoped the children also brought their own meanings and interpretation into the game. In both the Funchal and Kathmandu studies, some of the children referred to the conductor as the magician and to the singer as the ghost. One pair in Funchal thought the objective of the game was for the characters to run after each other; another pair suggested that the conductor has a baton so he could hit the ghost with it.

The reacTIVision Fiducial Markers used to control the avatars were both a prominent and highly visible feature of the sock puppets and a source technical challenge as the reacTIVision software has difficulties with fast-moving objects and the children often moved the puppets very fast. This turned out to be a boon as it showed the inventive ways in which the children adapted to challenges in the environment (most of the children were aware that the slow response rate of the game was a failure of the system). Rather than being fazed by the difficulties, they incorporated a form of experimentation into their gameplay, for example:

- Exploring the line of sight of the camera and seeing at what point the avatar stopped responding to their hand (puppet) movement.
- Playing with the open and close mouth actions. Some of the children constantly held the mouth open so that the open mouth fiducial marker was visible as this achieved the desired result. Others experimented with hiding the fiducial marker with their other hand to test whether the visibility of the marker was the controlling element.
- When the system did not respond as expected such as when the movement of a fast-moving hand was not effectively reflected in the movement of the avatar, the children most frequently responded by repeating the same action over and over to validate whether the avatar would respond as expected. In face of a non-compliant avatar response, the children would attempt at either moving the hand faster or/and moving the puppet closer to the camera at times within a few millimeteres of it to try to get the desired response.

5.4 The No Power Condition

The initial reaction of most children to the no power scenario was to try and get help pointing out that the computer is no longer working, when no help was forthcoming they adopted a wide range of approaches:

- Some of the children adapted the same approach they used in case of a slow response, i.e., continue to play and position the sock puppets in different ways to try and get a response from the system despite the fact that in the no power condition the screen was entirely black.

- A few tried to fix the system by pressing some of the keys or looking around the computer for the reset button. In these cases, it was usually one of the children who was the adventurous one trying to fix the system, while the other child was the cautious one, either telling his partner not to touch the system or physically preventing him from touching anything.
- The inability to get the system back to work did not, in most cases, deter the children from continuing to playact with the socks for a while. In some cases, the children followed the narrative of the game and even sang the singing avatar's tune. In one case, one of the participants also picked up a pen, so she can wave a wand just like the conductor on the screen; in others, they followed their own narratives some of which were created from elements of the game. For example, In both Funchal and Kathmandu, a pair of boys actually playacted a scuffle with the sock puppets explaining that that is how they see the game as they assumed the objective of the game is for the conductor to catch the singing ghost and that the conductor baton was a weapon to be used on the ghost.

Most of the children play acted for a short period of time as they were self conscious someone was watching them and some simply waited patiently for the facilitators to help them when all other attempts at either getting attention from the system or the facilitators failed.

We believe that the fact that the game maintained its playability despite its slow response to the hand motions of the children and that it maintained a certain level of playability after the loss of power suggests that if these were fully integrated into the design of the game, they would form a good basis for maintaining a high level of playability whether the power is on or off as the children would continue to seek out ways of working around difficulties in trying to complete the challenges posed by the game.

6 Inventame

Tablets have become a popular platform for the development of games for children due to the relative low cost of the devices and thus their high preponderance and their simple mode of interaction and high level of responsiveness that allows even the smallest of toddlers to interact effectively with a tablet.

However, while the screen offers high levels of response coupled with high-resolution images and high-pitched sounds, it offers a very limited set of interactions centered on a small surface and thus limits the scope for creative exploration and learning. This runs contrary to the way children think and explore with their hands (Antle 2013) as noted by Miyata (2013) "Children learn many things while they play, especially when they create their own play using whatever they find in their environment. For example, when they play in the natural environments, they

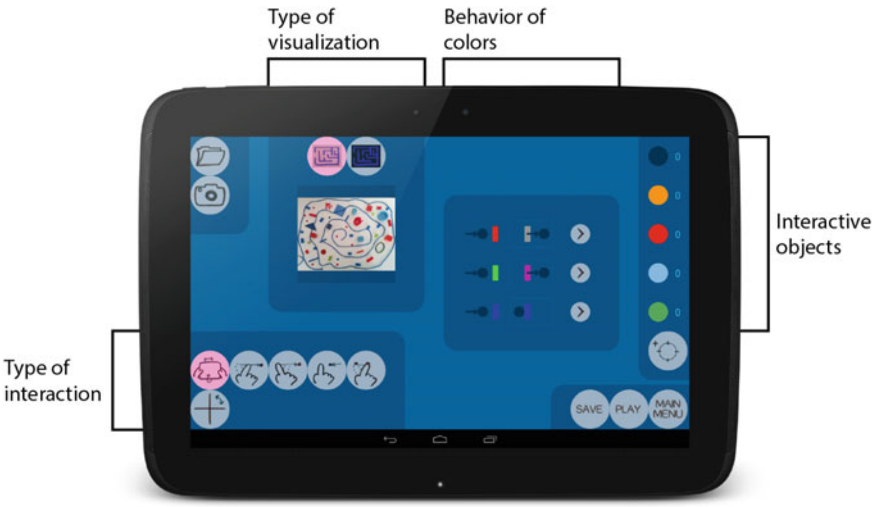


Fig. 10 The invention screen

can turn everything they find into toys. It is only recently that children play games designed and created by a handful of adults. In play, it is not just toys that they are creating: they learn to create good relationships with friends and build teams."

Some researchers and developers have turned their attention to hybrid approached that capitalize on the affordances of physical and digital technologies (Hinske et al. 2008; Osmo 2015) as a means of providing children with more open ended and exploratory environments that support children in creating their own games and forms of play where the freedom to create not only fosters creativity but provides a source of fun on its own right.

Inventame[3] (Ibanez Martínez 2014) is an Android application designed to facilitate the creation of videogames from handcrafted scenarios constructed using traditional materials such as pens, pencils, and colored blocks by allowing users to assign visualizations, behaviors, and interactions to digital representations of their handcrafted scenarios. It thus capitalizes on the allure of the screen and the freedom of free form creation in physical space to support children in creating games that benefit from the advantages offered by both worlds, while at the same time offering the ability to transcend their limitations.

To create a new game in *Inventame* users, load an image into the invention screen (Fig. 10). The picture can be one they have just taken of their scenario or one stored in the device gallery of photographs.

Once an image has been loaded, *Inventame* processes the image and produces an interactive surface to which users can ascribe behaviors and add interactive objects.

[3]http://inventame.org/.

Fig. 11 The interactive objects screen

Inventame is able to distinguish between three distinct colors in an image (red, green, and blue) and provides the user with the ability to associate specific behaviors to specific colors. The available behaviors are as follows: *collide*, when an object reaches an area of the interactive surface with that color it will collide with it, i.e., it will not be able to pass through it; *modify*, when an object reaches an area of the interactive surface with that color it will pass through and change its color to a predefined color (at the moment only gray and pink are defined as options); and *pass over*, when an object reaches an area of the interactive surface with that color it will pass over it without any effect. These behaviors act as feedback mechanisms through which various game semantics can be conveyed to a player.

Users are able to add or remove interactive objects by dragging any of the 5 colored circles to the interactive surface; a larger view of the surface is provided by interactive objects editor screen (Fig. 11). The location where the user places the interactive object will be their initial position when the game is started. The availability of several colors enables the creation of multiple representations, e.g., for multiple players, or for a player and a ball. The exact number of interactive objects will be determined by the user based on the specific game he wishes to create. For example, a football-like game will require the addition of several objects, while a labyrinth puzzle game may require only one.

Once the surface and objects have been set, the user can choose between a number of interactions which can be used to move the objects on the surface. These include *tilt* (tilt the device so that the interactive objects fall as if gravity would affect it), *push* (tap, hold, and pull forward to throw the object), *slingshot* (tap, hold, and pull back to slingshot the object), *follow the finger* (tap the screen and the ball starts moving toward the finger location), and *direct location* (tap the object, hold, and directly slide your finger on the screen toward the location where you want to locate the object).

6.1 Three Rounds of Las Chapas

To date, most of the investigations of hybrid digital/physical applications or tangible user interfaces have explored how the elements work together (Mazalek et al. 2011) or what are the differences when users use one modality as opposed to another (Esteves et al. 2013). Our aim in this investigation has been to explore the ways in which children switch between digital and physical variants of a game during a simulated power failure as a means of understanding the mechanisms we can use to create games that would continue to engage their players through periods of interruption to the power supply.

To focus the investigation, we chose "Las Chapas" (Fig. 12) a traditional street game that used to be popular in Spain and is still played in the physical education classes of some schools to act as the basis of a pilot study. The game consists of bottle caps (chapa in Spanish) and a circuit drawn by the players. Traditionally, the circuit was drawn on the sidewalk using chalk, but nowadays, adhesive tape affixed to the classroom or gym floor is the more popular solution.

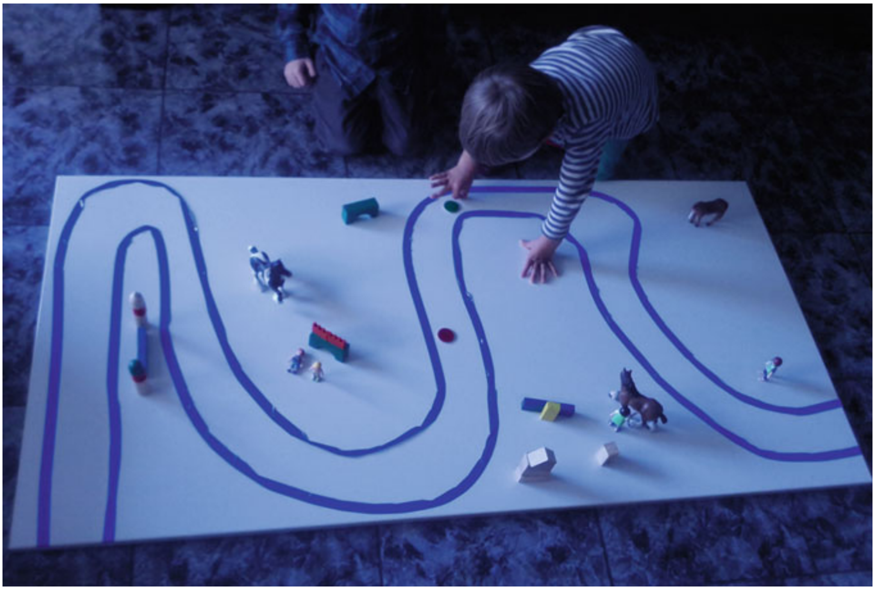


Fig. 12 Children playing "Las Chapas"

In essence, the game is a bottle cap race. First, all the bottle caps (one per child) are put on the start line. Then, the children take turns hitting their bottle cap with their index finger (following a pre-defined order). If a bottle cap goes outside the circuit, it should be put back on the point from where it left the circuit. The first bottle cap to reach the finish line is the winner.

The pilot study was conducted with three pairs of boys in the ages of 5 and 7, 6 and 7, and 8 and 10 in Barcelona, Spain. For each pair, we followed the following steps twice:

1. The children were provided with instructions on how to construct the physical track and how to play the game. They then proceeded to construct and play the game by themselves using the materials provided (two blue cords with a length of 7.5 m and a diameter of 8 mm and a number of bottle caps). We used cords as opposed to chalk or adhesive tape in order to support rapid reconfiguration of the track (Fig. 13).
2. The children were then provided with a Google Nexus 10 tablet with *Inventame* installed on it and instructed on how to create and play a digital version of the game. They then proceeded to create and play the game on the tablet. Figure 14 depicts a version of one of the digital tracks created by the children. The game mimics the physical game in that the blue lines act as a solid objects preventing the interactive cap from crossing the blue lines. The red line acts as a finishing line and will change its color to gray when pass over by an interactive cap.

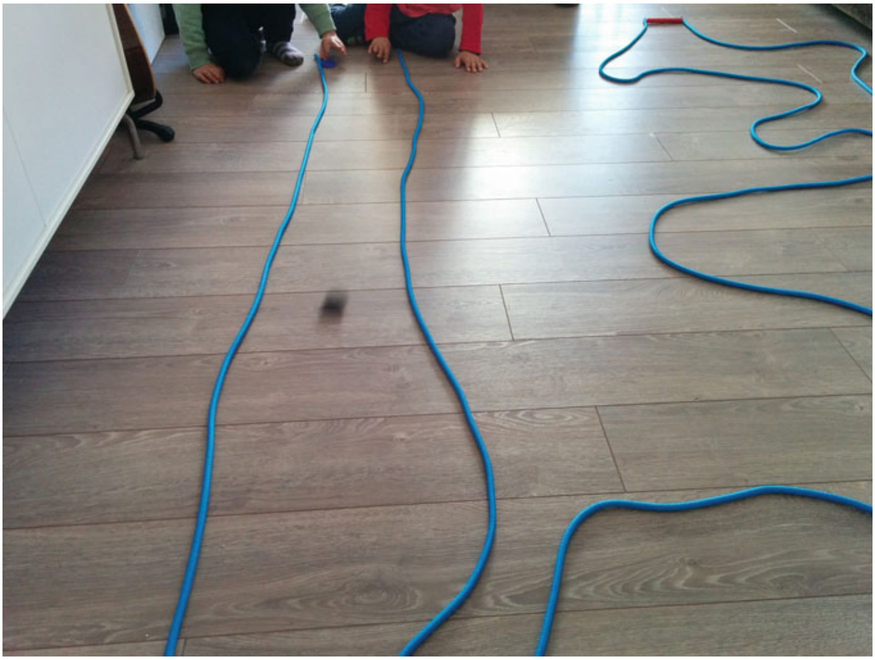


Fig. 13 One of the pairs constructing their track

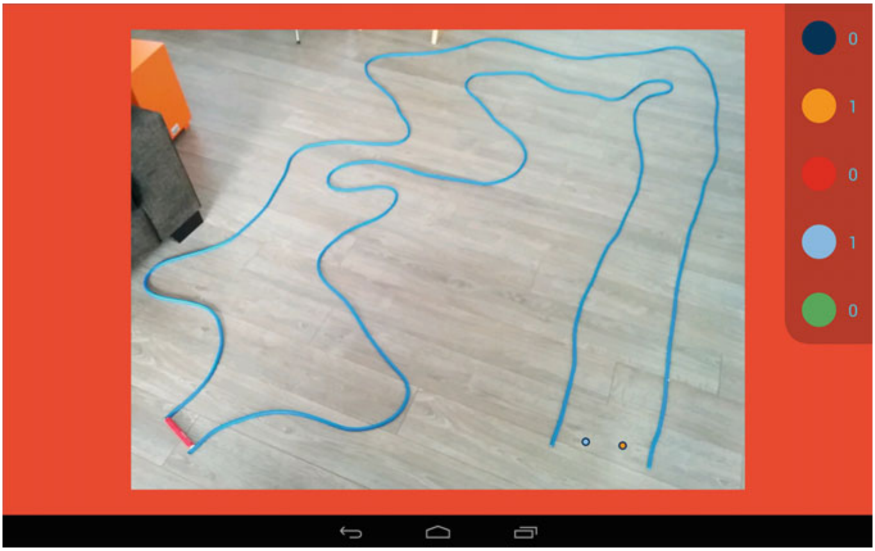


Fig. 14 A Las Chapas track on inventame

3. When the moderator noticed the children were engrossed in the game and have traversed more than 2/3 of the track, he sent an invisible signal to tablet, which caused it to shut off mimicking a power failure. We then observed the reaction and actions taken by the children with the aim of answering the following questions:

   R1: How would the children react to a power failure that prevents them from continuing to play with the digital game on a tablet?
   R2: Would the children return to playing the physical game?
   R3: If so, would they continue the current game (by locating the bottle caps at the same locations they had in the digital circuit at the moment the battery ran out)? Or would they start a new game?

As noted above, we followed this sequence of steps twice. In the first instance, we kept the physical circuit on the floor in the way the children left it; in the second instance, we dismantled the track and wound the cords once the children started to play the digital game. In both cases, we allowed the children to return to the physical game whenever they wished to do so.

6.2 Initial Observations

The cords proved to be well suited for the task of track creation, and the children found the task both easy and enjoyable. Two of the pairs designed typical circuits with a few curves, while the third pair designed a highly curved track with a number of narrow sections.

The creation of the digital game proved to be equally engaging with all three pairs experimenting with a number of the available interaction options before settling on one. Two of the pairs chose the slingshot option, while the other chose the push option.

When the children experienced the power failure during the first session of digital play (with the original physical track still intact), they went back to playing the physical game. Two of the pairs positioned their bottle caps at their respective locations when the tablet stopped working, i.e., they continued the same round of play while the remaining pair started a new round. All three pairs maintained the same physical track.

After the power failure during the second round of digital play (with the original track dismantled), the children again returned to the physical game. In all 3 pairs, there was some discussion on whether they should try to recreate the original track or construct entirely new ones? However, once started, they all opted to improve on their original designs. Once the new tracks were completed, two of the pairs started a completely new round, while the other pair started a new round but maintained the relative positioning they had in the interrupted digital game.

Our initial observations suggest that the physical game provided not only an engaging alternative to the digital game once the power ran out (and there was nothing to do but wait till the power returns or the battery charges up) but also a challenging addition to the overall interaction with the game. One of the children described the experience of having to rebuild the physical track in order to continue playing as “moving to a new level in the game,” and another echoed a similar sentiment by saying he enjoyed the challenge of creating trickier tracks. This anecdotal evidence is further bolstered by the fact that once told the battery was charged and they can continue to play with the tablet, the children did not want to continue playing their “old” games with the tracks they have previously created but wanted to transfer the new tracks to the tablet and continue playing using the new tracks.

If we examine the game solely from the perspective of the tablet application (Fig. 15), the playability of the game is low at the beginning, while the children are “designing” the game with the physical objects. However, once the children start to “define” the game with tablet, the playability rises back to the normal standard and maintains at the same level after the children start to play the game on the tablet.

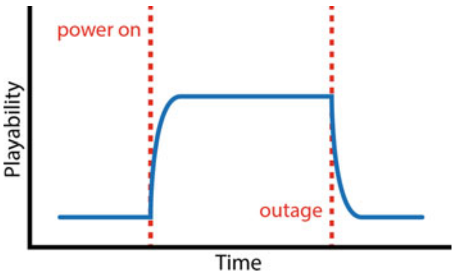
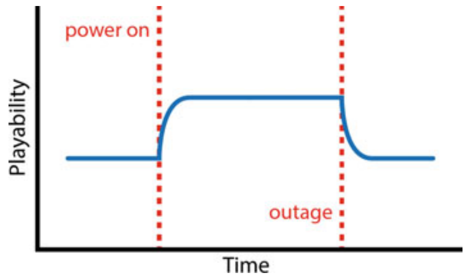


Fig. 15 Las Chapas playability from the tablet only perspective

Fig. 16 Las Chapas combined physical/digital playability



During the period of no power, the children cannot continue playing on the tablet thus playability falls down to zero.

But if we consider the combination of the tablet and physical game as a whole, we can see that the power failure and the resultant interruption to digital play did not hamper the children engagement with the game but provided them with the opportunity to reengage with the physical elements, and thus, a high level of playability was maintained throughout the game (Fig. 16) with the players changing between modes of physical play and digital play.

Although the game is competitive by nature (being a race), the children easily switched from a competitive mode while playing the game to a cooperative mode while constructing the tracks. They actively discussed their designs and collaborated in the construction of the track and were to reach consensus in spite of having contradictory preferences.

7 Conclusion

Puppets Duets and *Inventame* showed the viability and potential of the guidelines outlined in Sect. 4 to sustain playability during a power failure. Now, by way of conclusion, we will examine these guidelines from the perspectives offered by *Puppets Duets* and *Inventame*.

Experiencing the story In *Puppet Duets*, the children were able to experience the story by taking the characters of the game and bringing their own interpretations into play. Since the physical and virtual aspects of the puppets were the same, it was possible for them to continue with the story once the supply of electricity was interrupted. In *Inventame*, the narrative actually started in the physical world with the children laying out the racetrack using the blue cords. After the digital version of the game ceased to operate during the power failure, the children were able to either use the existing track they previously constructed or construct a new track in order to continue the race. Starting the game in with physical world will help children to continue the gameplay narrative during a power failure as the first physical narrative elements have already been set.

Completion In *Puppets Duets*, the children could complete the game as the singing could be carried out by the children themselves when the avatars vanished from the screen as a result of the power failure. In *Inventame*, physical artifacts such as bottle caps and other obstacles were nearby and handy, so the children could continue with the race.

Progression Although *Puppets Duets* was only a bare bones implementation designed as a proof of concept as opposed to a fully fledged out game, most of the children progressed from the power to the no power condition with relative ease. Since it is a simple game, the potential for progression is inherently low. That said, the degradation of the sense of progression is also limited. On the other hand, *Inventame* allows the children to easily recreate the last stage of the game and thus to quickly continue the race. The sense of progression appears to be almost the same during the power failure.

Socializing *Puppets Duets* is built on the interaction between two players and their on screen avatars, so it is cooperative and social in its very nature, and to a large extent, this cooperative social aspect is what drove continued engagement with the game during the power-off period of gameplay. The same applies to *Inventame*. The competitive and social nature of the racing game also kept the children engaged and willing to reconstruct the racing track in the physical world (if destroyed) in order to continue the game after the power outage.

Sensing Due to the musical nature of *Puppets Duets*, this aspect of the game was most glaring in its absence during the no power stage as the avatars and their singing were one of the main highlights of the game. However, as previously noted, some children sang and made sound effects to compensate the loss of aural experience due to no power condition. In contrast, *Inventame* was designed in a way that the sensory experiences were similar in both power and no power conditions and the children appeared to easily switch between the digital and the physical modes of play.

We started out this inquiry with the notion of providing continued engagement to players engrossed within a digital game during a power failure. We viewed power failures as a form of interruption, and as interruptions have long been a part of certain types of games, for example, live action roleplaying games or playing chess, by exchanging moves in letter form through the postal system, we sought gameplay opportunities through which we could continue the thread of gameplay through the interruption imposed by a power failure.

However, as the field studies conducted with *Puppets Duets* and *Inventame* suggest power outages can actually act as a liberating agent freeing the player from the constraints imposed on the activities and objectives of the game by the vagaries of particular platforms and interfaces be they a digital screen or a toy automobile. Therefore, we now think a more interesting avenue of research would be to explore ways in which playability can be increased and extended after a power failure (Fig. 17).

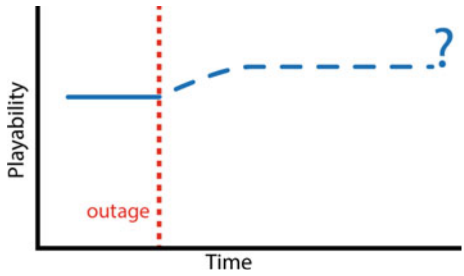


Fig. 17 Extending playability after the power outage

This avenue of research is quite a broad one offering several potential lines of inquiry in our next investigations we would seek to further explore ways in which we can:

- Expand the list of design guidelines, while exploring their application in practice
- Harness interruptions to the power supply as a means of cajoling players into exercising their imagination in rewriting and repurposing existing game designs (whether these designs are based on classical games or completely new games) with the aim of not only maintaining the playability but increasing it during and after a power failure.

We believe these explorations will propel us toward an exciting and untapped frontier of future game design.

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Responsive Make and Play: Youth Making Physically and Digitally Interactive and Wearable Game Controllers

Gabriela T. Richard and Yasmin B. Kafai

Abstract Most research on game making has focused on screen designs leaving aside the potentially rich domain of making game controllers for learning. In this chapter, we illustrate how youth created wearable or e-textile-based controllers with physical and digital feedback by combining tangible and digital construction kits, using Scratch, the MaKey MaKey, the Lilypad Arduino, and ModKit. In an eight-session workshop, 14–15-year-old youth not only programmed their own Scratch games but also created wearable or physically reactive game controllers using sensors to activate a response on the screen, through the physical artifact, or in both interfaces. In the discussion, we address what we learned about tool and workshop design to facilitate and support the introduction of such playful interface design to novice programmers.

Keywords Tangible interfaces · Wearable games · Tangible games · Youth design · Electronic textiles · Game controllers · Bidirectionally responsive design · Scratch games · Makey Makey · Lilypad Arduino · ModKit · Hybrid crafting · Physical computing · Digital games

1 Introduction

Augmented game controllers, which measure pressure, movement, and touch, have been around since the early days of gaming, starting most notably with Nintendo's PowerPad and PowerGlove in the 1980s (Tanaka et al. 2012). Newer technologies have allowed for more robust and dynamic sensing that can measure pitch and tilt, and gesture and body movement. While controllers with these features are now

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commonplace in many commercial gaming platforms, making them has been out of the reach for many players even though tinkering and building external gaming systems and controllers was an integral part of early days of digital gaming (Swalwell 2012). Increasingly, proprietary systems and costly development tools have made the design of such interfaces a complex activity, requiring extensive technical and material knowledge and skills (Millner 2010). With the recent availability of low-cost and easy-to-use tangible computational construction kits using Arduino as a platform, this barrier has been removed and put the design of augmented gaming peripherals back into reach of novice makers and game designers.

Making your own physically and digitally responsive game peripherals that use sensors to control action on the screen and can provide feedback to the physical controller itself is a complex activity, but one that potentially could enrich and extend game making for learning. In many youth online DIY communities, such as Scratch (Resnick et al. 2009), Kodu (Fowler and Cusack 2011), and others, making and sharing your games with millions of others is one of the most popular programming activities (Kafai and Burke 2014b). It is becoming an equally popular activity for serious gaming where games are seen as promising learning environments to promote problem solving, collaboration, and design thinking (National Research Council 2011). While most of the attention has focused on instructionist approaches, i.e., playing digital games for learning, current trends also focus on constructionist gaming, i.e., making games for learning (Kafai and Burke 2014a). It is here where serious gaming connects with efforts to promote programming (Kafai and Burke 2014b) and making (Honey and Kanter 2013) in schools. So far, most making and programming activities have been implemented outside of school, but designing physically and digitally reactive or responsive game peripherals could offer a promising opportunity to bring together crafting, computing, and gaming for school learning. First, studies of students designing their own touch pads (Davis et al. 2013; Lee et al. 2014) and augmented game boards (Vasudevan and Kafai 2015) provide indication that designing, crafting, and programming these peripherals can enrich constructionist gaming efforts.

In this chapter, we expand the constructionist gaming in two new directions: (1) by making controllers that are both physically and digitally responsive, and (2) by focusing on wearable or textile-based controllers. We present findings from a workshop in which high school youth ages 14–15 years learned not only how to program their own Scratch games but also how to make wearable controllers. We asked students to focus on bidirectionally responsive design, meaning that sensors would activate a response on the screen and through the physical artifact simultaneously. An example of such bidirectional design could be a wearable game controller glove, where touching the glove would not only result in a change in the digital game state but would also signal its responsiveness through changes in color or vibration on the glove itself, thus providing tangible feedback in the glove. To accomplish such responsive designs, students needed not only to program in Scratch but also to integrate textile elements using the Lilypad Arduino (Buechley et al. 2008) programmed via ModKit (Baafi et al. 2013), a visual block-based programming language similar to Scratch, and the MaKey MaKey (Silver et al.

2012). Using conductive materials such as special fabric or aluminum foil, they would integrate the Lilypad Arduino to create a physical response in the wearable or textile game controller (i.e., a light turning on or a vibration), and the MaKey MaKey to control elements of their game in Scratch. In the discussion, we address what we learned about tool and workshop design to facilitate and support the introduction of such playful interface design to novice programmers.

2 Background

Constructionist gaming has been a popular activity since the early 1990s when the idea was first introduced that children could program their own video games for learning about coding in an authentic and personally meaningful way (Kafai 1995). The designing of video games on 256k computers meant that students literally had to program every single pixel on the screen to produce the colorful graphics and interfaces that were popular with commercial video games sold by Nintendo and Sega. Today, most programming platforms such as Scratch, Kodu, Alice, Agentsheets, and many others use visual programming environments that remove the thorny syntax issues that traditionally plagued much of novice programming while providing visual feedback. Graphics can be imported from the Internet and modified to create professionally looking interfaces for their games. Game making is one of the most popular design activities in online communities where youth (alone or together) have created and shared thousands of games emulating commercial games or of their own creation. Numerous studies have examined the benefits of game making in terms of learning programming, collaborative and creative design, and many other aspects (Hayes and Games 2008; Kafai and Burke 2014a).

Noticeably absent from this research on constructionist gaming has been the inclusion of peripherals such as game controllers. While video games have always used a variety of peripherals beyond the keyboard, such as joysticks, powergloves, or dancing mats, the arrival of the Wii re-energized the search for new interfaces because it illustrated that game controllers could make gaming more accessible to a wider audience. Making such new interfaces, however, is a difficult enterprise, often limited to professionals with extensive technical skills and material knowledge, unlike in the early days of digital gaming and microcomputers. As noted above, modding software, building components, and hacking were often integral and encouraged aspects of digital game play. Reflecting on computer gaming in the home in the 1980s, Swalwell (2012) observed that “a number of early hobbyist microcomputers came in electronic kit form, requiring that users first assemble them” (p. 5). New toolkits and materials have begun to open up these “black boxes” (Resnick et al. 2000) in various ways (Tanenbaum et al. 2013). Most notable is here the Arduino (Kushner 2011) an accessible construction kit for creating physical computing and tangible design, and the Lilypad Arduino, the electronic textile counterpart to the Arduino (Qiu et al. 2013). The most recent addition is the MaKey MaKey (Silver et al. 2012), which seamlessly connects to the computer and allows the designer, without any programming, to replace keyboard functionality with conductive materials and alligator clips. These toolkits have helped to foster the “Maker Movement,” a do-it-yourself movement and ethos, which is transforming the way the individuals learn about crafting, construction, development, and design, often through nontraditional or informal learning spaces, such as Maker Faires.

A few studies have began to use these toolkits to engage youth in making their own game peripherals, starting with MaKey MaKey, that does not require any prior programming knowledge. Examples have been to have middle school youth ages 10–12 years design their own game controllers for Scratch games (Davis et al. 2013; Lee et al. 2014) or making augmented board games (Vasudevan and Kafai 2015). In one of these projects, youth crafted their touchpads using conductive Play-Doh, paper, and pencil drawings to make new controllers that they connected with the Makey Makey to their online Scratch games. At the end of the project, youth set up an arcade with their games for other students in their schools, to playtest and receive feedback on their games and interfaces. In the other project, teams of high school youth designed board games with augmented gaming components such as digital dice that connected via the MaKey MaKey to Scratch. Other researchers have used Lego construction kits (Martinez 2014) to create augmented game boards that interact with computer projected screen interfaces. In all of these projects, the control or feedback between the controller and the computer screen has been unidirectional, going into only one direction.

In this chapter, we propose a new approach that we call bidirectionally responsive design, meaning that sensors can either activate a response on the screen or through the physical artifact. Past efforts have been made to teach physical computing (O’Sullivan and Igoe 2004) to youth and teachers in K-12 settings in order to help them design their own tangible learning modules, with digital and physical interfaces, beyond any specific scientific concepts (Richard 2008). This approach relates to recent work on bifocal modeling (Blikstein 2012), an extension of physical computing, which has used sensor technology in tandem with real-time visual simulations to help students understand physics phenomena by measuring data and displaying them on the screen. While bifocal modeling integrates two modalities, it is still unidirectional by having the information from the physical data go to the digital screen. There is no feedback loop or control from the screen to impact the actual measurements or data in the other modality. Our approach also combines two modalities, the physical and the digital, but is distinct in two dimensions: context and directionality. For one, we are using gaming, and not physics, as an authentic and personally meaningful context to situate data sensing and feedback for students’ engagement. In other words, rather than to focus on data representation, we focus on data use. For that reason in responsive design, the visualization is not captured in a responsive diagram but rather in a light or sound display providing feedback. This approach is much closer to efforts in teaching programming such as media computation that uses the manipulation of images and sound to help students learn about algorithm use (Guzdial 2013). Efforts have been made to provide for tools that can foster “hybrid crafting” (Golsteijn et al. 2014), or the more seamless creation of digitally and physically augmented interfaces through building with simple construction kits. Despite the term "crafting," these kits focus more specifically on a Lego-type interface with a portable screen that the researchers designed and prototyped with users. However, instead of focusing on creating a new toolkit, we focused on construction kits that were readily available and could combine two interfaces with conductive materials. We also situated the physical design in a wearable context thus moving out of the laboratory into the physical space, where much of gaming nowadays takes place. Second, we also aimed for including bidirectionality by having a dual response in the digital and physical space. This second dimension, while important, also added further complexity on the design of the interface, and as we found out in our study, proved to be challenging to implement for some novice designers.

In asking students to design wearable responsive controllers, we examined the following aspects—students' actual designs and their reflective responses. Our first line of investigation focused on the gaming peripherals that students created and how the crafting and coding related to the game design. This approach brings together the work on programming and making activities that, respectively, have mostly focused on screen designs or physical artifact. Here, we were interested in how students navigated the spaces of learning coding, related computational concepts and practices, together with the material demands of building physical artifacts considering conductive properties of materials. Our second line of investigation focused on students' perceptions and examined how students reflected on their learning experiences in making responsive designs.

3 Toolkits and Implementation

In order to design the wearable interfaces with digital and physical interactivity, students had to learn how to use four different toolkits. The digital construction kits or programming environments were Scratch 2.0 (Resnick et al. 2009) and ModKit Alpha (Baafi et al. 2013), while the physical construction kits were the MaKey MaKey (Silver et al. 2012) and the Lilypad Arduino (Buechley et al. 2008). Scratch is a media-rich programming environment, which uses a visual block-based coding language (see Fig. 1). Like Scratch, ModKit is a visual block-based coding environment, which is used for various Arduino platforms, including the Lilypad Arduino and other robotics platforms (see Fig. 1). The MaKey MaKey is a plug-and-play physical computing construction kit designed to turn almost anything with conductive properties into a physical interface (see Fig. 2). The LilyPad Arduino is a sewable microcontroller that can be used with conductive fabric and thread to make interactive textiles and wearables; for the workshop, we used the Lilypad Arduino Simple Board, which works well with ModKit and has a more simplified design (see Fig. 2). We felt it was incredibly important to keep the programming modality consistent to lower the complexity involved, given that the workshop only lasts a few weeks; hence, why ModKit was used instead of the Arduino line coding environment. Also, ModKit had successfully been used in similar past workshops

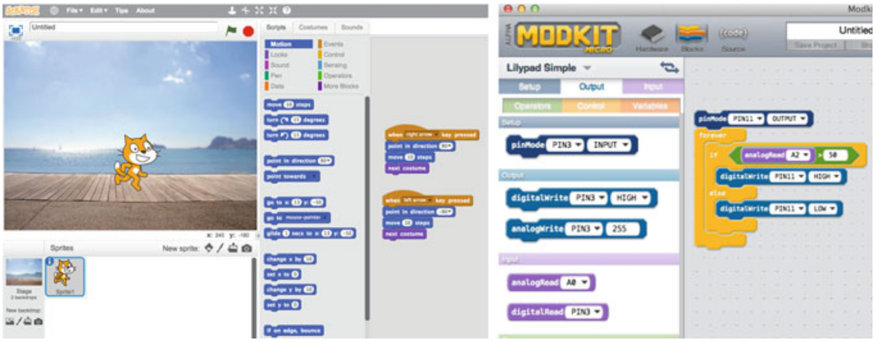

Fig. 1 (*Left*) Scratch interface. (*Right*) ModKit Micro Alpha interface

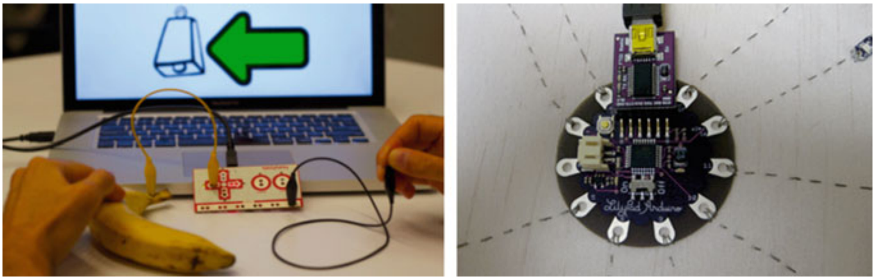

Fig. 2 (*Left*) The MaKey MaKey, as connected to a banana, replacing the left arrow key and completing the circuit by using human capacitance to ground the connection. (*Right*) Lilypad Arduino connected to sensors and actuators with conductive thread

(Qiu et al. 2013), despite its beta nature. In this pilot of the curriculum, we utilized ModKit Alpha, which is a newer version of ModKit that has worked out some of its initial bugs with the Lilypad Arduino (see Fig. 2).

Asking students to learn and work with that many different construction and programming kits to achieve responsive designs required decisions about sequencing the introduction of tools and activities. We choose to start with the Lilypad Arduino to introduce students to physical computing activities and to get them out of the typical screen-based interactions they were used to (even though most students had neither prior programming experience nor knowledge of Scratch or ModKit). ModKit was used as an entry-level to visual object-oriented programming for the Lilypad Arduino so that students could focus on making connections between creating circuit designs and coding behaviors and interactions of sensors and actuators (Fig. 3). We used the MaKey MaKey after students had experimented with different Lilypad Arduino designs because it allowed an almost seamless connection between conductive materials and the computer to replace the keyboard and mouse. Scratch was incorporated at the same time as the MaKey MaKey in part because it is often taught in tandem with it due to its ease of use that facilitates experimentation.

4 Workshop Design

The *Maker Innovators* workshop took place in a local public school associated with the museum in a large Northeastern city in the USA. The workshop ran for eight weeks, occurring once a week for 2 h, between February and April 2014. Thirteen ninth grade students (6 male, 7 female), aged 14–15, from a public, science magnet high school choose to participate in the workshop. The racial makeup was 62 % White, 15 % Black or African American, 15 % Asian American, and 7 % biracial (Black or African American and White). Ten of the 13 students consented to be interviewed, and all except one female and one male student consented to documentation. The workshop was designed and implemented by the first author with two assistants helping students with project designs and documenting with video class activities and designs.

The workshop was broadly divided into two parts: during the first four sessions, students learned how to use the different tools, while in the second half, students worked in teams on designing their own controllers (see Table 1). In the first session, we showed examples of videos of responsive interface designs by other youth or students who had worked with either Scratch, the Lilypad Arduino, or the MaKey MaKey. We also included here the promotional video of the MaKey MaKey. Since we could not locate examples of physically interactive electronic textiles integrated with Scratch and the MaKey MaKey, we asked student teams to brainstorm ideas for their interface designs.

Over the course of the next sessions, we transitioned from learning different toolkits to focus on understanding circuitry, coding, and computation. For example, we started off with ModKit to understand block-based object-oriented coding and the Lilypad Arduino to understand basic circuits. Students then would work on exercises with the various toolkits and were given reference and troubleshooting guides they could refer to throughout the workshop. During the first session, students learned to code in ModKit, starting with very basic coding to light up an LED. Students learned about basic circuits and electricity, as well as how to connect their Lilypad Arduinos to the LEDs with alligator clips. During week 2, after learning some basics about initiating pins, and sending out digital signals to light up an LED, they learned about analog signals and changing the brightness of LEDs. The students then experimented with block coding in ModKit to change the brightness of their LEDs. Following this, they learned about variables, conditional statements, forever loops, and functions in order to continuously change the brightness of their LEDs. They were also introduced to sensors and how they worked like our hands and eyes. They played with light and temperature sensors, and we made connections to how they worked like variables when coding. In this sense, when they added a new AnalogIn value in ModKit, it worked similar to a variable, storing, and sending different values that could affect the code. They also started working with conductive thread and felt to sew their connections together and understand how conductive thread worked like a live wire (Fig. 4).

Table 1 Weekly overview of workshop activities

	Summary	Activities
Week 1	Videos, discussion of possibilities, starting with the *Lilypad Arduino,* and electronic textiles	• Inspirational videos of wearable design projects created with the Lilypad Arduino or physical computing projects created with the MaKey MaKey • Brainstorming session on combining the Lilypad and MaKey MaKey • Lesson on basic circuits, sensors, and actuators • Working with the Lilypad Arduino and ModKit to design a basic circuit with an LED • ModKit used as a model for block-based coding • Coding exercises with loops
Week 2	Continuing work on the Lilypad Arduino and electronic textiles. Programming the *Lilypad* with *ModKit*	• Coding exercises with variables, loops, and conditional statements and reading in analog values from sensors received through the Lilypad • Playing with different sensors of their choosing (temperature, light, or slide switches), with different actuators (LEDs, buzzers, and vibrators)
Week 3	Working with *Scratch* and the *MaKey MaKey*	• Working with the MaKey MaKey and concepts on basic circuits • Playing with different materials, such as Play-Doh, graphite (from pencil drawings), aluminum and conductive fabric to understanding conductivity • Remixing and creating code in scratch to add different functionality
Week 4	Combining scratch, the *MaKey MaKey* and the *Lilypad Arduino*; Brainstorming and discussing ideas on teams	• Integrating the Lilypad with the MaKey MaKey to control a game in scratch with LEDs • Sewing conductive thread with the Lilypad • Brainstorming and discussing ideas for final projects
Weeks 5–8	Putting together design ideas through iteration; On week 8, showcasing work for an audience of experts and peers during the last hour of class.	• Working on design teams for final projects • During the final session, they showcased projects in their current form

During week 3, they worked with Scratch, creating a basic music game and a basic action game, using code that was explained during class time. They were encouraged to experiment and modify the code as they saw fit. They were then given MaKey MaKeys to play with (see Fig. 5), along with Play-Doh, or pencil

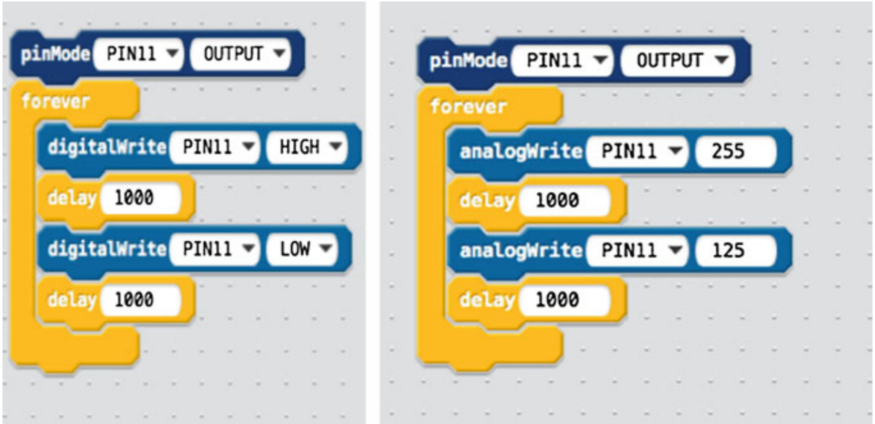

Fig. 3 (*Left*) Basic digital code to turn on and off an LED in ModKit. (*Right*) Basic analog code to vary the brightness of an LED in ModKit

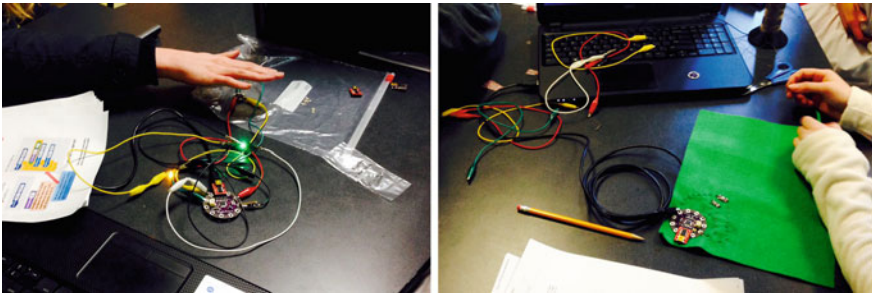

Fig. 4 (*Left*) A student playing with a light sensor to vary the brightness of an LED with the Lilypad. Students used alligator clips to connect sensors and LEDs during prototyping. (*Right*) Students sewing electronic textiles on felt with conductive thread

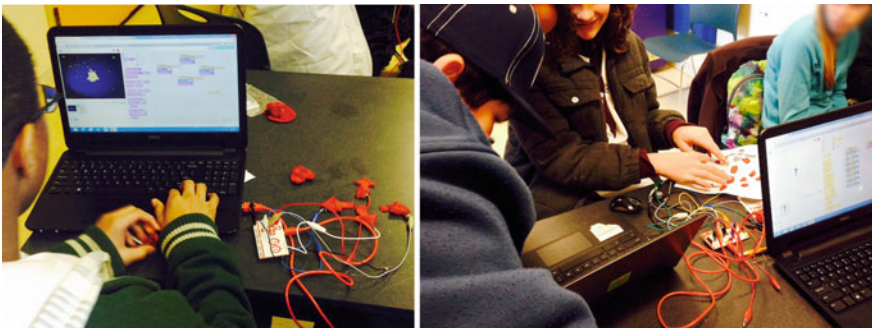

Fig. 5 Students working with the MakeyMakey, scratch, Play-Doh and pencil drawings to understand physical computing and conductivity

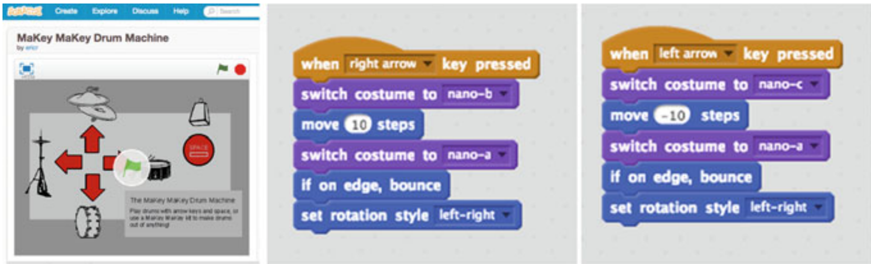

Fig. 6 (*Left*) Basic MaKey MaKey Scratch music game students remixed. (*Right*) Basic action game code we presented to learners to modify

drawings (graphite is conductive). They were also introduced to remixing code, first by working with the MaKey MaKey Scratch game (see Fig. 6), then by choosing any Scratch program they wished to play with. Finally, during weeks 4 and 5, they were reintroduced to the Lilypad Arduino, ModKit, Scratch, and the MaKey MaKey. They learned how to work with conductive fabric to change the brightness of an LED through the Lilypad and control movement in a game in Scratch.

During the second half of the workshop, students would work on self-selected teams with 2–4 members each, mapping and crafting their own responsive and wearable controllers. Beginning in week 5, they were asked to brainstorm project ideas and work in teams to create a project that would combine both environments. For the next few weeks, they worked on their projects in teams, figuring out what kinds of interactions they wanted in their physical textile interface and in Scratch. They were given free reign to come up with ideas and see them come to fruition. Author 1 was the primary course instructor who helped students think through their design concepts and work through issues that came up during their design process. Students were given handouts with all of the sample code used in class, a list of Scratch codes, and how to sew with electronic textiles. Five teams were formed among the thirteen students, of which four teams created fully working prototypes of varying complexity. The last class session was organized like a demo fair with students setting up their designs at individual tables. We had invited outside visitors —a professional board game designer and two education researchers (among them the second author)—to provide an audience and feedback along with their peers. Each team spent about 10–15 min for demonstrating and explaining their final designs to the visitors and other students in the workshop.

We used video and observation notes to document class activities and student interactions and design. We also documented all of the final projects created in the class. At the conclusion of the workshop, we conducted interviews with all of the consenting students. These interviews were transcribed and then analyzed to understand how youth conceptualized of their designs, their design process, and their understanding of bidirectional responsiveness.

5 Findings

So to what extent were the student teams able to realize wearable responsive game controllers? Implementing bidirectional designs turned out to be a formidable challenge despite all good intentions. Of the five teams, only one team succeeded in conceptualizing, coding, and crafting a design with full bidirectional functionality, while all other teams limited their designs to unidirectional functionality (mostly due to time limitations or being more focused on one utility versus another). Students conceived of the designs themselves, and the instructor (author 1) helped them to brainstorm and think through the bidirectional development process. Only one team of three students was unsuccessful in creating a working prototype by the final class (this team also suffered from multiple absences, excluding one member). However, these designs demonstrated the potential for wearable interfaces and also underscored students' understanding of the utility and potential of bidirectional feedback. In the following section, we provide case studies of some of the unidirectional and bidirectional designs. As part of our presentation, we include students' reflections on their choices and learning.

5.1 Unidirectional Wearable Game Controllers

Examples of unidirectional designs included a jousting game (see Fig. 7, left) by a team of three students (2 male, 1 female) who created wearable vests with different conductive parts to them. They also included swords out of found materials (coat hangers). They connected the MaKey MaKey to the swords and the vests. Play involved trying to block your opponent from tapping the conductive part of the vest. When unsuccessful, the matching Scratch game, would respond by awarding the opponent a point and reflecting a reaction between the characters in the game, complete with funny sounds (see Figs. 8 and 9). Another example was the finger flappy star controller (see Fig. 7, middle), which was designed by a team of three students (2 male, 1 female). It included a wearable, partial glove controller that used two fingertips and conductive fabric to control a version of the then popular Flappy Bird game that was remixed from someone else's version found in the Scratch site.

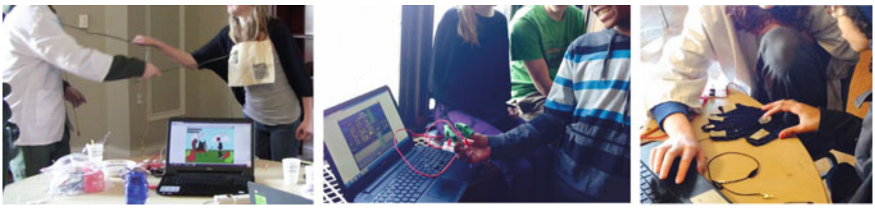

Fig. 7 Snapshots of select unidirectional designs: jousting sticks (*left*), flappy star game and controller (*middle*), and sensor glove (*right*)

Fig. 8 Screenshots of different game states of the jousting game

Fig. 9 Screenshots of the jousting game scratch project. (*Top Left*) Game interface and code for the Squirrel sprite on right. (*Bottom Left*) Game interface and code for the boy sprite on right. (*Top Right*) Code for the left pie-chart counter sprite. (*Bottom Right*) Code for the right pie-chart counter sprite

The conductive fabric was connected to the MaKey MaKey, such that the thumb piece was connected to ground, and the forefinger was connected to spacebar, which would be the normal controller for the game (see Fig. 10). As the player pinched their fingers together, the star would hop up on the screen. Finally, the sensor glove (see Fig. 7, right) created by a team of two students (1 male, 1 female). It included a multifunctional wearable device for controlling games in Scratch. Based on which thumb and finger combination was pressed together, there would be a different response in the game.

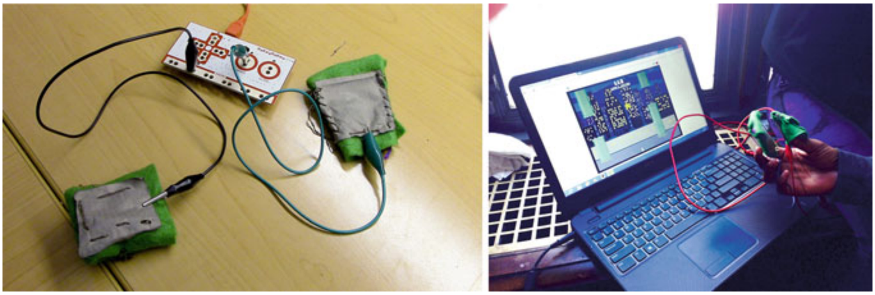

Fig. 10 (*Left*) How the finger controller was connected to the MaKey MaKey's ground and space bar key, effectively replacing the space bar control for the game in Scratch. (*Right*) Students demonstrating their game's functionality. When the conductive fabric is touched, the star sprite leaps up. When they let go, the star sprite begins to fall

The jousting game was created by a team of three students, two male and one female. The project consisted of vests with conductive fabric, which were connected to different arrows on the MaKey MaKey, "swords" made out of metal coat hangers, which were connected through ground on the MaKey MaKey, as well as a fighting game, that kept score through a pie-chart interface, designed in Scratch (see Fig. 8). Each player would use the swords to block their opponents or hit the conductive parts of their opponents' vests, which would trigger a point in the fighting game, as well as show one of the on-screen characters hitting or reacting to the other character. Each character would react with different sounds that matched the creative character design.

Each team member contributed a unique skillset to the team, which made working together dynamic in meeting their design goals. According to Colin, "we all had different skills. I was better with the computers and Michael was good with the stitching and Kara was good with the sprite design." However, Michael also displayed a strong aptitude for working with crafts and materials, in general. As he explained:

> Making the wearable sensors was what I wanted to get out of the game. The partner I had - Collin - he did a lot of the computing and a lot of the programming. I did more of the outside stuff because that's where I felt like I was enjoying myself, creating stuff for the outside, rather than the programming…. I had thought about doing that the entire time with copper wiring and just using some wood, but I wanted something that was conductive. I saw a rack of hangers, and I was like, 'I remember when I was a kid and I used to use those to mess around.' I was like, 'Oh, I could use them.' So I ended up using the coat hangers as a second idea.

In coding the digital game, the team benefitted from having an experienced programmer. While Colin had never worked with Scratch before, he had previous experience line coding in Basic. He found Scratch to be accessible for the kinds of on-screen interactions they wanted to create:

> Scratch, is really easy to use. It was another building block thing. Pretty much did that and made some sprites, record[ed] some sounds. What I thought was interesting about that was

that each program was tied to a specific sprite instead of all of the program being this general, the entire playing field.

Colin was able to create object responsiveness by utilizing object-oriented programming on the sprites themselves (see Fig. 9). He was also able to eliminate line coding, which he felt made the coding process easier.

The students on this team expressed that their original idea also included incorporating the Lilypad Arduino, by having lights that would indicate when a person was hit, thus reacting in a similar way to the trivia game. However, they experienced difficulty figuring out how to attach the Lilypad and the MaKey MaKey to power supplies while also having two mobile interfaces. Michael explained:

> We didn't get the Lilypad finished and on it, but we had planned to have like a little light so you know when you're hit. We had a small vest and we had conductive fabric and it was just a patch and another patch. Hit a certain area, put something into Scratch, and things happen on the screen. To know if you were hit or not without having to at least glance over at the screen, having a small light around your shoulder so it will flash up into your eye so you know when you're hit. That's what we were planning on incorporating it with the Lilypad, but it was taking a lot out of what we were already doing with the MaKey MaKey. We had a lot of electricity around, so it was kind of hard to get going with the amount of time we had.

Despite the limitations, both Michael and Colin appeared to understand the affordances of connecting the two interfaces and how they would be used. Kara, unfortunately, by her own admission, had missed too many classes and did not fully understand how all of the systems would work together; however, she and the other team members felt she contributed to the idea and added to the design by creating the inventive sprites. While some were skeptical about why the group created a fighting game, Michael's explanation demonstrates a heightened awareness of the affordances offered through the different toolkits and systems:

> …[We] were thinking of random games we could make, random genres, thinking of each one, and out of the ones that we had, it seemed to be most simple to make tangible pieces for because that's what we really had our minds on was the tangible pieces we could make for it, the fighting game. It originally started out an idea that you could attach something to your wristband. You conduct electricity. You hit a certain spot, but that kind of slowly grew… I felt we made like a very small simulator. I felt like we made a fighting game but simulated for being able to do it in the real world, rather than hitting buttons on a controller.

Michael's description fully articulates a design rationale that considers both the material and tangible affordances they were trying to imbue and felt a fighting game fit the genre best suited for the wearable and visual experiences they wanted to create with the tools they had available. While the group did not create a fully bidirectional design, their design rationale, and expression of limitations that hindered its fully realized development, indicate that they understood the utility of bidirectional responsiveness and may have been able to achieve it had they had more time.

The flappy star game was also created by a team of three students (2 male, 1 female). They created a wearable, partial glove controller that used two fingertips and conductive fabric to control a modded version of Flappy Bird, which they created by "remixing" someone's Scratch version of Flappy Bird. The conductive fabric was connected to the MaKey MaKey, such that the thumb piece was connected to ground, and the forefinger was connected to spacebar, which would be the normal controller for the game. As the person pinched their fingers together, the star would hop up on the screen (see Fig. 10).

While they remixed an existing Scratch project, they were committed to creating something unique in and that required a significant amount of work. Makhi[1] explained how remixing the Flappy Bird into a different object meant changing some of the sprite's properties, as well as the gravity that was preprogrammed in the original game:

> [The other male team member] drew the star… I changed the background in it, so the change of color of the stuff. Also with the gravity of the game, I had to change that, because the way the star was made, it wouldn't suffice. I learned how to change the way the game would have to react with the star size.

Originally, they were planning to have the light turn on in the physical glove when the conductive fabric was pressed. However, when they designed the final 2-finger controller, they realized there was not enough space to add the Lilypad, which they would have needed to control the LEDs. Even though they did not incorporate a physically interactive element in their wearable controller, they did find utility for it early on in the design process. As Makhi explained:

> [Working with the LED] would help us show if it was working or not. Because without the light, I remember you taught us that the light would indicate whether or not it's working. We had no other way to tell if it was working except by going on the game. But, we didn't make the game yet. We had to make sure the thing was working. That was just like our little guide to see. That was probably a big part because it helps us make the game what it is, now.

In other words, they were able to use the Lilypad Arduino, conductive fabric and an LED early on in the design of their wearable controller, and the activation of the LED was used for troubleshooting. Instead of creating a fully functional bidirectional design, they used different aspects of what was learned in class in their design process. However, Makhi felt that the workshop allowed him to think differently about how systems are designed and put together to be responsive in different ways:

> …because we were working on hardware… Now I'm thinking, because we know how it works, I'm thinking how does it work. I want to go in depth with it…. I'm thinking to myself, how did they know that this spark information would go there? How did they get everything to work so precisely? How did they get it to be so small?

The sensor glove was created by a team of 2 students (1 male, 1 female) who were excited to explore the possibilities inherent in different kinds of tangible interactions within a wearable interface. They were less focused on the digital

[1]The other two team members were not interviewed. One declined, and the other did not obtain parental permission.

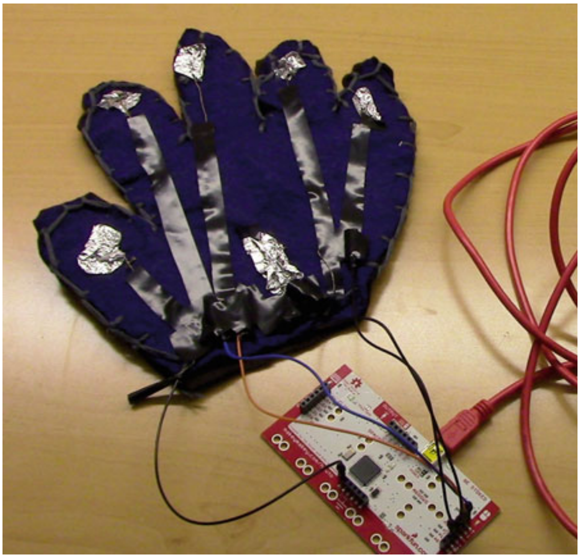

Fig. 11 Close up of the sensor glove prototype with the MaKey MaKey

environment and wanted to spend time perfecting the glove controller, which could essentially work to control any game with arrow key functionality (Fig. 11). As Kia explained:

> Our team made… sensor gloves, with touch sensors on the finger tips that connected with the MaKey MaKey so that when you pressed the sensor on your finger, depending on which finger it was, one was up, down, left, and right, and those controlled, they were the sensors of the MaKey MaKey, like directions and thumb was jump… [through the spacebar] and that connected with the MaKey MaKey with our Scratch game that we made and all together, we got to control the game using the gloves that we made.

However, early on the team experienced difficulties fabricating the final physical prototype and seemed to take different directions with the design. During my observations, I noted that Liam was very focused on coding, and Kia was focused on creating the glove interface, though they often struggled to bring everything together when it came time to beta test. As conveyed by Kia:

> …since we were working on a separate computers sometimes there would be a miscommunication and I would be doing something and he would be doing something else and then they wouldn't be compatible with each other… I would have to go back and fix what we were doing and so I think working separately was kind of the problem, but we were able to make it work.

This most likely contributed to some of the technical errors they later discovered with the glove interface. I was able to observe it working to control the basic pong game in Scratch Liam had remixed, but, by the time they had to show it to outside observers, it had stopped working. Kia explained that "there were loose connections [in the glove] and that was mainly [the] problem." Despite the technical problems, Liam felt "if we had had about two more weeks then I'm sure we could have gotten it." However, Kia was impressed that they were able to make a working glove controller that worked with Scratch through the MaKey MaKey, however, fleeting:

> We got it to work once and it was impressive for that one moment. And then everything fell apart, but I was really proud that we actually got this idea that we had in our heads and that prior to this I probably wouldn't think that I could do [it]… I was proud that we could make the thing work… all by ourselves and it was pretty cool.

Further, through all of the difficulties encountered and troubleshooting, Kia, who had previously not worked with hardware and had no programming experience, felt she had a stronger understanding of the design process:

> I feel like I learned, not only a lot about technical skills, like programming and how to use Lilypad and Modkit and Scratch but I also learned how to troubleshoot, fix problems and how to… even when your project doesn't work, how to make it so you can bounce back from that and if you can't fix it, to think of another thing that can be used as a replacement and I think that was really important.

Moreover, she enjoyed the utility of working with all of the toolkits and systems, which she felt brought different skill sets together in a meaningful way:

> Our design was based off of the combination of [the Lilypad, wearable sensors, the MaKey MaKey and Scratch] and I think… if we were to take it away our design would have been completely different. I felt like that was what I liked about it… it was able to incorporate what different people liked and put it all into one project. It was able to get different skill sets. Again, Liam is very good at programming, I'm very good with craft stuff and it was good to merge those, otherwise it would have been a lot more challenging. I liked that.

5.2 Bidirectional Responsive Game Controller Design

We now turn to a more extensive examination of one student team with Tuyet, a female designer, and Quinn, a male designer, who were able to successfully create a fully bidirectional responsive design. Their final project was an interactive trivia game in which players would have to answer questions related to historical questions appropriate for their grade level in school (9th grade). Some parts of this game were played on a colorful, flexible, felt game board made of conductive fabric, which, when triggered would roll digital dice on the screen in Scratch that would randomly generate a trivia question (see Fig. 12).

The design involved both the MaKey MaKey, which interfaced with Scratch and controlled the randomized trivia generating dice, as well as the Lilypad Arduino, which they hooked up to the same conductive fabric. When the conductive fabric was touched, two things happened: The interactive die would change on screen (and create a rolling sound), which would trigger the trivia question, and the LEDs on the game board would turn off to indicate that the fabric was touched, thus enabling a responsive element for players to respond to (see Figs. 12 and 13). They had also drawn unique characters, as game pieces, to go along with the game, though they

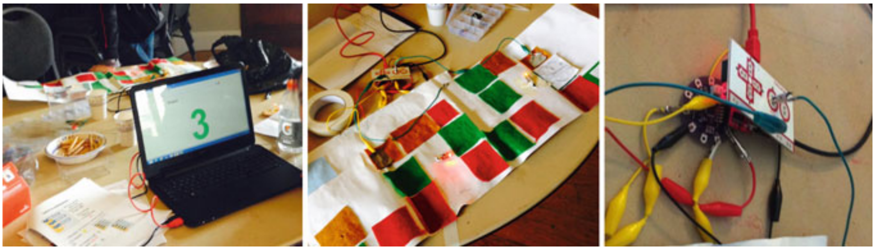

Fig. 12 (*Left*) Demonstrating the digital dice functionality on the Scratch screen. (*Middle*) Close up of the felt game board with MaKey MaKey. (*Right*) Lilypad Arduino under MaKey MaKey with conductive parts of the board connected to both

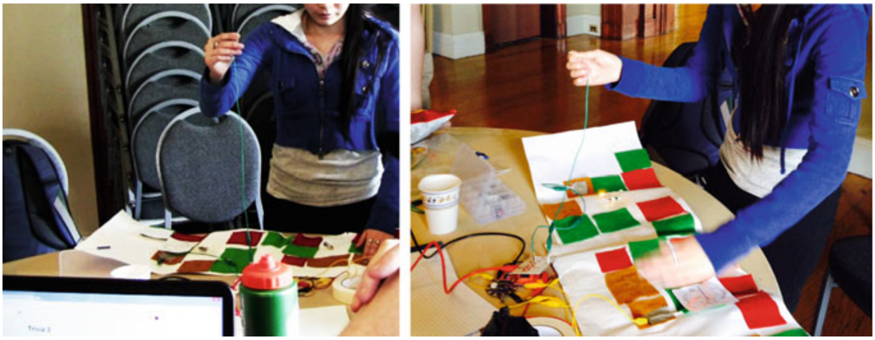

Fig. 13 Tuyet controlling the game board. On *left*, when the game board is touched, the LEDs turn off. When she lets go, the LEDs turn back on

expressed that they were unsure how to make them interactive with the bidirectional interface, since they had been created on paper, and did not have time to add the conductivity to the individual pieces (Fig. 13).

The team was successful in finalizing their bidirectional responsive design by making several interesting but also judicious design decisions. For one, they spend most of their time on designing the hardware instead of programming, so they had time to work out usability issues in their trivia game. Furthermore, they programed the game by remixing an existing Scratch program. Remixing is a popular and encouraged activity in the Scratch online community, where members can repurpose code from programs and use in their own projects (Kafai and Burke 2014b). Finally, they used the prototyping materials by keeping the original alligator clips used for prototyping, instead of creating the final fabricated design by sewing down all of the connections with conductive thread.

In order to create their final project, they had to engage in understanding and integrating material affordances (such as conductive and nonconductive materials), coding and computation, and the design process. Tuyet explained[2] how initial misgivings about material affordances meant redoing the design but also learning a lot about conductivity and usability in the process:

> We found out that paper is not so friendly. (laughs) We found out glue is not so friendly… We didn't realize that we can't put wire on top of paper and then put cloth on top of paper and then expect it to stay in place, so we had to puncture holes in it… We found out that you can't always have it the way you want the first time… So trying to keep it nice and clean for everyone thinking it's beautiful and yet underneath looks like a tornado of just random wires and poked holes and glue and tape.

While she and Quinn were frustrated by having to redo the project, and it meant limiting their final design, they also learned a lot about the design process, and how to present a final interface that is both functional and understood by users. As expressed, they were confused about material affordances when they first started to design, and the instructor had to remind them that they needed a textile element to work with the Lilypad Arduino. For example, while they initially started with felt, they wanted to draw an interesting game character, which they could only figure out how to do on paper. When they tried to piece it all together, it did not work as intended, and the instructor had to remind them about using conductive materials, so the MaKey MaKey and Lilypad could pick up the values.

Furthermore, they had to engage in understanding and integrating coding and computation. For example, they originally wanted the LEDs to turn on (not off) when someone touched the board. This actually was partially a result of the limitations of the ModKit software. While an original version of ModKit allowed for reading values from serial communication, the current one did not, meaning that students actually had to go back and forth between previously developed code in Arduino (the C-based, line coding programming language used with Arduino products) that allowed them to read in the changes to the values when the conductive fabric was touched and then to ModKit to adjust the code to reflect when the lights should turn on and off. Unfortunately, despite the prewritten code, this proved to be challenging for this team (as well as others) and added additional stress and time to the design process. As a result of this, another limitation to their design was that they did not have time to make either the physical side or the software side as polished as they intended.

As a means of trying to get a finished product, they engaged in computation practices, such as remixing and reusing, that expert designers often use (Brennan and Resnick 2012; Kafai et al. 2014a, b). While they originally wanted to do more with the Scratch interface design, it was through this expert practice that they were able to come up with a working prototype by the end of the workshop. Despite integrating a previously designed project, they felt they had to learn coding in Scratch in order for this to be successful. According to Tuyet, they had to learn "the codes… the building blocks of Scratch—we had to learn the different meanings and how to use them properly." However, they had all of the pieces of a working

[2]Quinn declined to be interviewed.

prototype, which would have only required a minimal amount of additional time to get it to where they wanted it.

Finally, they had to bring all of their amassed knowledge together into a representative system. Tuyet described how they learned to connect the different components to make their game bidirectionally responsive:

> We had to learn how to control the lights. We knew how to turn on the lights, because that's really simple, but then we had to make them blink [when touched]. We had to make them do certain things to go with touch and react to what we wanted them to do. The MaKey MaKey system, which was used primarily for the dice to control on the board—that was easy because we took [a game they remixed in Scratch] that was already made. We just created, or deleted certain parts of that dice and then we used that for the MaKey MaKey system and plugged that into the board… It ended up being just a couple of wires. But that's OK.

Despite the limitations and frustrations experienced during the design process, Tuyet expressed how working with all of the toolkits and coding environments added to her understanding of bidirectional design and their affordances:

> Yes [combining all of the systems added to our design]. Originally it was quite simple, our design for our project. Then as it grew we had multiple parts, which made it more dynamic in the fact that it was not just one simple board game that only had one function. It had multiple functions and you could do multiple things if you wanted it to… To combine all of them, it's not easy. They're quite interesting to use as a whole so when I used all of them… You got to see that they can also work cohesively with each other. They're just not one system does this, this system does this… They actually do work together. You just need to know how to use and connect the dots between them because they are not the same system whatsoever but they … can work together.

In conclusion, while only one team was successful in creating a fully bidirectionally responsive design, students from other teams revealed a better sense of the design process and had cleverly learned how to utilize prototyping and remixing strategies to test out functionalities and refine their design process. These case studies help to illustrate the trends we observed in the workshop: students not only got to engage in multiple design practices for the creation of complex projects with various physical and digital responses, but also learned to think about computation differently. Tuyet expressed how she came to think systematically about how all of the systems came together. The integration of multiple toolkits made their designs more dynamic and interesting. Further, by noting "they actually do work together," Tuyet expresses a sense of perceptual change fostered through the workshop and similarly expressed by other students, regardless of the outcome of their designs. For many students, the workshop did not just enable the potential for bidirectional responsiveness, but multiple entry points to learning about coding, computation, crafting, and tangible design. As a result of being able to integrate multiple skills and interests, and observing other projects that had been successful in achieving different aspects of responsiveness, most students walked away with a heightened understanding of bidirectionally interactive tangible design.

6 Discussion and Conclusion

Responsive wearable interfaces are becoming more commonplace in play, work, and school. Technologies such as *Google Glass*, *Oculus Rift, the WiiMote,* or even the *PlayStation 4* game controller, whose lights change to respond to on-screen game cues, have become highly visible and now also commercially accessible. However, designing such tangible and reactive interfaces is no trivial matter, and asking novice designers to do so turns out to be a challenging enterprise on both the tool and design level. In the following section, we discuss what we learned about tool and workshop design.

For creating the responsive interfaces, students needed to learn and design with four different tools—construction kits and programming languages—which included the MaKey MaKey that interfaced with Scratch and its block-based coding environment, along with the Lilypad Arduino that used ModKit its block-based programming language. We observed that most of the complexities for novices involved working with the Lilypad Arduino and ModKit, perhaps not surprising based on prior experiences we have of students learning to design with e-textiles (Kafai et al. 2014a, b). In contrast, the MaKey MaKey did not require any programming but let students engage with circuit design in a simpler way than the Lilypad Arduino. While learning Scratch programming seemed to come easier to the students, it is very possible this was due to learning about visual block-based coding earlier in the unit through ModKit. An additional affordance of working with Scratch was its integration of remixing, which allowed students to deconstruct the code behind other projects they liked in Scratch and wanted to incorporate with their workshop projects. While the tools were necessary, some participants clearly were more interested in the crafting and physical materials than engaging with serial communication and digital interaction design. Overall, a major constraint noted was the lack of time necessary to learn to master all the tools in order to make the kinds of fully functional designs students had conceived of.

Future implementation of such design workshops would benefit from a new generation of integrated tangible construction kits that could facilitate such responsive bidirectional designs. Rather than using four different tools, like we did in our workshop, students would only have to learn and interact with one tool, perhaps custom tailored for particular applications. For instance, the MaKey MaKey already simplifies bifocal design from what used to be an extremely complex process involving multiple sensors and back-end programming. There are already developments underway to achieve such designs. For instance, Sipitakiat and Blikstein (2013) have introduced the Pi-Topper, which adds to the Raspberry Pi by allowing it to work with sensors and actuators, creating physical computing capabilities in the Scratch programming and media design environment. However, understanding the utility of this toolkit for teaching bi-directional design still remains to be seen.

Providing integrated tools is one important support to introducing novice programmers to responsive design, while another equally important support is creating a workshop and curriculum structure that coordinates tool introduction and design phases. Based on the teaching experiences in this workshop and prior physical computing workshops (Richard 2008), a better model would involve using the previously created projects during this course as exemplars that can be deconstructed into project-based units. We are currently redesigning the curriculum such that it focuses on successively building from simple e-textile designs, to increasingly complex wearable interfaces that interact in both the physical and digital environments. These units will be used as buildable models of how to work with Scratch, the MaKey MaKey, the Lilypad Arduino, and ModKit, so that, once students come to build their own projects, they have done more focused building and troubleshooting within contained models they can use as building blocks to more complex design. Future work will explore how this newly tailored curriculum impacts students' designs and understanding of bidirectionally responsive and wearable game controllers and interfaces.

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Part II
Designing Interactions with Nature, Animals, and Things

Human–Computer–Biosphere Interaction: Toward a Sustainable Society

Hill Hiroki Kobayashi

Abstract This chapter presents the author's vision of human–computer–biosphere interaction (HCBI): toward a sustainable society. HCBI extends the subject of HCI from countable people, objects, pets, and plants to an auditory biosphere that is uncountable, complex, and nonlinguistic. By realizing HCBI, soundmarks in a forest can help us feel as one with nature, beyond the physical distance. The goal of HCBI is to realize the benefits of belonging to nature without causing environmental destruction. This paper presents the concept overview, related work, the method, and developed interfaces.

Keywords Human–computer–biosphere interaction (HCBI) · Nature conservation · Nature interface · Smart fashion · Soundscape visualization · Sustainability · Sustainable interaction design

1 Introduction

To maintain human civilization, man requires a transformation in his relationship with nature, which has been destroyed in the process of urbanization. Ironically, the nature conservation movement, which promotes conservation areas for preservation purposes, has increased the demand for tourism in these areas and thus has accelerated the speed of environmental destruction.

Nevertheless, a sense of belonging to nature is essential for emotional balance. Japanese Zen Buddhism, for example, encourages deep meditation to achieve a sense of being one with nature (Suzuki 1959). A reverent attitude toward nature can provide a starting point for finding a way to mental and physical well-being (Williams and Harvey 2001). Likewise, the sounds of birdsong, buzzing insects, gently swaying leaves, and the trickling of water in a forest convey the beauty of

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Fig. 1 Iriomote Island, Japan, an example of a magnificent ecosystem. (Photograph by Yoshinobu Takagi)

nature (Fig. 1). Distancing ourselves from the technologies of modern life and evoking the beauty of nature can help us slow down the pace of daily life. Therefore, it is necessary to establish a concept, a method, and an interface, Sustainable Interaction with Ecosystems, by which we can achieve a feeling of belonging to nature without causing environmental destruction and in which humans and nature can coexist.

This chapter presents our vision of human–computer–biosphere interaction (HCBI) by introducing the concept overview, related works, a developed interface, and related discussion. This paper is not intended to propose a solution to any one single problem. Rather, it proposes a new view of HCBI-based design and interfaces to support our future society in a multidisciplinary approach.

2 Background

Our relationship with nature is constantly evolving as human civilization progresses, yet natural environments are suffering ongoing destruction caused by urbanization. Environmental movements, which promote conservation and preservation through news and other media, have ironically increased tourism in undeveloped and pristine areas, which accelerates the speed of environmental destruction.

As shown in Fig. 2, the Iriomote cat (*Felis iriomotensis*) is a wild cat about the size of a domestic cat and only lives on Iriomote Island. It was discovered by Imaizumi in 1967 and is considered a "living fossil" because it has not changed much from its primitive form (Yoshinori 1967). The Iriomote cat is currently the most threatened subspecies of leopard cat, with an estimated population of fewer than 100 individuals. It has dark brown fur and a bushy tail and is unable to sheathe its claws. In 1997, the Iriomote cat was declared a Japanese national treasure in response to development pressures, which are a very serious threat. Because of this, one-third of the island has been declared a reserve where trapping of the cat is

Fig. 2 The Iriomote cat (*Felis iriomotensis*) has been listed as an endangered species by the international union for conservation of nature and natural resources (IUCN) © Iriomote wildlife conservation center, http://iwcc.a.la9.jp/img/topimg.jpg

strictly prohibited. The International Union for Conservation of Nature and Natural Resources (IUCN) has listed the Iriomote cat as a critically endangered species (Resources 2014).

One of the most significant threats to the declining cat population is roadkill deaths (Kobayashi et al. 2009a). In Taketomi Chou, which is located in the cat habitat, there were fewer than 500 registered cars in 1979. However, that number increased to more than 3000 as of 2005. This increase has been accompanied by a drastic increase in the number of cats struck by motor vehicles. Ironically, the reason behind the rapid increase in registered vehicles and related cat deaths is improvements to the local economy thanks to tourism. As the fame of the Iriomote cat spread, it added significant value to the island's tourism industry and numerous tourists visit the island in the hope of seeing the endangered cat before it becomes extinct.

As the number of tourists increased, so did the number of rental cars. This, in turn, pushed up the number of roadkills. A spiral then ensued as news media reported cat deaths by roadkill, which increased interest in the cat further, thus resulting in even more tourists and hastening the animal's decline toward extinction.

If information technology could be used to provide us with the simulated experience of being close to nature while promoting the need for nature conservation, the number of roadkills of the endangered species in world heritage areas by ecotourists might decrease. Even though conservation scientists have actively advocated environmental protection by describing current critical situations and reaching out to people with state-of-the-art information technologies, a high-resolution picture of an endangered animal killed by a car can never be more than human–computer interaction and thus will be ineffective in preventing further such deaths.

What is lacking is not knowledge and technology but an interface through which we can commune with nature, where destruction is occurring at this moment, and experience the current state of incompatible relations existing between human beings and the natural environment. Therefore, a methodology that separates human beings from natural environments that require preservation is necessary.

3 Concept Overview and Related Work

The HCBI concept (Fig. 3) proposed by the author is an extension from human–computer interaction (HCI) and human–computer–pet interaction (HCPI). HCI is described below as:

> A discipline concerned with the design, evaluation and implementation of interactive computing systems for human use, and with the study of major phenomena surrounding them (Hewett et al. 1992)

In this research, the author proposes HCBI, which extends HCI and HCPI from countable objects, pets, and plants to their auditory environments, which are uncountable, complex, and nonlinguistic soundscapes.

Computer-supported cooperative work (CSCW) uses computer systems to exchange messages that support task-specific activities. For example, we routinely exchange our ideas, thoughts, theories, and other messages by encoding and decoding words via computer media, cell phones, e-mail, and chat systems. However, in our daily social interactions, we also unconsciously exchange and share a significant quantity of nonverbal cues related to emotion and physical states. This cue information helps us to find appropriate contexts during the verbalization process so that the intended message can be easily received and understood by its intended recipient. The purpose of "*Tsunagari Communication*" is to foster a

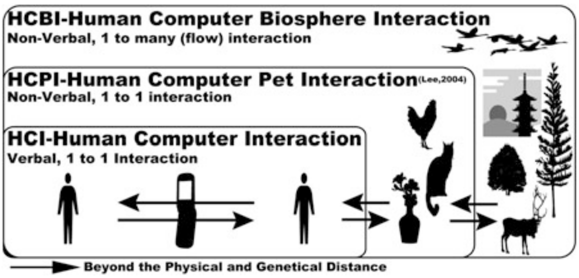

Fig. 3 Human–computer–biosphere interaction (HCBI) concept, an extension of HCI and HCPI. © 2008 Hiroki Kobayashi and Ryoko Ueoka (Kobayashi et al. 2009a)

feeling of connection between people living apart from each other by exchanging and sharing cue information. One example of this is the “family planter system” (Fig. 4), which uses network and HCI technologies (Itoh et al. 2002).

Previously, a number of studies were conducted that explored ways of establishing interactions between computers and wildlife by means of HCI, HCPI, and other methods. However, while the technologies used in some of those projects are very similar to those of our research project, our method of interaction between humans and wildlife, which allows users to experience nature via computer systems, remains unique.

Botanicals (Bray et al. 2009) were developed to provide a new way for plants and people to interact in order to develop better, long-lasting relationships that transcend physical and genetic distances. This system allowed computers to become an intermedium among different biosphere species in a way that allows nonlinguistic expressions to be perceived and understood by individuals of differing species, something that would appear to violate the rules of linguistic science. The botanicals system allows plants to place phone calls when human help is required. For example, when a plant on a botanicals network needs water, it can call a person

Fig. 4 “Family planter” terminals on the network are connected to each other through a network. The system detects human motion and shares it with other terminals in real time. The optical fibers at the *top* of the terminal illuminate to indicate when a human is detected and then rotate to orient on human motions. These exchanges are designed to blend into the everyday life of the users

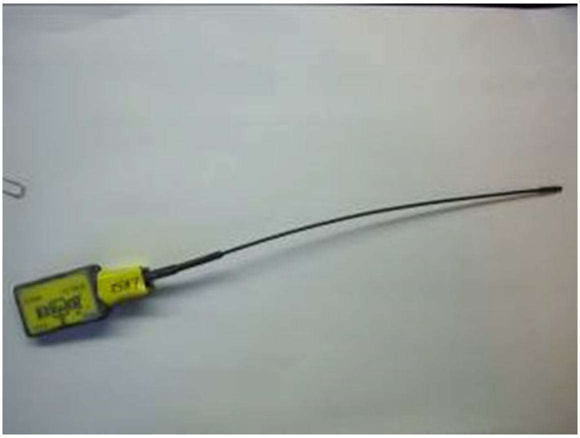

Fig. 5 VHF signal transmitter collar—positioning system (Kobayashi and Matsushima 2014)

and ask for exactly what it needs. When people phone the plants, the plants apprise callers of their botanical conditions.

Furthermore, HCI technologies can be employed for wildlife monitoring to remotely observe target animal behavior. Such usage allows every element of a target animal, from its movement pattern to excrement disposal, to be monitored by biology researchers over the course of its life. A normal system incorporates radio tracking and positioning utilizing a VHF signal transmitter collar and receiver, as shown in Fig. 5. In the case of the Iriomote cat, researchers can use triangulation to estimate the current position of a monitored cat from the signal strength of its radio.

More recently, for audiovisual monitoring, weather-resistant video systems have been commonly employed by researchers to monitor animal movements. The author previously studied an audio-based monitoring method that involves recording and analyzing bioacoustic information obtained from several monitoring sites simultaneously (Kobayashi et al. 2009a), as shown in Fig. 6.

Similarly, the Electronic Shepherd (ES) project (Bjørn et al. 2004) at Telenor R&D provides a tracking system for monitoring the movements of grazing sheep. The system, which was originally created to address the needs of sheep and reindeer farmers seeking a way to keep track of their animals during the grazing season, utilizes several wireless devices for positioning and data communication. The main difference between the ES project and this research is that the former tries to trace the movement of a group of sheep via various wireless communication technologies, while this research focuses on interactions with single animals in the wild.

The ZebraNet project (Juang et al. 2002) at Princeton University involved the creation of a tracking system for monitoring zebra movements. The system is designed to calculate the latest position of a number of zebras in areas where no cellular service or broadband communications are available. The system utilizes GPS collars, flash memory, wireless transceivers, and a small CPU. The primary difference between ZebraNet and the research described in this thesis is the smart

Fig. 6 Live sound collected from a subtropical forest on Iriomote Island. A pair of networked microphones (wrapped in a *thick black-colored sheet* of waterproof sponge and a plastic hard mesh) is tied to the trunk of a tree. Live sounds from the forest have been streamed to users in real time, 24 h a day, everyday, since 1997. Photograph (*right*) by SoundBum (Kobayashi et al. 2009a)

device system, which includes a GPS tracker, a CPU, a battery, and a wireless communication device. This device allows the latest positioning information to be calculated and transmitted to remote observers.

This nonverbal interaction also increased the efficiency of wildlife monitoring. In comparison with traditional one-way monitoring, acoustically active monitoring is unique and efficient because it actively interacts with the target and acoustically extends the observable period, thus increasing the probability of success by influencing the movement of the target wildlife. This achievement indicates that HCI technologies can facilitate remote interaction between computers and biosphere entities. As a result, it can provide a practical and effective countermeasure against further ecological destruction.

Moreover, these technologies have also been applied to nature education materials. Periscope (Wilde et al. 2003), an educational tool, was created to provide information about the forest life cycles during digitally enhanced children's "field trips" to woodland settings. The system uses a display, a network device, and a collection of Petri dishes fitted with RFID tags that enable children to conduct experiments with their results shown on the display.

Randell (Wilde et al. 2003) demonstrated another type of digitally enhanced field trip for schoolchildren, in which pairs of children were equipped with a number of wireless devices and allowed to explore and reflect upon a physical environment that had been prepared in advance with a Wi-fi network and RF location beacons. While communicating with a remote facilitator by walkie-talkies and handheld PDAs, the children explore, examine, and learn from the environment around them as they move through and interact with English woodlands.

However, no matter how advanced the technologies used, these are human-centric interactions. We expect some perceivable feedback from others as a response to our inputs before we end an interaction. In contrast, in our daily lives, there are many nonhuman-centric interactions. These include the sounds of birds, insects, swaying leaves, and trickling water in a beautiful forest, all of which can implicitly imprint the beauty of nature in our minds. When we are emotionally stressed, recalling the beauty of nature can help us recover a sense of well-being. A crucial factor here is not the means of conveyance, that is, words or language, but the sense that there is “something” hovering around or the atmosphere that we cannot precisely identify (Suzuki 1959).

This type of interaction follows the teaching of Zen Buddhism. Zen is one of the products of Chinese culture, which developed in the first century A.D. after the culture’s exposure to the Indian teachings of Buddhism. Suzuki noted the Japanese love of nature as follows:

> It consists in paying nature the fullest respect it deserves. By this it is meant that we may treat nature not as an object to conquer and turn wantonly to our human service, but as a friend, as a fellow being, who is destined, like ourselves, for Buddhahood. Zen wants us to meet nature as a friendly, well-meaning agent whose inner being is thoroughly like our own. (Suzuki 1959)

Thus, the author proposes HCBI, which extends the range of interaction from countable objects, pets, and plants to auditory environments, which are uncountable, complex, and nonlinguistic soundscapes, much like Zen elements described above. By realizing HCBI, we can experience the soundscape of a forest, or other natural environment, which is integral to helping us feel one with nature. Furthermore, with HCBI telepresence, we can listen to and experience the global ecological system, integrating all living beings and their relationships, including their interaction with the elements of the biosphere. With HCBI, we can begin to interact with subjects beyond normal physical and genetic distances.

4 Goal of HCBI

HCBI attempts to facilitate nonhuman-centric interaction with nature by integrating computer systems into the global ecosystem.

The key HCBI concepts are (Kobayashi 2010):

- Physical separation: Current information technologies allow people to communicate over long distances in real time without direct contact between the caller and the receiver.
- Information connectivity: Current information technologies are capable of conveying not only explicit objects such as text and voice messages, but also nonverbal messages, even though the feelings expressed may often be unclear or open to misinterpretation. Despite limitations, the application of new aspects and interfaces is advancing information communication in ways that extend human and biosphere interactions beyond the language barrier for nonhuman-centric interaction.

- Ecological neutrality: By combining physical separation and information connectivity, nonverbal information interaction between human beings and the biosphere is possible. These are "virtual" interactions, and their environmental impact never exceeds their virtual impact, which may be effective for nature conservation.

Ultimately, application of these concepts allows us to create virtual impacts on wild animals without ever interacting with them physically. In doing so, we can facilitate interactions among remote animals and the environment in a manner analogous to people's interactions with their family members at home. Such interaction could eliminate the need for tourism that results in the death of an endangered species, as mentioned previously. Currently, HCI research and applications are primarily focused on human-centric interactions. However, there are many nonhuman-centric interactions in daily life. Using HCI technology to increase people's awareness of nature and facilitate benign interaction with nature is a key challenge for HCBI.

5 HCBI Method Design

Natural communities contain a wide spectrum of life forms that interact with (Krause 1987) each other (Begon et al. 1996), and it is generally agreed that the essence of ecology is the study of ecological interactions among species in animal communities (Begon et al. 1996). In particular, animal communities in tropical forests have extremely complex interactions involving numerous species (Ricklefs and Schluter 1993; Leigh et al. 1996), with the structure of natural sound in rainforests convincingly demonstrating the extraordinary relationships that exist among the many insects, birds, mammals, and amphibians that inhabit these environments. If one creature starts vocalizing, others immediately join the chorus (Krause 1987). These bioacoustic interactions between animals vary depending on the biological diversity of the natural habitat. This research used bioacoustic information to develop a wildlife–computer interaction model and to propose a novel cybernetic interface for use as a mobile technology for human–wildlife bioacoustic interaction.

The author proposes a novel cybernetic interface that uses mobile technology to create human–wildlife bioacoustic interaction. To establish interaction with wildlife, the monitoring system artificially creates a "prey field" to control the movement of the target wildlife under three conditions: predator–prey relationship, interspecific communication, and interspecific communication in mixed reality.

First, predators hunt for prey in their native habitat (Fig. 7). Bioacoustic information is one of the signals used by predators to detect the existence of prey. For example, in natural environments, real frogs respond to the initial call of virtual frogs and begin singing in chorus. The predator then detects the emergence of a prey field using acoustic cues acquired from the frog chorus before approaching and entering the prey field near the system to hunt. Bioacoustic interaction has thus been

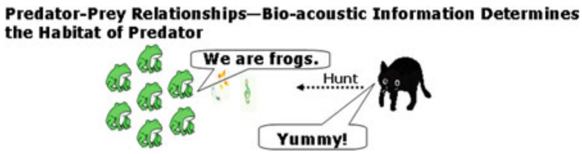

Fig. 7 Predator–prey relationship

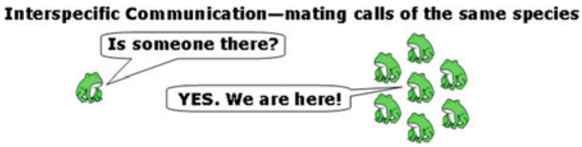

Fig. 8 Interspecific communication (Kobayashi 2010)

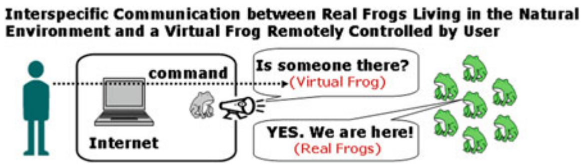

Fig. 9 Interspecific communication in mixed reality (Kobayashi 2010)

established and a predator hunts prey in its habitat, as shown in Fig. 7. Bioacoustic information is one of the deterministic factors by which a predator detects the existence of prey in its habitat (Searcy and Nowicki 2005; Krebs and Davies 1993). A lack of prey indicates the absence of predators from the habitat.

Interspecific communication is considered to be a chorus produced by a group of members of the same species (Figs. 8 and 9), similar to the Packet Internet Groper (PING) command of the Internet control message protocol between two computers (Kobayashi 2010). A single individual, the caller, begins by calling to other individuals of the same species to confirm their presence (Kobayashi 2010). Other members of the same species then randomly respond to the call and thus report their existence to the caller.

Third, a species can conduct interspecific communication in mixed reality. Real frogs answer the initial call and report their existence. The initial call—which is a virtual call broadcast from the speaker—can deceive the real frogs into believing that it was made by another real frog in the area, as shown in Fig. 9.

Finally, to establish the wildlife–computer interaction, the author proposes an interface that artificially creates an actual prey field to influence the movement of the target wildlife, as shown in Fig. 10, under the three conditions mentioned above. The interaction method is designed to proceed as follows:

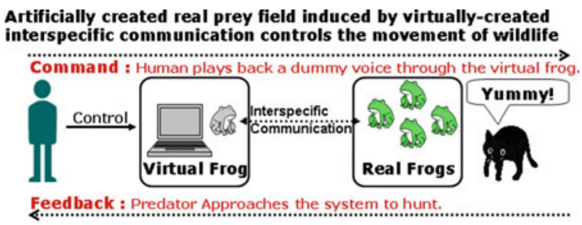

Fig. 10 A user playing a prerecorded sound of an initial call from an acoustic speaker. The speaker is placed in the natural environment and remotely controlled by a PC over the Internet (Kobayashi 2010)

1. A user remotely controls the PC to initiate interspecific communication with real frogs by broadcasting an initial call through a speaker placed in the natural environment.
2. Real frogs in the natural environment respond to the initial call. The virtual and real frogs start singing in chorus.
3. The predator acoustically detects the emergence of the prey field through the frog chorus.
4. The predator then enters and stays in the prey field near the system to hunt, thus establishing bioacoustic interaction.

To evaluate this hypothesis, the author participated in the construction of a system designed to evaluate the bioacoustic interaction system using a networked remote sensing embedded system. In the evaluation system, instead of a user controlling the system to initiate interspecific communication, the system monitors the movement of the target wildlife remotely.

The challenge currently faced by conservation managers is the development of a behavior control system for wild animal species whose positions and movement patterns are both unknown and unpredictable in a natural environment. An HCI system of this type needs to be small enough to be carried in the field by researchers, capable of being controlled remotely by system engineers, and "smart" enough to interact with wildlife nonverbally. Furthermore, the system must be capable of operating under the extreme conditions found in hot and humid subtropical forest environments until such time as the target wildlife species arrives at a monitoring site. This requires the use of weather-resistant, energy-efficient, and highly stable equipment.

6 Wearable Forest: HCBI Clothing

The Wearable Forest (Kobayashi et al. 2009b) is based on the HCBI method. As shown in Fig. 11, the Wearable Forest is a garment that bio-acoustically interacts with wildlife in a distant forest through a networked remote-controlled speaker and

Fig. 11 Wearable Forest clothing system (Kobayashi et al. 2009b)

microphone. It is intended to emulate the unique bioacoustic beauty of nature by allowing users to experience a distant forest soundscape. This interaction between humans and nature can occur with minimal environmental impact. The Wearable Forest received first place in a juried selection process for the 12th IEEE International Symposium on Wearable Computers, 2008.

The Wearable Forest consists of a local audiovisual interactive clothing system and a remote audio I/O system, similar to the HCBI system, which is placed in a forest. The remote and local systems facilitate intraspecies communication with wildlife in a mixed-reality environment through a real-time bioacoustic loop. The remote system, consisting of weather-resistant microphones and speakers, was placed in an uninhabited subtropical forest on Iriomote Island.

To interact with wildlife, users can touch the textile sensors, which transfer the user-selected, prerecorded sounds of wildlife from the garment to the speakers in the forest. Figure 12 presents a diagrammatic representation of the system. The bioacoustic loop, which transfers live sounds bidirectionally from the remote and local sites, gives the user the opportunity to interact with wildlife. For example, in a relatively quiet period after a brief rain shower in the subtropical forest, users in an

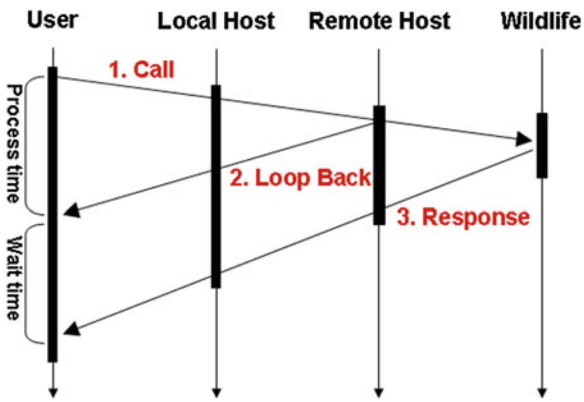

Fig. 12 Nonverbal interaction between user and wildlife © 2008 (Kobayashi et al. 2009b)

urban location can play back the croaking of frogs through the remote speaker; in response, actual frogs might start croaking.

In this choruslike mixed-reality experience, intraspecies communication between the user and the frogs could potentially give the user a sense of belonging to nature, similar to the peak experience in music therapy (Lowis 2002). During the first exhibition, the out-of-synchronization problem was confirmed. The problem made it difficult for the visitors to identify a specific sound from other sounds on the audio live feed from the remote forest. This results in it being auditory impossible for the user to recognize the potential response from the wildlife, even if they actually responded to the user in the distant forest. Therefore, even if no response is transferred from the wildlife after the loop back call of the initial call, other acoustical activities in the forest are sent as responses, such as the sounds of birdsong, buzzing insects, gently swaying leaves, and a tree falling. Those sounds indicate the non-linguistic telepresence of entities in the forest. From a psychological aspect, participants who experienced the Wearable Forest at the ACM SIGMM'08 art exhibition (n = 20) described "a sense of oneness" with the remote forest.

They rated the episode on a number of scales reflecting characteristics of transcendence (Williams and Harvey 2001), such as sense of union, and timelessness. The result indicates that the Wearable Forest–HCBI interface is able to create a sense of oneness between humans and wildlife beyond the physical and genetical distance. Future research is necessary to increase the degree of the sense of belonging to nature.

7 Tele Echo Tube: HCBI Speaking Tube

The Tele Echo Tube (Kobayashi et al. 2013), shown in Fig. 13, is a speaking tube installation that vocally interacts with equipment located on a distant mountain in a remote forest through networked remote-controlled speakers and microphones. It

Fig. 13 Tele Echo Tube for human–computer biosphere interaction. © 2009 (Kobayashi et al. 2013) (*note* the chair is not a part of this art work)

allows users to interact with a forest in real time to experience a distant forest soundscape, thus connecting humans and nature without great environmental impact. The Tele Echo Tube is based on the HCBI system.

The Tele Echo Tube consists of local and remote speaking tube systems with a one-way echo canceler through a full-duplex audio I/O system. The remote and local systems perform a remote interaction and create a pseudo echo experience. The system is designed to emulate the imagined response of Yamabiko, or "Echo," a mythological tree spirit (Cabanel 1887), shown in Fig. 14, believed to answer when one calls out. The remote system, consisting of weather-resistant microphones and speakers, has also been placed in an uninhabited subtropical forest on Iriomote Island.

To interact with the "Echo," users speak into the local speaking tube, as illustrated in Fig. 15. Users usually enthusiastically shout something like "Yo Hoo." The loop back call at the remote host occurs because the sound from the speaker is captured and transferred back to the user by the remote host with spontaneous network delay. When users hear the loop back call, "their voices within the soundscape" (Kobayashi et al. 2013) from the forest, accompanied by a slight vibration in their hands provided by the interface, they recognize that their vocalization did actually travel through the forest environment.

This echo-sounding loop, which transfers live sounds bidirectionally from the remote and local sites, creates an echolike effect and, in doing so, gives the user the opportunity to feel the presence of "a fickle ECHO" (Kobayashi et al. 2013) in the forests in a manner similar to ancient times. The Tele Echo Tube (island version) was selected to be included in the Artech Exhibition of International Conference on

Fig. 14 The nymph Echo in Greek mythology, painting by Alexandre Cabanel

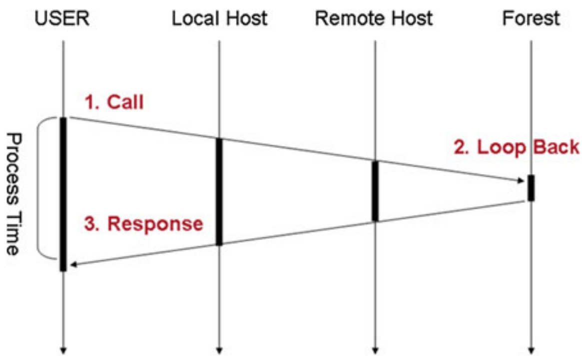

Fig. 15 Diagram of nonverbal interaction between user and forest. © 2009 (Kobayashi et al. 2013)

ASIAGRAPH 2008 at the National Museum of Emerging Science and Innovation, Tokyo, Japan. The audience (n = 50) was used as the subject of this experiment. Thirty-one individuals out of 50 changed their expression to a smile. One individual out of 50 returned a visible surprise on their face. Three individuals out of 50 changed their expression from visible surprise to smile on their faces. Fifteen individuals out of 50 returned a neutral expression on their faces.

8 Discussion

8.1 Technical Problems

In this section, we discuss how HCBI can facilitate ecological two-way interactions by examining current environmental preservation activities and reviewing work related to our proposed method. The results from this study can play an important role in the field of HCI by creating a new kind of interaction among humans, computers, and the biosphere beyond cultural and imaginable boundaries. There are a variety of applications that can be advanced through research by applying this information.

Maintaining the system with high-quality streaming sound in operation for 24 h over 365 days requires advanced computer engineering knowledge. The quality of the digital signal processed by the real-time audio processing software decreases as the recording system works for a longer period. In most cases, the processed signal contains many “clipping” sounds. The “clipping” sounds are caused by slowing down the computation power of the CPU (central processing unit), which is located on the motherboard of the recording system.

Generally, the computational power being slowed down is caused by heat and memory leak. The heat is generated by the recording system itself as the recording system runs in an extremely high-moisture and high-temperature environment in the subtropical forest. The memory leak, losing necessary memory blocks for a computational process, occurs on the recording system because the recording system runs for 24 h over 365 days. Therefore, to solve the heat and memory leak problems, two identical recording systems are necessary that are placed to run separately for 12-h shifts each. While the first system is in operation, the second system is not in operation. By following this time shift system, the CPU temperature of the two identical systems is decreased and the memory leak problem is solved.

However, this hardware-switching mechanism is an extremely difficult function to run under unmanned conditions. To be exact, detection of a system shutting-down process on one system followed by a system starting-up process on the other system every 12 h is not easily achieved under unmanned conditions. Because this system shutting-down process is not only caused by this 12-h shift control software but could also be caused by a long-time power cut, software error could occur as well as other hardware problems. Therefore, to operate all the systems for a long period under unmanned conditions, an intelligent autonomous control system is needed. All the systems were improved several times in the last nine years, and finally, stability of the systems was gained. The latest software of all the systems has been operating under the unmanned conditions for the last two years, more than 17,520 h without a single error.

8.2 Beyond Cultural and Imaginable Boundaries

A comparable type of complex presence existed in Japanese culture. For cultural and mythological reasons, in ancient times, interactions between nature and human societies were more balanced than the interactions that characterize modern society. Before human beings became capable of dramatically altering natural landscapes, humanity and nature were physically separated but spiritually and emotionally connected. Although Japanese farmers interacted with nature in their local environment, the mountainous wilderness areas of Japan were considered to be the domain of gods and mythological creatures. Japanese farmers prayed to the gods during seasonal festivals for favorable weather conditions to ensure successful crop production, and the general population was taught to respect the gods that resided in and protected the mountains. Consequently, wild animals and their habitats in the mountains were left undisturbed for the most part, and Japanese culture was characterized by respectful and benevolent interaction between nature and humanity.

8.3 Animal–Computer Interaction

The author and his associates initially introduced the concept of HCBI at HCI venues focused on environmental sustainability from 2009 (Kobayashi et al. 2009a, b, 2013; Kobayashi 2010). The theory, method, and evaluation of human and wildlife interaction were not discussed in detail because the research was not sufficiently well developed. However, the future direction of HCBI has been suggested by several researchers.

In 2010, DiSalvo et al. (2010) stated that HCBI points out the inherent contradiction in attempting to use technology to create more intimate connections with nature and Pereira et al. cited HCBI as an example of sustainable computing (Pereira et al. 2010). Giannachi et al. (2012) stated that HCBI clothing, for example, the Wearable Forest system (Kobayashi et al. 2009b), facilitates the creation of a human–computer environment that enables new forms of communication.

Mancini explored animal–computer interaction that aims to foster the relationship between humans and animals by enabling communication and promoting understanding between them and emphasized that the study of interactions between animals and computing technology has never entered the mainstream of computer science (Mancini 2011). Mancini also organized the ACM CHI 2012 and hosted a Special Interest Group on Animal-Computing Interaction at the CHI 2012 conference. The missing factors that would facilitate more robust studies of interactions between animals and computing technology are not knowledge or technologies.

The missing factor is an interface that can facilitate human interaction with remote animals and the environment in a manner similar to the interactions with pets and their surrounding environment at home. Before human beings became capable of leveling mountains with heavy construction vehicles, farmers prayed to gods in seasonal festivals with the tools or the weather conditions needed to ensure successful crop production, and the general population was taught to respect the gods that resided in and protected the mountains. The sounds of singing birds, buzzing insects, swaying leaves, and trickling water in a mountain forest implicitly imprint the presence of nature in our cultural way. When we are away from the mountains, recalling the memory of a mountain takes us back to the same place. The crucial factor here is not the means of conveyance (words or language), but the "something" that hovers around, an atmosphere that we cannot identify exactly but that lasts beyond cultural and imaginable boundaries with information technology.

8.4 Toward a Sustainable Society

As described in Fig. 2, the Iriomote cat (*F. iriomotensis*) is a wild cat about the size of a domestic cat and only lives on Iriomote Island. One of the most significant threats to the declining cat population is roadkill deaths (Kobayashi et al. 2009a). Ironically, the reason behind the rapid increase in registered vehicles and related cat deaths is improvements to the local economy thanks to tourism. As the fame of the Iriomote cat spread, it added significant value to the island's tourism industry and numerous tourists now visit the island in the hope of seeing the endangered cat before it becomes extinct. As the number of tourists increased, so did the number of rental cars. This, in turn, pushed up the number of roadkills. The spiral also increased the conflict among local people, administrative officers, and academic researchers, resulting in difficult court proceedings. The spiral was exacerbated as news media reported cat deaths by roadkill, which increased the popularity of the cat further, thus resulting in even more tourists and hereby hastening the animal's decline toward extinction. If information technology could be used to provide us with the simulated experience of being close to nature while promoting the need for nature conservation, the number of roadkills of the endangered species in world heritage areas by ecotourists might decrease. However, even though conservation scientists have actively advocated environmental protection by describing current critical situations and reaching out to people with state-of-the-art information technologies, a high-resolution picture of an endangered animal killed by a car can never be more than human–computer interaction and thus will be ineffective in preventing further such deaths in reality.

There are many historical and current examples of people peacefully coexisting with nature (Raskin 2005). However, these are not applicable to the Iriomote cat case. Due to the dependence of the local economy (including the taxation for conservation budget) on tourism, the number of tourists and rental cars has increased. The number of tourists has never been restricted since the discovery, even today. Therefore, administrative officers and conservation specialists have seriously asked drivers to remain under the speed limit to avoid roadkill accidents, but the situation has not improved at all. In the meanwhile, there are many information technologies available for use on the road in urban areas today. Smartphones (Olson et al. 2014) are technically capable of detecting and reporting the arrival of crossing wildlife on the road with the networked technologies sending messages to drivers in real time to avoid roadkill. This information also helps illegal hunters to capture the cat. Indeed, there is a rumor that an illegally captured Iriomote cat was merchandised in Tokyo at one time. Including by lighting the road at night, it is possible to let the illegal hunter know the arrival location on the road. As a result, this kind of direct use of information technology is not applicable to the Iriomote cat case for conservation reasons.

Therefore, our society has to ask drivers to drive their cars under the speed limit but is not able to provide them with current positioning information about the cat to avoid traffic accidents. In addition, wildlife crossings such as "wildlife underpasses" are naturally and widely used to avoid accidents. Such underpasses are a special type of construction that allows wildlife to cross under artificial constructions such as roads that cut across their habitat. Whenever biologists discover a new cat's tail on the unrecorded roads on the island, an underpass is requested. However, the use of the passage (underpass) has to be monitored for at least three years after construction: It may take wildlife two years or more to adapt, especially if they use the area only for seasonal migration. The impact of HCBI might help this migration at the early stage. However, it is evident that the impact of virtual bioacoustics on a natural environment is not negligible (Cramer and Bissonette 2005). The obvious outcome would be that, over time, the cat will learn that when a call from a prey species comes from that location, there is never a prey species there, and it will learn to ignore the call ("habituation"). A large set of different prey species calls, produced randomly, might overcome this problem, at least until the cat realizes that calls from that location never lead to a kill (which might take a long time or never occur, depending on the frequency of visits). These techniques are often used in the control of harmful birds and mammals to protect farming land from them. Further studies are needed to enable the learning problem to be overcome.

In addition, HCBI draws an alternative approach between humans and biosphere through information technologies toward a sustainable society. By physically separating our human society from the habitat of the Iriomote cat, we can reduce the number of cars dramatically so roadkill does not occur. This is the most effective method of preventing further roadkill. However, the local economy historically depends on the island's tourism industry and the fame of the Iriomote cat. The removal of human society from the habitat would have a devastating effect on the current tourism industry, requiring an alternative activity to sustain and advance the local economy through the HCBI approach. To this end, information technology takes responsibility for sustaining and advancing the local economy. In other words, if information technology could be used to provide ecotourists with the simulated experience of being close to nature, the number of roadkills of the Iriomote cat would decrease without promoting the need for nature conservation.

It is evident that the impact of HCBI on a natural environment is not negligible. There is no right or wrong answer, but moderation is the key, just as it is the key to a sustainable society. Any activity, if conducted too often, can be destructive. One example of a behavior that is only eco-friendly in moderation is ecotourism, which is defined as "Responsible travel to natural areas that conserves the environment and improves the well-being of local people" (Society TIE 1990). However, it is estimated that more than 3000 ecotourists visit Iriomote Island everyday. Such visitors come from urban areas to experience the island's magnificent ecosystem. Six thousand feet walk in the jungles and trample on plants everyday. Furthermore, rental cars driven by tourists accidentally kill endangered species in areas that have been set aside for their protection. Ironically, the increased demand for tourists in these areas to raise awareness of the need for conservation has accelerated the speed of environmental destruction. No matter how calmly and nonintrusively such tourists attempt to behave, their presence inevitably disturbs nature conservation efforts.

In contrast, the authors and their associates have been operating a networked bioacoustic streaming and recording system on the same island (Kobayashi et al. 2009a) since 1997 as a basis for this study. To maintain the remote system, they enter the tropical forest to replace system components just once a year, thus allowing users to listen to live sounds of the ecosystem over the Internet without physically going there. Even though, in essence, the authors become tourists, not to mention potential killers of endangered species, the environmental destruction caused by two pairs of shoes in one day is much less than that caused by 3000 pairs everyday for 365 days a year. Thus, it can be contended that people who visit the island for ecotourism purposes become "ego-ecotourists," even if that is not their intention. Applying electronic technology in natural areas as a conventional wildlife monitoring system that uses widely accepted hardware is moderately eco-friendly. Although it is not the ideal solution, it is a better solution than the alternative.

Furthermore, this study focuses on ecological neutrality. HCBI is virtual reality. Simply turning off the power to the remote devices terminates all interaction in the future. In Amami Island, Japan, thirty individuals of the small Indian mongoose (*Herpestes javanicus*) were released in Amami Island, Japan, in 1979 to control the venomous habu snake (*Trimeresurus flavoviridis*) and the black rat (*Rattus rattus*). However, the mongoose has had a major negative impact on agriculture and the native animals in mountainous areas instead of controlling snakes. A total of 3886 mongooses were trapped by local government pest control measures and an eradication project of the Environment Agency in the first year of the project (Watari et al. 2013). The mongoose population and annual growth rate were estimated at 10,000 individuals and 30 %, respectively, before the eradication project. What if the impact of HCBI were able to control the behavior of the snake and the rat? We could control the effect until a major negative impact on native animals was found. The operation cost of the HCBI is much smaller than the eradication project cost in the case of Amami Island, Japan (excluding the raw materials and energy cost for making the technology). Thus, this study is not aiming to replace current practical and realistic conservation technologies in the conservation field; rather, it aims to provide other solutions for future use if our current decision with current technology goes wrong in the future. Again, although the impact of virtual bioacoustics on a natural environment is not negligible, it is just a virtual presence and is never able to exceed the real presence, such as that provided by introduced species.

Information connectivity with a remote ecosystem under physically disconnected conditions can enable us to control the degree of impact resulting from HCBI. By turning off the power source of the computer system, we can prevent the virtual impact on the remote ecosystem. This brings us to the point of ecological neutrality, which would minimize side effects if correct solutions were applied.

9 Conclusions

Recent technological and information advancements, including satellite imaging, have been unable to confirm the presence of mythological creatures in undeveloped natural locations, and very few humans now believe in the existence of creatures that control the weather or other farming conditions. However, because we no longer embrace the presence of such cultural and imaginable metaphors in our daily lives, especially in city life, there has been little outcry at the severe materialism brought about by the globalization process. This paper presents this author's vision of HCBI: toward a sustainable society. Modern society requires reform in its relationship with nature, which has been damaged in the process of urbanization. HCBI extends the subject of HCI from countable people, objects, pets, and plants to their sounding environment, which is uncountable, complex, and nonlinguistic. With HCBI, we can listen to and feel the telepresence of the global ecological system, thereby integrating all living beings and their relationships, including their interaction with the biosphere, without causing environmental destruction. Therefore, HCBI can become the relationship solution to the problem of man and nature.

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Envisioning Future Playful Interactive Environments for Animals

Patricia Pons, Javier Jaen and Alejandro Catala

Abstract Play stands as one of the most natural and inherent behavior among the majority of living species, specifically humans and animals. Human play has evolved significantly over the years, and so have done the artifacts which allow us to play: from children playing tag games without any tools other than their bodies, to modern video games using haptic and wearable devices to augment the playful experience. However, this ludic revolution has not been the same for the humans' closest companions, our pets. Recently, a new discipline inside the human–computer interaction (HCI) community, called animal–computer interaction (ACI), has focused its attention on improving animals' welfare using technology. Several works in the ACI field rely on playful interfaces to mediate this digital communication between animals and humans. Until now, the development of these interfaces only comprises a single goal or activity, and its adaptation to the animals' needs requires the developers' intervention. This work analyzes the existing approaches, proposing a more generic and autonomous system aimed at addressing several aspects of animal welfare at a time: Intelligent Playful Environments for Animals. The great potential of these systems is discussed, explaining how incorporating intelligent capabilities within playful environments could allow learning from the animals' behavior and automatically adapt the game to the animals' needs and preferences. The engaging playful activities created with these systems could serve different purposes and eventually improve animals' quality of life.

Keywords Animal–computer interaction · Games · Playful · Interaction design · Ambient intelligence

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1 Introduction

The world's diversity of species is one of its most impressive characteristics. There are approximately 1.1 million of known animal species in the world,[1] each of them contributing and giving shape to the ecosystems we live in. However, as a consequence of this vast heterogeneity of animal beings, having a common way of communication between all of them becomes impossible. Even within the *Homo sapiens* species, some handicaps arise when humans with different cultures and/or languages try to communicate. Nevertheless, there exists one behavior present in the majority of animal kinds which seems to remove the communicative barriers among species, facilitating the interaction and creating strong bonds between participants: play.

Play is one of the most natural and inherent behaviors among animals.[2] In Huizinga's own words (Huizinga 1985):

> Play is older than culture, for culture, however inadequately defined, always presupposes human society, and animals have not waited for man to teach them their playing.

As Huizinga points out, animals do not need to be taught to play with each other or with humans. For them, it stands as a natural activity which may have several purposes that are not yet completely understood (Bateson and Martin 2013). In fact, one of the main aspects of play is that it is fun, and this is the main source of motivation for all sorts of animals, including humans.

This aspect, being fun, has motivated humans not only to play but to design artifacts that make the play activity even more attractive. The nature of human play has therefore evolved with technological innovations from primitive stone skipping to modern interactive electronic games. However, in this hominid evolution giving rise to what Huizinga called the *homo ludens* and some call today *homo ludens electronicus*, other species have been left behind. This is the case of animals, as animal play has not experienced yet this digital ludic revolution in the same way as human play has.

This chapter firstly describes the factors which led to the emergence of a new technological trend focused on animals as the target users of digital systems, explaining how animal play could be of great importance in this new research field. Secondly, a review of existing work on technology-mediated interaction with animals is presented, with a specific discussion of previous playful digital games for animals. Based on this review, we propose a new and more flexible way of understanding animal playfulness with digital systems: Intelligent Playful Environments for Animals. A conceptual development framework for these systems is defined, presenting an analysis of existing playful games for animals under this framework. This analysis will help to detect lacks and needs in terms of digital

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[1] http://www.catalogueoflife.org/annual-checklist/2014/.

[2] For now on in this chapter, when referring to animal beings, we are not including humans in this group, although the *Homo sapiens* species is included in the animal kingdom.

Fig. 1 Dog playing with a *Sphero*

playful interfaces for animals. Finally, application scenarios, emerging issues, and opportunities for interdisciplinary research are described for further exploration.

1.1 Animals as Target Users of Digital Systems

Since the emergence of human–computer interaction (HCI) as a discipline, the benefits that HCI applications and studies have brought to human well-being are countless. Understanding how humans interact with digital systems has allowed researchers and developers to design and build innovative and more natural interfaces, improving the user experience and lowering the gap between the virtual and the real world. More specifically, the contribution of HCI studies to the evolution of human play has been of extreme importance. HCI studies have allowed us to build digital devices which enhance our playful experiences, by making them more immersive and realistic: high-performance portable video consoles, joysticks, motion sensing devices, technology for augmented reality scenarios, etc.

In the last years, we have seen how electronic devices meant for humans have been tuned or adapted for animals to play with them. Sometimes, even animals by themselves get interested in the devices around them and start using our digital gadgets in a way we would never have imagined. In Fig. 1, a dog plays with an electronic ball, called *Sphero*.[3] This commercial device is controlled by a human, who uses a smartphone or tablet application to make the ball move while emitting light. Both the movement and lighting factors cause the animal to really get involved in a playful activity chasing and touching the electronic ball. Figure 2

[3]http://www.gosphero.com.

Fig. 2 Orangutans playing with an iPad as part of the *Apes with Apps* initiative

shows two orangutans in a zoo using an iPad application as part of the *Apps with Apes*[4] initiative. *Apps with Apes* aims to provide stimulating activities for orangutans in zoos by allowing them to play with several iPad applications. There are applications for painting, playing the piano, exploring pictures, etc. A volunteer approaches the iPad to the orangutans' cage and holds it as long as the orangutan wants to play.

Animals' interaction with our digital world is sparking our interest, as we begin to wonder whether they would be able to play with our human-centered electronic devices. However, little research has been done for developing digital systems specifically designed for animals in comparison with the efforts that have been focused on the construction of human–computer interfaces.

Recently, an emergent discipline inside the HCI community called animal–computer interaction (ACI) (Mancini 2011, 2013) has started to shape. ACI principles are based on recognizing animals as target users of digital systems and developing computing technology specifically designed for them by studying how they interact with digital interfaces. Understanding animals' behavior with computer-mediated systems will help to develop systems more suitable for them, eventually improving both humans' and non-humans' quality of life. The ACI community is aware of the ethical issues derived from conducting studies with animals, and some guidelines have been proposed in order to ensure animals' welfare at all possible means (Väätäjä and Pesonen 2013).

However, ACI studies with animals have to face an important obstacle. If animals are going to be the target users of the systems, they have to be included in the design and development process, in the same way HCI includes human

[4] http://redapes.org/multimedia/apps-for-apes/.

stakeholders in the construction of new interfaces. Generally, usability studies with humans rely on verbal or written communication for both giving instructions to the users on how to use the system and for gathering information and feedback from the users about the system being evaluated. The impossibility of verbal or written communication with animals forces ACI researchers to look for other evaluation methodologies that allow them to communicate and understand the animals' interaction with the digital system. In addition, a psychological perspective is required in future ACI studies. The inability to verbally communicate with a group of interest can lead to erroneous conclusions when conducting studies based on choices (Ritvo and Allison 2014). If a subject is presented with two options, her choice could be based on the most desired option (which would be our assumption) or on the least aversive one (which does not mean it is a good option). Careful assessment should be performed in this kind of studies.

When looking for effective ways to understand how animals interact with computer-mediated systems, ACI applications should rely on their most natural and intrinsic behavior: play. The ACI community should take advantage of the animals' natural disposition toward playing and set playfulness as the basis of any system targeted at them. The use of technology-mediated playful experiences within the ACI field will provide engaging ways of conducting usability studies with animals, as well as an effective and worldwide understood way of communication between species and play. Moreover, advances in the ACI field will lead to the improvement of the digital devices used in playful experiences. These digital devices will become more and more suitable for animals as ACI insights are applied on their development process. As a consequence, a symbiotic relationship between ACI and animal playing will be created, giving rise to the era of the *animal ludens*.

1.2 Playful Environments as Intelligent Ecosystems

Several works have already addressed the design of playful experiences for humans (Nijholt 2014), even analyzing the effects play has on human pleasure. According to Csikszentmihalyi (1975), Costello, and Edmonds (2007), the pleasures of play should be studied by considering multiple categories related to creation, exploration, discovery, difficulty, competition, danger, captivation, sensation, sympathy, simulation, fantasy, camaraderie, and subversion. However, these constituent elements of playful experiences that apply to humans may not be applicable to other species. They may need to be adapted for different types of animals or even be tailored for specific individuals or situational contexts in a transparent way.

Context awareness, adaptation, and transparency are the main building blocks of a currently growing technological approach known as ambient intelligence (AmI) (Weiser 1991; Norman 1998). The AmI research community seeks for the disappearance of computers as we already know them, providing users with seamless systems comprised of plenty of interconnected digital devices (ubiquitous computing). The communication between all these devices should be invisible to the user (transparency), and the system's main goal will be providing the users what they need taking into account their contextual situation (context awareness). The infinite range of possible contexts and user preferences prevent developers from building a specific system for each situation. Instead, the solution lies on applying some sort of *intelligence* in a way that environments can learn from people's behavior and automatically adapt themselves to the context, even anticipating people's needs. For this purpose, diverse computing areas merge their efforts to come up with a fully integrated intelligent environment: artificial intelligence for activity recognition and decision making, sensing devices for monitoring users and environmental status, HCI advances to provide easy-to-use and useful interfaces, etc. As a result, AmI advances are helping to improve human well-being without any doubt.

There are certain parallels between humans' need for intelligent systems and animals' playful revolution. Playful experiences for animals will be diverse and should be tailored to their specific characteristics and needs. Thus, developing a specific playful system for each contextual situation will not be feasible due to the extensive range of possible scenarios. Playful environments could be provided with the same kind of *intelligence* that AmI proposes for human environments. Therefore, playful environments will have multiple digital playing elements, which could communicate between them in a transparent way for both humans and animals. These environments, which we call *Intelligent Playful Environments for Animals* (*IPE4A*), would extract knowledge about the animals inhabiting them, learning from their behavior and preferences. The environment could rely on this information to evolve and auto-adapt to the situation, creating suitable playful activities for each context without having to develop a specific system for each purpose/situation.

The next section will review existing works on animals' interaction with computer systems. This review will provide the reader with the adequate background to better understand the purpose of Intelligent Playful Environments for Animals.

2 Related Works

Despite ACI being a recent research field, studies concerning animals, their cognitive capabilities, and the way they understand their surroundings have existed for a long time (Rumbaugh 1977; Rumbaugh 2013; Matsuzawa 2003; Mancini et al. 2012). This section will analyze how computer-mediated interaction with animals has evolved over the years, giving a closer overview on the recent emergence of technological playful interfaces for animals.

2.1 Computer Interfaces for Animals

In the 1970s, the *LANA Project* was one of the first attempts where computer-based interfaces were used to study the linguistic capabilities of chimpanzees (Rumbaugh et al. 1973; Rumbaugh 1977). The system consisted of a keyboard with *lexigrams*, i.e., abstract symbols representing nouns, verbs, and activities These lexigrams allowed the construction of sentences in an English-like language called *Yerkish*. Lana, in Fig. 3, was the first chimpanzee who learnt how to use the lexigram keyboard to communicate with humans. Touch screen computers and iconic keyboards have also been used in later projects with chimpanzees, such as the *Ai Project* (Matsuzawa 2003), named after the female chimpanzee that pioneered the study. This project aimed to deepen into the cognitive capabilities of chimpanzees, and results suggested that they are able to outperform humans regarding simple memory tasks. Due to the DNA similarities between chimpanzees and humans, the interaction methods used in these systems were similar to the ones conceived for humans.

Fig. 3 Chimpanzee Lana using the lexigram keyboard to request food (Image courtesy of. Dr. Duane Rumbaugh)

Fig. 4 Chicken wearing a jacket which simulates human touching sensation (Image courtesy of Dr. Adrian David Cheok)

Communication between dolphins and humans has been another area of interest. The *SpeakDolphin*[5] project uses a *Panasonic Toughbook* to introduce dolphins to the use of touch screens. Using this interaction modality, dolphins have to perform cognitive associations between real objects and pictures on the screen, selecting on the touch screen the picture of the object they are shown in real life. The next step would be adding symbols associated with actions in order to create a useful language interface.

One of the first attempts to apply HCI methodologies and user-centered design for building computer interfaces for animals is *Rover@Home* (Resner 2001). This work grounds on the idea that the communication between humans and dogs is asymmetric. Therefore, the interfaces for dogs have to differ from the interfaces for humans in order to adapt to the communicative subject in each case. A computer-based system for clicker training with dogs is presented, allowing humans to remotely train their dogs.

Wearable technology has also been used for improving remote communication between pets and their owners. This is the case of *Poultry.Internet* (Teh et al. 2006; Lee et al. 2006), which proposes a tangible interface for poultry and humans at different locations. The chicken wears a special jacket (see Fig. 4) which emulates human touching when the human touches a pet doll. Also, the movements of the chicken are monitored and notified to the human using a haptic device that the human wears on his toes. In addition, computer-mediated tactile interaction with dogs has been studied, claiming that this interaction modality could help to alleviate

[5]http://www.speakdolphin.com.

dogs' stress and anxiety (Väätäjä 2014). For the purpose of this study, dogs' behavioral problems and possible causes of stress have been analyzed. The main goal of this work is to provide a useful framework for improving the development of future wearable devices for dogs which emulate human touch.

Some studies have reported how traditional human–animal interaction is affected by the use of technology, in this case, a positioning system for hunting dogs (Paldanius et al. 2011; Weilenmann and Juhlin 2011). This system allows hunters to follow in real time the position of their hunting dogs. This additional information enriches the perspective the hunters have about the dogs' behavior. As a consequence of knowing where the dog is, hunters begin to imagine what the dog will be doing based on its movements. The relationship between the dog and the human changes, as the hunter gives instructions to the dog based on the location information he is receiving. However, the study points out the need for user-centered design when building technology for human–animal interaction, and it also advocates for ensuring animal welfare in the design process.

ACI principles have also been used to improve the task carried out by diabetes alert dogs (DAD) (Robinson et al. 2014). A DAD is a dog trained to detect changes in blood sugar levels in real time. These dogs are paired with a human suffering from diabetes and alert the human when their sugar levels decrease rapidly. However, if the human falls into a coma due to a hypoglycemic attack, the dog is unable to help him. This work proposes several dog-oriented interfaces which could allow the dog to alert emergency services if a critical situation arises (see Fig. 5). The task of cancer detection dogs can also be improved by using animal-centered interfaces such as the one described in Mancini et al. (2015). Dogs can be trained to

Fig. 5 Diabetes alert dog using a prototype of the alert device used to communicate with emergency services (Image courtesy of Dr. Clara Mancini and Charlotte Robinson)

Fig. 6 Dog using the cancer detection interface (Image courtesy of Dr. Clara Mancini)

recognize several odors from cancer cells using biological samples from the patient. When the dogs find a positive sample, they report it to their trainers by performing a specific signal convention. However, sometimes a dog's reaction to a sample is uncertain or spontaneous, and the dogs have no method to indicate the degree of certainty on ambiguous samples. This project proposes a canine-centered interface which allows the dogs to sniff normally on a plate placed over the sample, as they usually do. Using a pressure sensor, the system captures and records the pressure the dog puts on the plate containing the sample (see Fig. 6). Each kind of sample causes the dog to sniff with a specific pattern, i.e., the time spent sniffing the sample and the pressure applied on the plate. As a result, the pressure pattern extracted from the sensor allowed more natural and reliable responses from the dogs. Both the project of diabetes alert dogs and cancer detection dogs demonstrate how animal-centered interfaces can not only improve animals' interaction and well-being, but also save human lives by enhancing interspecies communication.

2.2 *Playful Experiences Within Animal–Computer Interaction*

The motivational factors which bring animals to play have been the focus of several dissertations (Bekoff and Allen 1997; Burghardt 2006). Although there is no universal answer to the reason why animals play, several works within the ACI research field believe that playful-based interactions with animals should bring better results in terms of engagement, communication, and user satisfaction (Hirskyj-Douglas and Read 2014; Pons et al. 2014).

There have been several studies where play is used as the fundamental tool to stimulate animals to participate in the activity and interact with the system voluntarily. The main goal of these studies is to improve animals' welfare by addressing different issues that can affect the animals' quality of live: sedentary lifestyle, anxiety/stress, routine and boring training exercises, etc.

Several studies have attempted to motivate physical activity among pets using playful devices which cause the animal to move and perform some physical exercise. *Feline Fun Park*[6] is one of the tangible playful interfaces which promotes pet activity. It consists of three sensors which monitor the pet's activity level. Depending on the activity level of the cat, the system has three mechanisms to motivate the animal to play at different levels of intensity: two mouse toys and tracer lights. The pet owner is also notified about the cat's activity, and he can activate remotely the different mechanisms of the system to encourage playing. However, the playful mechanisms provided are not changing with time, possibly causing that the cat loses interest and stops playing, even if the system continues triggering actions.

Pawsabilities (Mankoff et al. 2005) presents a HUI (human user interface) and a DUI (dog user interface) to reduce canine pets boredom when their owners are not at home. When the system detects that the dog is becoming bored (e.g., by lying on its bed), the HUI notifies the owners remotely so they can activate a mechanism to throw a ball for the dog to play with. On the other hand, whenever social activity is detected on the human side of the system, the DUI activates the video streaming, showing the owners' activity to entertain the dog. This system has not yet been evaluated with enough dogs in order to extract solid conclusions about its benefits to the canines.

LonelyDog@Home (Hu et al. 2007) is a Web-based interface allowing humans to interact with their dogs whenever they are away from home. Through a Web interface, humans can have a look at their pets, feed them, and engage into remote playful activities with them. This work mostly focuses on reducing owner's worries about their pets' well-being when they are left alone at home. Pet owners can connect to the system located at their home using any Web browser and communicate with their pets using an action-oriented interface such as the one shown in Fig. 7. On the dog's side, there is a ball thrower and an electronic feeder connected to the system, speakers, and a Webcam. Pet owners can issue prerecorded audio commands, throw a ball, give the dog a treat, or feed him. Although some efforts have been done on the animal's interface in order to provide suitable mechanisms for the dog to interact with the system, there are still some issues regarding the suitability of verbal interactions and visual communication. Dogs' hearing frequencies are different and more acute than ours; thus, excellent quality of the audio system is required. Regarding visual communication, *LonelyDog@Home* allows pet owners to see their dogs, but dogs are not provided with a way of communicating with their owners. Therefore, benefits on animal welfare and anxiety reduction should be further studied for this system.

[6]Feline Fun Park: https://www.youtube.com/watch?v=HB5LsSYkhCc.

Fig. 7 LonelyDog@Home graphical interface for pet owners (Image courtesy of LonelyDog@Home's authors)

Other works such as *Canine Amusement and Training* (Wingrave et al. 2010) use play as a mechanism to help both the human and the dog to spend more time together while introducing dogs into training. It offers several kinds of games focused on calmness, obedience, and joy. In each game, lights and figures are projected on the ground, and the human is required to give appropriate commands to the dog, which vary in line with the goal of the game, e.g., obedience games require the dog to remain quiet next to the human. In this way, the dog learns how to obey commands in a way that is amusing for both participants. This work allows the human to spend more time with his dog, strengthening their relationship, while providing guidance in a complex task such as dog training. The game has been designed with the assistance of a canine trainer, and the sensing infrastructure has been prototyped with dogs of different sizes.

There are some other systems designed just for the fun of playing and competing. *Cat Cat Revolution* (Noz and An 2011) is a digital game for iPad which shows an animated mouse moving across the screen. Early prototypes of the game allowed to test several combinations of brightness, size, color, and movement of the digital mouse in order to accommodate the interface to cat's visual characteristics. The iPad application combines graphical hints and sounds to incite the cat to capture the mouse. There are two playing modes: the digital mouse is moved randomly across the display or is controlled by a human. In the latter case, the human user connects its iPhone to the iPad application, and the screen on the iPad is replicated on the phone. In this way, the human can control the mouse's orientation and velocity by using his fingers. Observational findings derived from a study with 7 couples of cats and their owners showed that the humans considered the game as fun and useful to reinforce their relationships, as well as to create new forms of communication with the animal.

Metazoa Ludens Cheok et al. (2011) proposes a mixed reality game where a human and a hamster can play together. The playful interface for the hamster is a physical moldable surface which adapts its shape using mechanical actuators. The hamster can enter and exit the playground freely. The human interface consists of a virtual 3D game where two avatars are represented, one for the user and another one for the hamster. The human can move its own avatar through the virtual terrain, and these movements are transferred to a physical bait in the hamster's playground. The real movements of the hamster are also captured and imitated by the hamster's avatar in the digital game. Therefore, a chase between the hamster and the human occurs both in the digital and in the real world simultaneously.

The *Playing with Pigs* project (Alfrink et al. 2012) is an innovative interspecies game designed to strengthen relations between humans and pigs as companions. The pigs are situated in front of a large touch-sensitive display showing a light ball controlled by a human player through an iPad application. The iPad application shows the virtual replica of the light ball and the pigs' snouts when they approach the ball. The user has to keep the pigs in contact with the ball and lead them through a triangular target on the screen to score points. However, although this game may be interesting for humans, as they have a scoring scale and goals to meet, it is questionable how much time will pigs pay attention to the game or how could this benefit pigs if they are not aware of the human who is playing with them.

Felino (Westerlaken et al. 2014; Westerlaken and Gualeni 2014) is an interspecies video game designed using ACI principles. The design and development of the game is informed with the animals' experiences and observational feedback gathered from cats' human companions and annotated video-recorded sessions. The game allows a human and a cat to play together on a shared tablet screen (see Fig. 8). Cats can catch fish and other sea creatures which appear and move across the screen, while humans can control several options of the game, such as the size, speed, and movements of the creatures. Moreover, every time the cat catches a fish, a sphere is released. Those spheres can be caught by a crab avatar which is always on the screen. The crab is controlled by the human player, and by collecting spheres, new crabs appear following the older ones. Cats can also interact with the trail of crabs the human creates. Therefore, human and cat can cooperate in a shared digital world, and the human can adapt the game to the cat's reactions and preferences.

Fig. 8 Cats playing with *Felino* (Images courtesy of Michelle Westerlaken)

Although all these projects are based on playful activities, each one has been specifically designed for its own purpose. Moreover, these systems do not adapt automatically to changes, and in most cases, the activity has to be started off by a human. If the ACI community wants to take a step forward in developing natural systems for animals, intelligence, automation, and reactivity have to be present in playful environments in the future. In the same way as Ambient Intelligent systems adapt themselves to their inhabitants, by recognizing and anticipating their needs, Intelligent Playful Environments for Animals must learn animals' behavior and preferences in order to be able to react properly. A playful environment with these features could automatically create and adapt play activities to engage the animals in physical exercise, raise their mood, or train them while having fun. The next section will give a definition for future Intelligent Playful Environments for Animals, and the features these systems should include.

3 Situating Intelligent Playful Environments

This work sets the foundation for Intelligent Playful Environments for Animals starting with a definition of what they are:

An Intelligent Playful Environment for Animals, or IPE4A, is an animal-centered ecosystem with intelligent capabilities which is able to learn from the animals' behaviors and interactions, using the acquired knowledge to adapt itself to the context, creating engaging playful activities which do not necessarily need human mediation to evolve.

In order to provide a conceptual taxonomic framework for the future construction of these environments, their requirements are listed as follows:

- *Playfulness*. The environment has to consider play as the conductive engine of any activity it creates.
- *Intelligence*. The environment must be able to capture and analyze the occupants' interactions and behaviors, extracting patterns, and preferences. This knowledge will be useful for the creation and evolution of playful activities, whose purpose and dynamics will be adapted to the context.
- *Reactivity and interaction*. The system must react suitably to the animals' interactions and also provide proactive stimuli to the animals to foster communications between the system and the users (both human and non-human).
- *Animal-centered design*. Every intelligent playful environment must be designed and developed specifically for animals, with appropriate devices and interaction methods and prioritizing the animals' comfort, safety, and well-being.

There are also several features that can vary from one playful scenario to another and should be considered in the design of future IPE4As:

- *Number of participants* (*single player, n-player, and multiplayer*). The playful environment can be designed for one participant (single player), a fixed number (n-player), or it can respond to any of the participants that walk into the ecosystem (multiplayer). If more than one participant is considered, the design of the environment should include ways to handle abandoning scenarios, i.e., when one or more players leave the game or physically come out of the ecosystem.

- *Species of the participants* (*one species vs. multiple species*). Animals probably do not perceive their environment in the same way humans do (McGrath 2009). Moreover, different animal species may not have the same conceptual view of the world. As a consequence, animals from distinct species will not behave similarly given the same scenario. This affects several design decisions in the construction of interfaces and interactive systems targeted at animals: from the way in which they will be encouraged to play to the reference health values the system will use to create a physical activity. Consequently, the intelligent playful environment can be designed specifically for a single animal species, or it can be designed to recognize the animal's species and adapt itself to it.
- *Human participation* (*participant vs. non-participant*). Humans may or may not take part in the playful activity. In the former case, the system will only react to animal interaction. In the latter case, it will respond to both human and non-human actions.
- *Human presence* (*physical vs. virtual*). If humans take part in the playful experience, they can either be physically present in the environment or participate remotely. The remote participation may encompass a wide range of scenarios: from pet owners in their spare time at work, to child patients in hospitals seeking amusement and distraction.
- *Control*. The intelligent features and reasoning engine of the playful environment can learn and take decisions autonomously, i.e., without human intervention, or they can be guided by explicit human knowledge. The latter idea implies that IPE4As can provide mechanisms to allow human users to define explicit behavioral patterns the system must follow. For example, if a zoo worker wants the activity to be paused every day at midday to feed the animals and resumed after all the animals have finished, she should be able to easily program the system with such desired behavior.
- *Information acquisition*. The system inputs can be gathered by different technologies: wearable devices, sensing (motion sensors, pressure sensors, etc.), video and audio recordings, etc. In all cases, the selected capturing devices should be non-obtrusive and ensure the animals' safety and comfort.
- *Learning inputs*. Both humans and animals can coexist within the playful environment, interacting with the system and with each other. The design phase of the environment has to establish which of these interactions will serve as learning inputs for the intelligent system. It also has to be decided if only animal interactions will be included or if human inputs will also be considered. In some cases, human interactions with their pets could provide very valuable information to the learning system. As an example, pets are not able to verbally communicate when they are bored, but their owners can recognize their mood and start playing with them. The system could therefore learn which activity raises the pet's mood by looking at the owners interactions with the animal.

Table 1 List of requirements and features of intelligent playful environments

Requirements	Features
Playfulness	Number of participants
Intelligence	Species of the participants
Reactivity and interaction	Human participation
Animal-centered design	Human presence
	Control
	Information acquisition
	Learning inputs
	Sense-guided stimuli
	Single-purpose versus multipurpose activities

- *Sense-guided stimuli*. Since distinct species may behave differently in the same context, their preferences and motivations may also differ. Some species might therefore feel more attracted by visual stimuli such as lights or mobile mechanisms (e.g., cats), while others would respond more eagerly to olfactory clues (e.g., dogs). In order to use the proper actuators and devices to capture the animal's attention, IPE4As should rely on the most suitable stimuli for each animal species in a given context.
- *Single-purpose versus multipurpose activities*. Playful activities created by the environment can be focused on solving just one issue of animal well-being, e.g., a game which only fosters physical activity. On the other hand, more complete activities covering several issues can also be created, e.g., a game which includes a training element at the same time as physical activity is being monitored and fostered by the system.

Table 1 summarizes the list of requirements and features presented above in order to clarify the concepts and provide a schematic view for future references.

4 Situating Current Playful Environments for Animals

The design and development of future intelligent playful environments comprises many factors that should be analyzed and informed by the existing digital games involving animals. Table 2 shows a classification of the existing digital playful experiences for animals described in Sect. 2 in terms of the game features outlined in Sect. 3. The next subsections will open the discussion about where should intelligent playful environments put their efforts to improve current lacks in playful scenarios and how could ACI research inform the design of future intelligent systems for animals.

Table 2 Analysis of existing playful games for animals under the proposed framework

Work	Number of participants	Species of the participants	Human participation	Human presence	Control	Information acquisition	Learning inputs	Sense-guided stimuli	Purpose
Pawsabilities	Two	Dog Human	Yes	No	Human System	Camera pressure sensors	N/A	Visual (movement)	Avoid boredom
LonelyDog @Home	Two	Dog Human	Yes	No	Human	Dog: camera Human: web-based interface	N/A	Audition	Avoid loneliness
Canine Amusement and Training	Two	Dog Human	Yes	Yes	Human	Sensors on the dog (breathing, position, etc.)	N/A	Visual (colors) Audition	Training Fun
CatCatRevolution	Two	Cat Human	Optional	Yes	Human System	Direct touch of the device screen	N/A	Visual (movement) Audition	Fun
MetazoaLudens	Two	Hamster Human	Yes	Optional	Human Animal	Hamster: movement detection Human: keyboard and mouse	N/A	Visual (movement)	Fun
Pig Chase	Two	Pig Human	Yes	Optional	Human Animal	Pig: direct touch of the interactive surface Human: direct touch of the tablet	N/A	Visual (movement, colors)	Fun
Feline Fun Park	One	Cat	No	No	Human System	Sensors (weight, light, movement)	N/A	Visual (movement, lights)	Fun Physical activity
Felino	Two	Cat Human	Optional	Yes	Human System	Direct touch of the device screen	N/A	Visual (movement, colors, size)	Fun

4.1 Game Participants: Static or Dynamic Approach?

Human participation is considered important if we want to strengthen the relationship between humans and other species. Nevertheless, some works have left open the possibility of the human joining the game, allowing the animal to participate alone if the human is not available. This should be an important requirement if the animal is going to spend considerable time alone or separated from the human.

In games requiring human participation, two tendencies have been detected. The philosophy behind games such as *Pawsabilities* and *LonelyDog@Home* only makes sense when the human is distant from the animal, and thus, remote communication is the only way of human interaction with the system. Other works such as *MetazoaLudens* or *Pig Chase* can take place either with humans physically present in the same environment or with them remotely interacting with the interface provided. In order to reach a higher degree of flexibility, we propose that intelligent playful environments support both animals playing alone and together with their human companions, the latter case with its two modalities: remote or in-person participation. The environment should adapt the game to the context of the moment, allowing the human entering and exiting the game at any time without causing frustration to the animal. For example, if a human is playing with her dog but suddenly a phone call interferes, the human should be able to answer the phone without causing the game to terminate. The game should be adapted to continue without the human player, and if eventually the human wants to get back into the game, the system should create the appropriate game flow in order to incorporate the human back into the playful activity.

The same argumentation can be applied to animal participants. The feature *number of participants* in Table 2 indicates the number of players the game was originally designed for. As an example, it is understood that several cats could be playing simultaneously to chase a mouse on the screen of *CatCatRevolution*. However, the system does not distinguish between the touch of different cats on the same screen, and thus, to the system's knowledge, there is only one cat playing at a time. It can be seen that only games for one or two players have been designed, and two player games always include a human participant. A more dynamic approach should be provided in future intelligent gaming environments, where several animals and/or humans could participate. The participation of an animal/human in the game implies that the system recognizes him as a new and differentiated user from the other participants of the same species. Therefore, both animals and humans should be able to enter and leave the game whenever they need to. Neither the human nor the animal should become deprived for their decisions about participating or not in the game. The game should be adapted to the number of current participants, starting when the first participant comes in and terminating when the last participant abandons the game.

Until now, humans are the agents mediating the interaction between animals and computing interfaces. From the eight games being analyzed, six of them require the human to start the playful activity. Only two of them can autonomously perform some interaction to attract the animals' attention, and both of them monitor the animals' activity level in order to notify the human in case they want to intervene. It is essential for the future development of intelligent playful environments that the system itself could decide to initiate or terminate a playful experience. Firstly, if the system detects some need on the animals and there are no humans around, the environment should be able to start the playful interaction in the same way a human would do when detecting some animal's urge. Secondly, some animals may want to play the whole day, but it might be inadequate because of health and behavioral reasons. The system should be able to end the playful activity when it detects that the purpose of the activity has been met. In this context, there are several questions that need to be previously addressed:

- How can the animal be aware that the system wants to initiate the interaction?
- How can the system involve voluntarily the animal into the playful activity?
- How can the system itself communicate or attract the animal in order to start a playful experience?
- How to end the playful activity without negatively affecting the animal?
- How to make the animal understand that the playful activity has ended?

Another important issue that has not been addressed yet is the possibility of the animals initiating the playful experience. How can we build successful playful experiences for animals if we do not allow the animal to start playing freely at their own will? Several questions arise around these ideas, and further studies within the ACI field should bring new insights on how to provide the best suitable way to let the animals decide when to play:

- How can animals initially learn that the system will respond to their actions by starting a playful experience?
- Which mechanisms/behaviors will animals use to start the interaction with the system? Will they use the same behaviors they use to communicate playful intentions with humans/other animals?
- How can the animal withdraw from the playful experience?
- How can the system recognize that the animal wants to stop playing in order to stop all the interaction?
- Could the system analyze the factors which lead to the end of the activity and use this information to improve the next playful experience, by making it more appealing and time lasting?

4.2 Adapting Computer Interfaces to a Broader Audience: Species Awareness and Interrelationships

Regarding the species of the animals' participants, it is observed that most of the games have been designed for dogs or cats, while only one game has been developed for small pets such as hamsters. It is remarkable that only one of these games has considered animals outside the pets' domain as active players, which gives an idea of what kind of users ACI research is currently addressing. Perhaps pet companions are the first animals coming to our minds when we think about the animal kingdom, but we shall not forget to address other animal species that may also require playful environments. Wild animals could also benefit from ACI advances: if computer-mediated interaction can help us to communicate with wild species by means of play, our knowledge about them will improve significantly. Moreover, semi-wild species such as animals living in zoos could also benefit from playful interactive environments, as it will be described in Sect. 5.

Another issue to be solved is that current digital games for animals only address one animal species at a time. Interspecies relationships between animals, although frequent in natural environments, are not supported by current playful interfaces. An Intelligent Playful Environment for Animals should support this variability and foster interspecies relationships, creating suitable games for different animal species playing together. This is a challenging requirement, as different species understand their surroundings in a different way and react differently in front of the same situation. The design of this kind of games should be informed by previously studying the relationships and playful dynamics of the involved species. Nonetheless, there might exist some cases where the playful interaction cannot be performed due to several reasons: physiological incompatibility of the animals, opposed behavioral reactions, etc.

Despite the difficulties introduced by species variability, ACI studies should take advantage of these differences when it comes to perception and motivational factors. Existing playful games have already tried to appeal to the animals' sensing acuity, capturing their attention with visual clues such as moving objects, audio commands, or sounds. However, it remains to be studied the effects of different types of stimuli in the animals' attention regarding its species, in order to give a detailed classification which could inform the development of future engaging playful scenarios. Some questions to be addressed are as follows:

- Which is the most appropriate mechanism to start the interaction with the playful environment for a specific animal species? How can this mechanism vary among species?
- Which stimuli are more adequate for each animal species in order to capture and maintain the animal's attention during the game?
- How can animals be motivated to perform some specific activities/tasks during the game? How are these motivational factors influenced by the animal's species?

4.3 Broadening the Horizon: More Devices, More Fun!

The reported games rely on a single electronic device to interact with the animal. Only *Feline Fun Park* and *LonelyDog@Home* introduce more than one device to entertain the animal, but still there is no communication between the different devices being used, nor a coherent relation between them. Animals playing with the same device over and over again are likely to become bored or lose interest when the novelty factor vanishes. The same could happen eventually with several unrelated devices in the same environment.

An intelligent playful environment should be comprised of not only several and diverse devices, but also interconnected and meaningful. The devices conforming the intelligent environment should be able to cooperate and communicate with the system and the other devices, in order to create elaborated activities which can vary from one iteration to the next one. As an illustrative example, we could think of an intelligent playful environment including several electronically controlled balls, a flying drone with a camera, and an electronic pet feeder. The goal of the interactive game would be to teach sheepdogs to bring the flock to their masters and learn commands that are commonly used in this task. In this case, the electronic balls would represent the flock and would move according to the behavior that needs to be taught. A sound system would reproduce voice commands, and the drone with a mounted camera would track the behavior of the sheepdog by using computer vision algorithms. If the dog would not act as previously trained, the system would notify this situation so that further training would be later performed with the presence of a human master. However, if the sheepdog reacted as expected, a reward would be given by the automated feed machine. Having several interactive balls would allow the simulation of different real situations that may occur with real flock that needs to be kept under control. The flying drone would also control the position of the electronic running balls so that they move in a challenging way depending on the capabilities of the dog being trained. The coordination of several devices in this scenario would allow the autonomous training of sheepdogs when master trainers may not be present.

The final goal/s of the activity will help to identify which kind of devices would make sense together. The system should learn how to better connect and join together the different individual devices, and how to evolve the game when required.

4.4 Decision Making and Adaptation: Who Controls the Controllers?

Although some of the aforementioned games allow the human user to modify several options such as movement direction of the objects, releasing treats, etc., these are just straightforward ad hoc configurations. When the human does not intervene, the system can run the game with the default configuration without any major concern. However, having multiple interconnected devices will significantly increase the configuration possibilities, and the human user will not always be participating in the playful experience to control or guide the decisions of the game. As a consequence, the system should intelligently manage the resources and take control of the decisions, adapting the game to the context and the current players, such as in the sheepdog example in Sect. 4.3, where the electronic balls adapt their movement to the command to be practiced.

Context awareness and adaptation should be performed in the same way as AmI scenarios adapt themselves to human users: by extracting knowledge from the users' interactions with the system. None of the presented games in Table 2 apply any type of reinforcement learning from the inputs of the system. The construction of future intelligent playful environments should consider these interactions as essential inputs for the learning subsystem.

Nevertheless, not all the responsibility of the game creation should rely on the learning capabilities of the system. There are many situations where the system may not have the best information to take a decision. Moreover, not all the possible scenarios can be controlled or anticipated. Specially, external knowledge from the human users could be essential in the first attempts of the environment to create a new game, when the learning algorithm still has no information. Hence, human users should also be provided with an adequate way of participating in the decisions beside the need for learning algorithms to implement context awareness in playful environments. Human users without programming experience should be able to manage the environment and define the explicit behavior to inform ambiguous decisions, or specify particular scenarios. HCI techniques and studies have already been applied in order to come up with easy-to-use and useful interfaces to allow the definition of explicit behavior by end users (García-Herranz et al. 2010; Maternaghan and Turner 2011; Catalá et al. 2013). The same philosophy could be applied to bring intelligent playful environments with explicit knowledge from the human participants.

5 Application Scenarios for IPE4A

Considering the described requirements and features that Intelligent Playful Environments for Animals should accomplish, and after studying the lacks and limitations of existing approaches, the scenarios in which these systems can be deployed have been analyzed and the benefits they can provide in different domains are presented here.

5.1 *Mental Well-Being*

Not only humans but also animals need to socialize. However, domestic pets spend most of their day alone at home without interacting with their human friends. Even when the human is at home, they may not receive all the affection they need. Similarly, zoo animals live inside a restricted ecosystem, sometimes being the only one of their kind and without being able to interact with humans on the other side of the glass in any way. Another risk group are animals living in shelters (Mancini and Linden 2014), where volunteers are unable to give all the animals the attention they require due to lack of resources and people. All these animals can suffer from isolation, sadness, and anxiety (Schwartz 2002, 2003; Amat et al. 2014), far from achieving a fully happy existence. An intelligent playful environment could detect whether an animal is becoming bored or stressed, and study the best way and best moment to create fun activities to stimulate and entertain him and keep his mind active. For this purpose, the intelligent environment should have previously learned the animal's favorite games and interactions and the most effective sense clues to gain his attention. However, these kind of playful activities, the moment when they are conducted and the consequences on the animal's well-being, should be studied in depth in order to avoid behavioral problems or causing stress.

5.2 Physical Activity

Another crucial element to enhance animal well-being is physical activity, which has to be stimulated in cases such as the ones described above when the animals do not receive all the required attention for long periods of time. When an animal does not receive any external stimuli or is feeling depressed, it would not feel like initiating physical exercise. In this case, the environment could capture the animal's attention and engage it in playful activities to make it move and perform some physical exercise. The system could adapt the exercise to the animal's physical attributes and habits in order to create a healthy and amusing routine. Other variables to be taken into consideration should be the frequency, duration, and time when the activity should take place. The potential improvements the environment could bring on animals' welfare should be studied considering the aforementioned factors in Sect. 3.

5.3 Training

Playful environments can also be an enjoyable way of fostering training activities without overloading the animal with strict orders. Tough training and repetitive activities can cause loss of attention and refusal to participate. By transforming the learning activity into a game, it would not be presented as a mandatory and strict activity, and animals might be more inclined to participate. Using playful activities for training could also alleviate the animals' stress and sense of responsibility derived from such a demanding task.

The design of intelligent playful environments for training scenarios should be carried out with the guidance of a professional trainer. Intelligent environments for animals should allow playful training with or without the presence of a human. In case of pet owners, not skilled in training activities, the environment could help them to perform successful practices. The owner's participation in the activity could also reinforce his bonds with the animal. However, some animals will not have the opportunity to be trained by playing with a human, such as in shelters where few volunteers have to attend hundreds of animals. The environment should then be responsible of teaching new behaviors to the animals, adapting the training to their learning pace and motivation.

5.4 Therapy

Animals can help in the rehabilitation of people recovering from illnesses or disabilities (Filan and Llewellyn-Jones 2006; Kamioka et al. 2014). Interactions with animals can reduce patients' anxiety (Barker and Dawson 1998) or help children with autism in socializing tasks (Solomon 2010). In the digital era where we live, some rehabilitation tasks rely on computer-based technology (Leo and Tan 2010). Understanding animals' interactions with computer-based systems could help to introduce animals within these therapeutic activities, e.g., incorporating animals in the context of rehabilitation tasks for people with disabilities such as brain acquired injuries, or creating playful health oriented activities with animals for elder people.

In situations where the animal cannot be physically present with the subject, the playful environment could serve as a bridge to bring the patients closer to the animals. Patients could remotely interact with the system via a human–computer interface, by activating devices in the environment or responding to the animals' interactions. As a consequence, some sort of non-verbal communication could emerge between humans and physically distant animals, originating an enriching experience for both sides.

6 Challenges and Considerations

Developing intelligent systems capable of adapting themselves to the context requires ensuring several safety aspects. The system should not harm the environment nor the users in any possible way. This is of special relevance when users cannot be taught how to use the system, and thus, free interactions and behaviors are allowed. *Therefore, the system should respond to the predefined interactions only. Unexpected behavior must not trigger any reaction of the system.*

As has been previously defined, playful systems could allow the animals to play without human supervision. It implies that the animals could be the ones who decide when to start the game, or end it. However, animals may not be conscious about the emotional or physical effort the activity is demanding from them. For example, if a dog is playing a throw-and-catch ball game, which they usually love, it will not stop demanding another round unless it gets exhausted. This physical fatigue may eventually become dangerous if it happens repeatedly. *The system* *should control the animals' physical activity in order to avoid exceeding the limits of what a healthy exercise should be*.

Another potential pitfall when allowing the animals to play without human supervision is the material damages that they can unintentionally cause in their environment. The game should be conducted within a safe area where physical objects, such as furniture or electrical amenities, do not interfere in the activity. Otherwise, the animals may collide with these elements, injuring themselves or damaging them. *For these reasons, the system or the human should define the physical boundaries of the playing area. The devices involved in the game should be placed within this area, and their operational range, i.e., the area where the animals will interact with the device, will not surpass the defined limits. Potential dangerous objects for the animal should not be placed within this area. Moreover, fragile or valuable objects shall not be placed either in the playing area in order to avoid unwanted consequences*.

When addressing animal safety, we are not only considering physical welfare: mental well-being should also be guaranteed. Even if the game does not demand hard physical exercise, the animal could get extremely excited because of the joy it is experiencing. Enjoying the playful activity is essential, but the excitement levels should not exceed the limits of what is salutary. Expending long periods of time under these conditions, inadequate playing schedule (such as allowing play when the animal should be sleeping), or even an abrupt termination of the game by the system could led to stress, anxiety, and/or overexcitement. Humans are able to handle these undesired feelings, calming themselves down and returning to a more peaceful state. However, animals may not manifest the same kind of self-control over their emotions and the physical response these emotions trigger. *In order to avoid unhealthy mental feelings, the emotional states of the animal should be gathered. The playful environment should detect whether the animal is entering into an undesired emotional state, readapting the activity to take the animal back to a more relaxed situation. Moreover, some limitations should be defined on the schedule and duration of the playful activity, either by the humans or by the system. It will help to create a healthy routine, avoiding bad behaviors derived from inadequate schedules.*

The potential of emotion identification is only comparable to the difficulty of conducting such a complex task. Identifying emotional states is a challenging requirement for any kind of system, although there are some successful results concerning human emotion (Picard 1997; Mocholí et al. 2007). Within the animal domain, the physical evidences of an emotional state may differ from one species to another. Nevertheless, for each species, there might be some physical parameters which could help to identify their emotions. We could classify these parameters into two different categories: observable and measurable. Examples of observable parameters are ear position, body posture, or tail movement. The aggressive emotional state of cats is easily identifiable using observable parameters: ears back, open mouth showing teeth, and bended body. Regarding measurable parameters, we could refer to the heart rate or the number of times per minute an animal waves its tail. Excitement, for example, is an emotional state which could be better identified using measurable parameters. However, gathering measurable parameters imply the animal has to wear specific devices, which could be obtrusive and interfere with its normal life. In contrast, observable parameters will require using cameras and sophisticated image recognition methods, which could restrict human privacy in shared environments. *The identification of emotional or mental states in animals and its use in the adaptation of the playful environment should be carefully studied for each case, analyzing the benefits and trade-offs its deployment could lead to.*

The intelligent playful environment must, in all cases, be unobtrusive both for the animals' and humans' lifestyles. The animals' natural behavior must not be biased nor interfered by the devices which form the environment and the mechanisms used to gather information about them. Domestic animals are more used to face new objects and even digital elements in their daily routines. However, wild animals live in natural ecosystems, being unaware of the existence of any digital elements. Similarly, semi-wild animals use to live in either delimitated areas, like farms, or in artificial spaces which reproduce their real ecosystems, like zoos. Semi-wild animals may be used to human presence or even cameras, but the interaction between them and the digital world is limited, if not inexistent. *If any technology is intended to be used within these environmental conditions, the animal must not perceive it as a potential danger. One way could be introducing the different elements conforming the playful environment gradually, i.e., one at a time and introducing the next element once the animal has become used to the previous one.*

7 Conclusions and Future Work

This work proposes a new line of research in the recently emerged field of ACI: Intelligent Playful Environments for Animals. These environments will ground on the most inherent behavior of animals: play. Around playfulness, an intelligent environment will generate engaging games for animals. The environment will learn from the animals' interactions, adjusting the game to their needs and requirements. The playful activities created by these environments could help animals to overcome possible issues such as isolation, poor physical condition, repetitive training exercises, or remote digital interaction with human beings. Moreover, we believe that Intelligent Playful Environments for Animals would be the perfect scenario in which to study animals' interactions with digital devices, as the animals will engage voluntarily in the playful experience. The benefits derived from IPE4A could apply both to human and animals' well-being.

A conceptual taxonomic framework has been laid down for the future design and development of these environments. Existing games based on technology for animals have been analyzed in terms of the proposed framework, detecting some shortcomings that intelligent playful environments could help to resolve. Several applications have been outlined, highlighting the benefits of applying intelligent playfulness to animals' interactions with digital ecosystems.

Future work essential for the successful construction of IPE4As includes the definition of a formal development methodology covering the aforementioned features and requirements. Each of these features should be carefully studied in order to determine how they will affect the construction of the environment and the users' well-being, and whether they should eventually be taken into consideration in the development process regarding the specific circumstances.

The first step for the design of intelligent playful environments should be studying the most fundamental game phases, which will be common in a range of playful experiences that could be created. Considering the playful activity as a story/performance in which the actors will be the animals, the most basic and common phases in which we can decompose such stories will be the introduction, development, and conclusion. Therefore, the most fundamental interactions within an intelligent playful environment will be the initiation of the activity (introduction), the transition from one stage/goal to another (development), and the termination of the game (conclusion). A set of experiments is being designed to study these three game phases that every playful experience contains. These experiments aim to answer some of the questions raised in Sect. 4.1: how could the environment gain the animals' attention and whether animals would be willing to initiate the playful interaction. These experiments will also study how different types of stimuli affect the animals' engagement in each of the three aforementioned game phases. For this purpose, we will evaluate the animals' reaction to smell, sounds, lights, and moving devices in order to find the most suitable interaction for each context.

In addition, we are defining in our ongoing work a flexible intelligent behavior management system for reactive environments. It will learn from the users' habits and preferences, extracting behavioral rules. The human end users of the system will also be able to define their own personal behavioral rules and incorporate them into the environment. The behavior management system will therefore combine two ways to incorporate behavior based on automatically acquired knowledge and explicit knowledge specified by humans. This powerful combination will allow the development of playful environments able to adjust to a wide range of situations more effectively, without having to develop a specific system for each scenario.

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Playful and Gameful Design for the Internet of Things

Paul Coulton

Abstract The emerging vision of an Internet of things (IoT) as a global infrastructure of networked physical objects is undoubtedly compelling across a range of potential application areas. While the vast majority of implementations thus far have presented IoT objects in a passive sensing role, or used them to provide some form of remote access/control, there are considerable opportunities for the creation of novel playful or gameful experiences. In particular, the creation of hybrid physical/digital IoT objects presents designers with a number of interesting opportunities as they can (i) blur the boundaries between physical objects and virtual worlds; and (ii) they provide opportunities for embodied physical play outside a virtual environment. However, in order to maximize these opportunities, designers need to develop new approaches to their interaction design that combine understandings from both product design and computer interface design. In this chapter, I consider the nature of IoT objects and how the digital and physical affordances of such objects can be combined using examples of a number of gameful and playful IoT systems.

Keywords Design theory · Playful design · Gameful design · Phygital design · Internet of things

1 Introduction

Although there is some discussion on how the term Internet of things (IoT) originated, it has become synonymous with the anticipated shift of society as we move toward a ubiquitous form of computing where every device is connected in some way to the Internet (Greenfield 2006). While a clear consensus has yet to be

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emerge about how best to realize the IoT, a global infrastructure of networked physical objects (Kortuem et al. 2010) or things that are readable, recognizable, locatable, addressable, and/or controllable via the Internet (NIC 2008) is undoubtedly compelling for a range of applications such as wearables, connected homes, connected cars, connected cities, health care, and industrial control. Thus far many of the implementations of IoT have emerged as part of ‘Smart Cities’ (Greenfield and Kim 2013) research and have often presented the objects in a largely ambient sensing role, or as some form of remote access or remote control. However, undoubtedly the most successful implementation of IoT yet seen is the Activision game Skylanders[1]: Spyro’s adventure, along with its subsequent revisions of swap force and trap force, which places the physical game objects (the things) at the center of the activity by using them to control the characters and activities within for digital game running on a console (Coulton 2012) or tablet.

Skylanders is a role playing game (RPG) in which the characters are actually radio frequency identification (RFID)/near-field communications (NFC)-enabled physical game objects, as shown in Fig. 1, that are used to swap characters in and out of the virtual game, or enable certain abilities or locations within the game, using the ‘portal’ (RFID/NFC reader which connects to the console/tablet via USB or Bluetooth) (Coulton 2012). One of the other unique aspects of the game pieces is that a characters type, name, and abilities are modified through game play and stored on the physical game piece rather than on the console. This focuses on the thing produces a number of very interesting effects such as blurring the boundary between toys and games, expanding existing modes of game play to the physical world, providing the opportunity for physical play outside the game, creation of innovative interfaces that combine the real and the virtual, and a business model around the sale of the physical things alongside the virtual game (Coulton et al. 2014).

In the wake of Skylanders, other game publishers have created similar systems most notably Disney Infinity[2] and Nintendo Amiibo[3] both offer NFC collectable figurines synchronized to game play using an NFC-enabled base or controller. The notable difference with Disney Infinity is that they have added a ‘sandbox’ mode within the video game which may offer the opportunity for more free-form play to emerge. While Skylanders, Disney Infinity, and Amiibo are arguably the most notable examples of IoT in terms of games, there are also a number of ‘app toys’ appearing such as LEGOs Life of George,[4] Disney’s App Mates,[5] and the YetYet from Totoya Creatures.[6] However, despite all these notable examples, toys and

[1]www.skylanders.com.

[2]www.infinity.disney.com

[3]www.nintendo.com/amiibo.

[4]www.george.lego.com

[5]www.appmatestoys.com.

[6]www.totoyacreatures.com.

Fig. 1 Skylander toy and portal

games are two developer communities that have largely operated independently although this novel interplay between toys and games facilitated by IoT could bring them together to produce new and mutually beneficial opportunities in terms of both games (Coulton et al. 2014) and new economic models (Ng 2012). While research is starting to emerge to describe the hybrid games/play that these objects facilitate (Kultima et al. 2013) in this chapter, I am primarily concerned with the factors which designers/researchers of playful and gameful systems must consider in relation to the interaction modalities available through these objects. However, before considering the design of such systems, it is important to consider the nature of IoT objects compared with other products and the options for connectivity to the Internet which are integral to a successful design.

2 Types of Thing

As yet there is no accepted way of classifying IoT objects and in order to help contextualize them alongside objects more generally, I draw upon the work of science fiction writer Bruce Sterling in his nonfiction book Shaping Things who characterized classes of objects into their varying human–object relationships (Sterling et al. 2005) as:

- ***Artifact***: Artificial objects, made by hand, used by hand, and powered by muscle.
- ***Machine***: Complex artifacts with integral moving parts with a non-human/non-animal power source.
- ***Product***: Non-artisanal uniformly mass produced artifacts supported by large transport, finance, and information infrastructures.
- ***Gizmo***: User alterable and programmable multi-functional objects commonly linked to network service providers.
- ***Spime***: Networked objects with extensive and rich informational support that are designed on screens, fabricated on screens, and tracked in space and time throughout their lifespan.
- ***Biot***: Is an entity that is both object and person that provides data to the network.

It is the vision of objects as Spimes that IoT has been most closely associated (Bleeker 2006). Sterling defines the dawn of the Spime in relation to the United States Department of Defense decision to require all of its suppliers to fit RFID tags to all military supplies (Sterling et al. 2005). This decision, which has ultimately spread to the operation of commercial inventory systems, means that objects can be tracked through space and time, and with the majority of such objects being designed and fabricated digitally, our potential knowledge of such objects can go from cradle to grave. This view is particularly attractive for those striving to produce more sustainable products as Sterling also describes them as 'enhanceable, uniquely identifiable, and made from substances that can and will be folded back into the production of future Spimes' (Sterling et al. 2005). Given the advances in 3D printing, open-source operating systems, open hardware, and improved connectivity designers and researchers are now in a position to create such objects without requiring access to elaborate manufacturing facilities.

The notion of the Biot is effectively emerging through both the quantified self-movement and personal health care monitoring (Swan 2012) and as such we are arguably all becoming part of the Internet. While this may not immediately seem applicable to designing gameful and playful interactions, it is worth considering Biots in the context with exergaming (Garcia Wylie and Coulton 2008) and green exercise (Rashid et al. 2008) which are gaining popularity with the rise of obesity in many societies.

In essence, Sterling's classification provides us with a useful framing for the new human–object relationships that are emerging and they should not be treated as a set of rules to be used to rank IoT systems in relation to some perceived quality about what may or may not make a 'good' IoT object design, but rather as aids to help designers reflect on the nature of the objects they are trying to design. Overall, these characterizations are perhaps representative of the broader notion that we should in the near future no longer be considering the Internet as a space we visit but rather as the place we live in.

3 Connecting Things

When designing IoT systems, it is important to understand that there is no one particular configuration that such a system may take and the reality is that the IoT will offer infinite range of connection potentiality within an amorphous sprawling network of heterogeneous objects (Speed 2010). The current reality of the IoT, and in particular some of the IoT objects available in the market, is that they are not developed in such a way where they can be easily combined. Apart from the obvious differences in the wireless communications technologies (i.e., Bluetooth LE, WiFi, ZigBee) utilized, these IoT devices also employ range of architectures designed to support the development of services utilizing these devices such as:

- ***Web Server Device***: These are devices that incorporate a server within their architecture allowing them to be easily controlled by a Web browser. This configuration is now more commonly used for home hubs; for example, the Microsoft HomeOS.
- ***Virtual Cloud Device***: These devices generally have in-built firmware that communicates with a defined cloud server. An example would be the ill-fated Little Printer from Berg.
- ***Peer-to-Peer Device***: Such devices allow direct communication from device to device and are exemplified by the range of products designed to work with smartphones such as the Sphero Robot Ball.

It is worth noting that there are other configurations that blend these characteristics but the main point here is to highlight the current challenge when developing systems capable of supporting multiple objects simultaneously.

4 Designing Interactions with Things

As this chapter is concerned with gameful and playful interactions, I am primarily addressing the design IoT objects that can be regarded as a form of tangible user interface (TUI). TUIs can be defined as providing a physical form of digital information and facilitates the direct manipulation of the associated bits (Ishii 2008). However, in the context of games, such as Skylanders, where the game pieces reside both in physical space and within the game space on a screen, they could also be considered a form of augmented virtuality (AV) (Coulton et al. 2014) as defined on Drasic and Milgram's virtuality continuum (Drascic and Milgram 1996) as shown in Fig. 2.

AV represents a specific point on the continuum that describes physical objects that are dynamically integrated into, and can interact with, the virtual world in real time (Drascic and Milgram 1996). Although it is not wholly compliant with Drascic and Milgram's original definition, which was primarily concerned with the mixing of visual images of the real object within the virtual world on a display (Drascic and

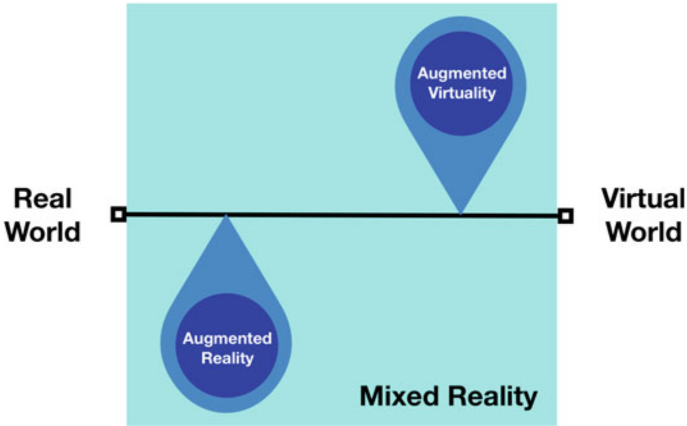

Fig. 2 Virtuality continuum

Milgram 1996), the physical location of the object on the screen presents a comparable interaction. Additionally, many of the desired features for TUI design are applicable to AV (Kato et al. 2000), in particular:

- The form of objects should encourage and support spatial manipulation (Kato et al. 2000);
- Object affordances should match the physical constraints of the object to the requirements of the task (Kato et al. 2000).

The affordances of an object help users construct coherent mental models from which new tasks and uses can be inferred. The users' knowledge is built on affordances and relate to interactions performed by the users in multiple scenarios using objects and systems that provide similar interactions (Verplank 2009). Thus, the interaction design of IoT objects requires designers to understand the affordances of both the real and the virtual aspects to ensure they do not cause confusion to the user. This understanding goes beyond the notion of the physical icon (phicon) introduced by Ishii and Ullmer (1997), as they are not simply attempting to represent digital functionality in a physical form. It is therefore important to consider the concept of affordance in more detail and in the following paragraphs I will present such a discussion.

The original concept of affordance was conceived by Gibson (1977) to define the actionable properties between the world and a person, and he highlighted the example of a flat surface that affords 'sitting on,' whereas a 'pointy' one would not. The important aspect of Gibson's definition was that the affordance of object exists whether it is acted upon or not. The concept of affordances was most notably developed for design by Donald Norman who extended from what he regarded as Gibsons real affordances to include perceived affordances (Norman 2002) arguing that affordances 'play very different roles in physical products than they do in the world of screen-based products' (Norman 1999) and unlike Gibson he considered affordances could be dependent on the cultural experience of users for example, in Japan you would expect to read comics right to left and front to back. Norman also used this to distinguish between the properties of an object that are controllable by the designer and those that are fixed. In the case of the design of real objects, both the actual and the perceived affordances are controllable, whereas for screen-based interaction generally only the perceived affordances are under the direct control of the designer, 'as the computer system comes with built-in physical affordances' (Norman 1999). For example, all phone or tablet screens support the affordance of touch whether they are touch sensitive or not. If we add a graphical target (e.g., a button) on a touch-sensitive screen, we are providing visual cue that advertises the affordance that touch interaction is supported, which creates the perceived affordance within the user. Bill Gaver clarified the importance of this stating, 'affordances exist whether or not they are perceived, but it is because they are inherently about important properties that they "need" to be perceived' (Gaver 1991). Gaver also introduced with the concept of sequential affordances to highlight that a user action on a perceptible affordance often leads them to information indicating new affordances which is particularly applicable for games as the range of interactions is often extended as the player progresses through the game. Gaver presented his consideration of the interplay between affordance and perception (Gaver 1991) as shown in Fig. 3.

This diagram implies that a false affordance exists when there is no action possibility but the perceptual information implies that there is, although, McGrenere and Hon would argue that it is not that the affordance is incorrect but rather the perceptual information (McGrenere and Hon 2000). A hidden affordance exists when the affordance is present but the specifying perceptual information is not. Dan Saffer suggests hidden affordances may actually be created deliberately as part of the design process and could therefore be regarded as 'discoverable' (Saffer 2013)

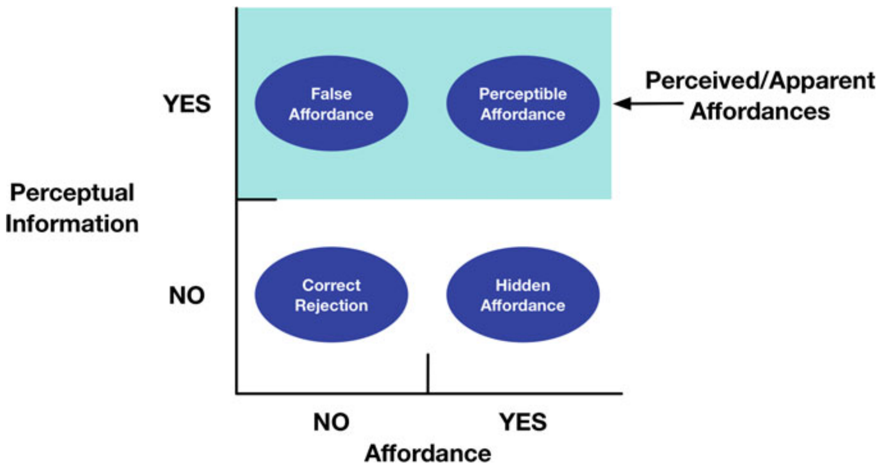

Fig. 3 Affordance relative to perceptual information

in recognition that designers may deliberately allow them to be revealed through accidental use or deliberate exploration. This is similar to the practice of game designers leaving hidden elements, or 'Easter eggs,' within their games that are discovered by accident; this practice hints at a possible interesting opportunity yet to be applied to IoT game objects (Coulton et al. 2014).

In addition to affordances, Norman also described 'cultural conventions' (Norman 2002) which derive from users' conventional interpretations of how they should interact with a particular object. Norman subdivided these constraints into physical, logical, and cultural. Physical constraints are related to the artifact, logical constraints are when users make judgments to deduce the nature of the interaction, and cultural constraints are conventions shared by a cultural group. This highlights the role of context within interaction design and for IoT object design and particularly the space within which the interaction occurs.

5 A Space for Things

Before we consider specific examples of playful IoT systems, I will consider how the space within which the interaction occurs changes the nature of the resulting experience. Although we are not specifically concerned with games, a useful framing for this topic is provided by Juul in his book The Casual Revolution (Juul 2009) when he divided game space into the following: player space, screen space, and 3D space in order to highlight that in many casual games, such as those using a Wii Sports, the player space plays a much more significant role than many more traditional console games (Juul 2009). This division of space allows us to address how IoT objects are designed to act in various scenarios thus allowing designers to consider: Where and how the interaction takes place; and where and how feedback on that interaction should be presented to the player/user. Figure 4 provides four possible interaction scenarios, and unlike the casual games explored by Juul the question whether the games are either single- or multiplayer does not dominate the discussion as it is anticipated all scenarios could support either single or multiple users.

- ***IoT Object***: In this scenario, the IoT is the focus of the users' interaction and all affordances would be associated with the object.
- ***IoT Objects in Player Space***: In this scenario, we expect multiple IoT objects to be used to enhance the physical space. While a screen might form part of this scenario, the IoT objects would not operate with it directly.
- ***IoT Object with Tablet***: In this scenario, the screen of the tablet provides a surface through which the physical objects interact with a virtual game that could be represented as either 2D or 3D space (Coulton et al. 2014).
- ***IoT Object with Screen***: In this scenario, movements of the physical object are transferred to the screen via a wired/wireless link and as with the previous case the virtual game can be represented as either 2D or 3D space (Coulton et al. 2014).

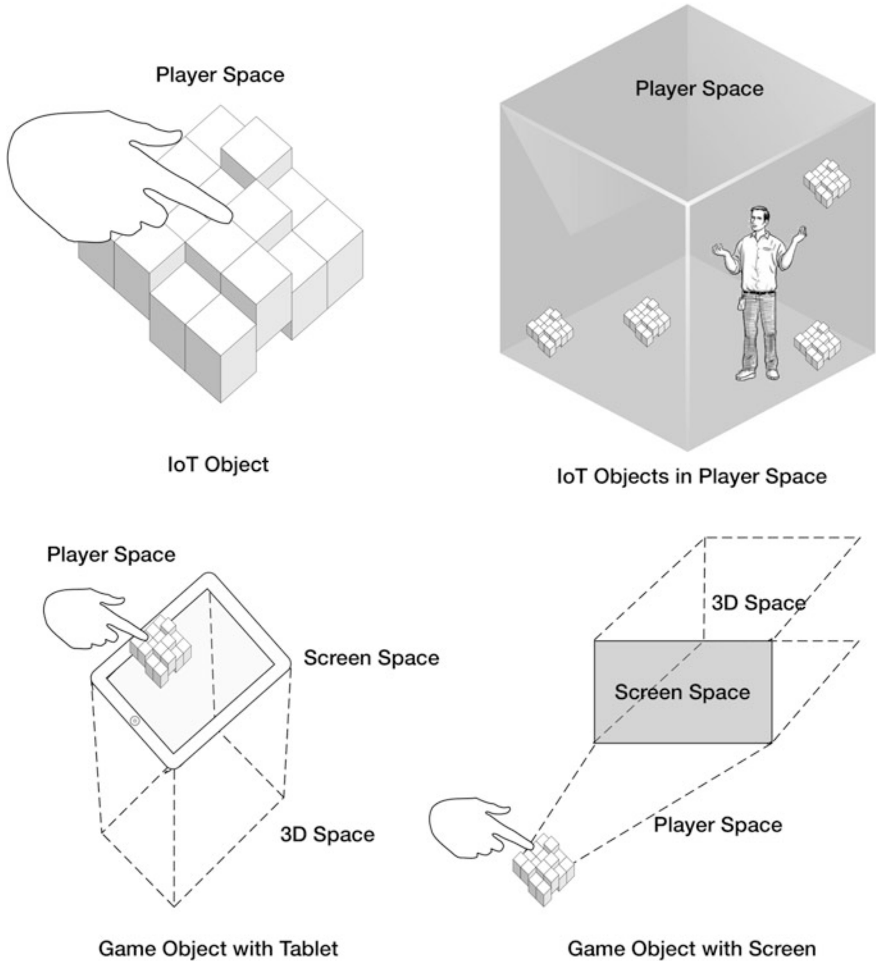

Fig. 4 Spaces of interaction for IoT

It is important to note that although these scenarios are representative of just some of the current implementations involving IoT objects, they are not the only possibilities and designers are also free to configure such interaction spaces, as they desire.

Having provided some general guidance of factors that must be considered for the design of IoT object systems in the next section, I will consider practical examples of how these may be put into practice.

6 Playful and Gameful Things

Rather than considering IoT games directly (Coulton et al. 2006, 2014); (Burnett et al. 2012), in this section we consider systems that adopt playful and gameful design approaches and each of which represent different approaches for IoT design in this area.

6.1 Embodied Interaction in IoT

6.1.1 CheckinDJ

The term jukebox originated in the USA in the 1940s to describe a music-playing device that allowed a user to select the songs to be played in a venue, such as a Diner, thus effectively giving the customers direct influence on the ambience of the venue. Users typically navigated through a list of songs/albums and were able to select a particular song to play by inserting money whereby this selection was added to a playlist of previously chosen songs not yet played. Typically, it is a single person that usually operates the jukebox and as people often spend a long time choosing their songs to play, this means others wanting to interact may have to wait or miss out and the resulting music may not therefore be representative of the wider audience. While jukeboxes once seemed ubiquitous, we are seeing fewer venues providing them for their patrons, most likely due the high rental costs and maintenance of such systems, which is resulting in the increased use of music players that are solely controlled and operated by the venue staff.

The rise in location-based services (Rashid et al. 2008) enabled by the now ubiquitous provision of global positioning system (GPS) chips within smartphones, and the cheap readily available mobile data, has resulted in many social networks incorporating geo-tagging within their services. While Twitter and Facebook both provide the functionality to tag tweets/updates with location, this is arguably not part of their core functionality, whereas Foursquares' entire premise was built upon users sharing their location. This sharing has been 'encouraged' through a game-like activity whereby users are awarded points, badges, etc. for checking-into a particular venue. This form of system feedback is now commonly referred to as 'gamification' and is often touted by game-based marketers (Zichermann and Cunnigham 2011) as if it were a magic bullet for increasing user engagement. However, the lack of evidence that supports long-term user engagement, even on services such as Foursquare, has led to significant criticism among games designers who argue that it simply focuses on the feedback mechanisms and fails to provide meaningful interaction to its users (Coulton 2015). This has led to the alternative proposal of gameful design (Deterding et al. 2011), which proposes to go beyond such simple points and badge-based system to create more opportunities for meaningful interaction. Further, inaccuracies of GPS mean this can easily be exploited as a players' physical presence is not necessarily required to check into and unscrupulous players can gain advantage of such offers without actually entering a venue (Nandwani et al. 2011). The lack of long-term engagement and inaccuracy of GPS could be among the reasons why we are not seeing a significant number of venues adopting to approach to attract patrons and is behind the proposal of using NFC-enabled objects to ensure an actual physical check-in at the venue (Nandwani et al. 2011).

Although the use of NFC as a method to control music has previously been proposed for producing music by choosing individual songs via NFC tags, it has not been used to crowdsource a communal playlist (Burnett et al. 2012). Therefore, this research presents the design and development of a platform, we have termed CheckinDJ, that goes beyond the simple game-like activities of Foursquare by encouraging users to physically check-in so that they may help curate of the music being played at the venue (Burnett et al. 2012).

To ensure quick and easy interaction with the system in the venue, it was decided that users are required to initially register their NFC-enabled objects' unique ID number along with their social networks (Twitter, Facebook, or Foursquare) and their three music genre preferences. Upon activation, the NFC object has an influence value which is used to affect the playing order of the music genres when they check-in the venue as their chosen genres in the venue playlist are incremented by this value. Players can increase their influence value by authenticating their social network accounts with the service. Players who are checked into the venue who are friends on Twitter and/or Facebook earn extra influence for each friend checked into the venue and the player who is the current mayor of that venue on Foursquare gets an additional bonus (Lochrie et al. 2013).

The CheckinDJ venue unit uses a RasberryPi with an NFC reader to stream music via the online streaming music service Spotify as shown in Fig. 5. A server is used to control the playlist which the venue unit polls every 20 s to get the highest rated genre. The venue unit then removes all but the current and next track to be played from its current playlist and then adds ten songs from the 'new' genre to the playlist by using Spotify. The system maintains a log of all songs that have been played so that if users like a particular track or indeed the whole playlist they can download a copy.

The system has been trialed on a number of occasions in the campus bars at Lancaster University, as all the students possess an NFC-enabled library card. The system proved extremely popular with a number of spontaneous competitions between groups emerging to try and dominate control of the genre being played (Lochrie et al. 2013) and some groups developed other tactics such as nominating a member of the group to checkin all the other members NFC cards at regular intervals as shown in Fig. 6 which was taken during one of the trials.

Although the research outlined was principally aimed at improving the experience for the patrons of the venue, we believe there is a strong incentive for adoption by the venue owner as the system encourages loyalty by allowing users to be directly involved in creating the venue ambience. However, a longitudinal study is required to evaluate the system experience for both the venue and its clientele (Lochrie et al. 2013).

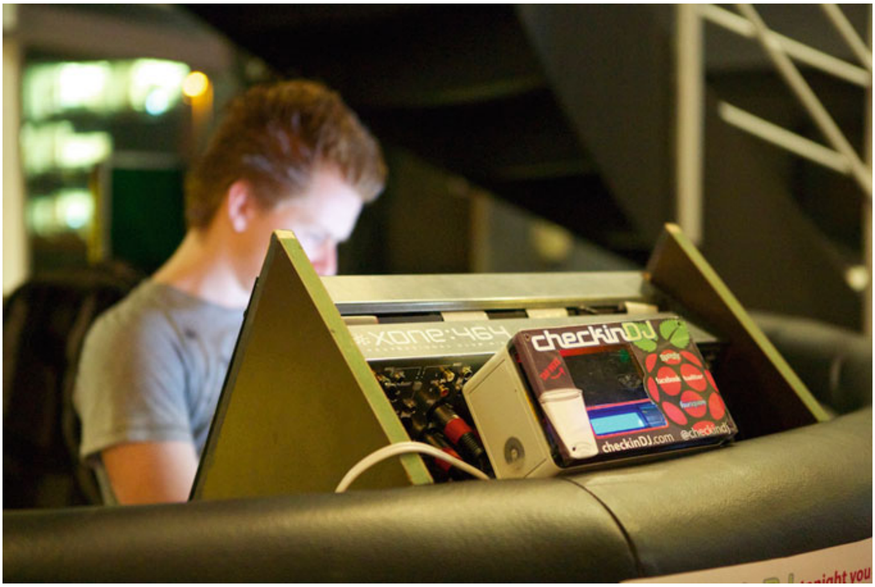

Fig. 5 CheckinDJ venue unit

Fig. 6 Users attempting to game the CheckinDJ system

6.1.2 IoT Storytelling

While it is often argued that IoT offers an alternative to the current dominance of screen-based interactions, there is also the exciting prospect of IoT objects being used in conjunction with all types of existing broadcast media to provide richer storytelling experiences and in Fig. 7 I present the possible design of such a system. The physical/digital system presented is but one particular configuration that such a system may take and this indeed is one of the great challenges for design within this space as any storytelling will need to adapt to the makeup of the things available within a particular space and at a particular time. This means IoT storytelling systems will be required to provide dynamic context personalization during the course of a program. As television services are already offering personalization by profiling the viewing habits of their audience, we also anticipate that the IoT will undoubtedly allow a richer range of sensing (e.g., presence, context, and physiological) opportunities to inform such personalization. It is important to note that this context personalization may go beyond recommendation systems and altering aspects of the audiences' physical environment to include the actual program content itself as demonstrated by the BBC's Perceptive Radio Project (Forrester 2012).

The current hardware 'sketch' of the IoT storytelling demonstrator was developed in conjunction with BBC Research and Development at Media City in Manchester, UK, and is based on Fig. 7 and controlled by the program script describing the Triumph of the Vertebrates episode of the BBC David Attenborough Documentary series Rise of the Animals. The script is provided in the form of an XML feed which the BBC currently uses to support subtitling services for the deaf. At present, the XML feed contains information relating to all the speakers within the program, the exact times within the program that they speak and what they say.

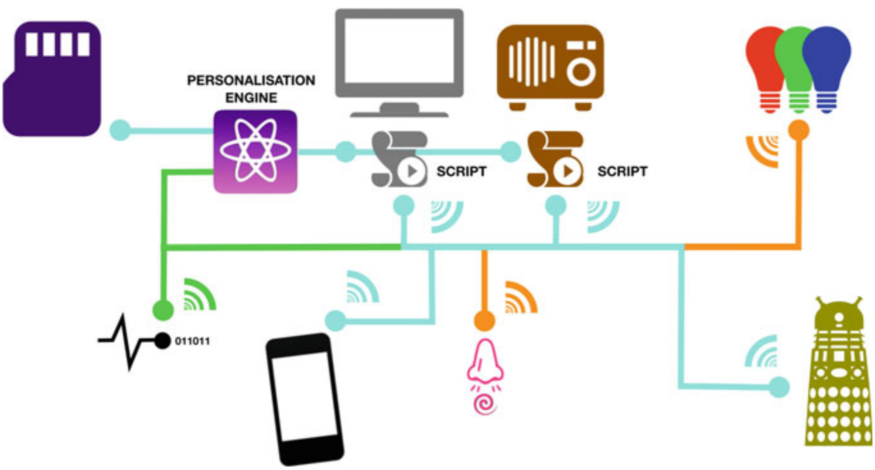

Fig. 7 IoT storytelling system

While there are some simple descriptions of the scenes, they currently only provide basic information, although more elaborate scene descriptions are provided in services for the blind and partially sighted and could easily be incorporated into a more extensive XML feed.

The current demonstrator is controlled via a Web interface and database that allows IoT objects to be associated with certain elements within the script and currently includes:

- Three Philips Hue lights that are ZigBee enabled and up to 50 of which can be controlled within a single home using the supplied bridge. Thus, such an array of lights could be used to:
  - indicate when a particular individual is speaking;
  - indicate time of day within the program, i.e., sunrise or sunset;
  - the mood of the characters within the scene;
  - represent the dominant color palette of the scene;
  - for sports events, such as football, the color could be used to indicate the team currently in possession of the ball in the match.
- An interactive toy created from a Makielab doll fitted with and NFC reader and LED eyes that are controllable using a SparkCore WiFi-enabled Arduino board is shown in Fig. 8. Depending on the sophistication of a particular toy, it could be used as a physical avatar of characters on the screen, which is likely most

Fig. 8 Connected toy

Fig. 9 Scentee olfactory device

applicable of children's programs. Further, features such as the NFC reader allow for direct interaction between the audience and the program as it can allow a large array of objects to be 'given' to the toy that could then be reflected within the program;

- A Scentee olfactory device which can be programed to emit a fragrance at a given point in the program is shown in Fig. 9. The device currently allows only single cartridges containing one of a range of smells (e.g., coffee, strawberry, and buttered potato) and can be programed through either Android or iOS to deliver burst of the scent for a specified time period. While these restrictions limit the opportunities within the current demonstrator, there are olfactory devices designed for venues, such as cinemas, that can provide a range of smells. Therefore, we could therefore see more versatile home use devices emerge in the future that could provide the smell of the sea or a pine forest for programs.

While this configuration of the demonstrator does not yet provide all the functionality envisaged, it is allowing us to directly consider the design challenges and opportunities for traditional media, as they become part of the emerging IoT. This research thus far has not only revealed the technical challenges of combining many disparate IoT objects but also the complexities of the design space as each object offers different opportunities for enhancing the storytelling experience of traditional media. We recognize that further extensive design research is required in this area as it is already apparent that physical and digital design cannot be considered separately in this context and must be combined to form new holistic design practices.

6.2 Participatory Design of IoT

6.2.1 ScareBot

The origins of this project date back to 2003 when the community from the small village of Wray in Lancashire, who had been campaigning for broadband to be made available to their community without much success, approached Lancaster University for help. In 2004, a new research project that involved the university and the community building a new wireless mesh test-bed within the village was initiated.

The original project has had a considerable impact, not only in terms of academic research output but also, more importantly, in terms of its social and personal impact within the village. It enabled approximately 100 rural businesses to get online and provided 230 families with free Internet access after years of campaigning for a connection. It was the first project to be developed by the Rural Connected Living Lab and has facilitated the investigation and understanding of the 'real-world, real-time' impact of numerous interventions (Coulton et al. 2013).

This particular project was initiated as part of the Engineering and Physical Sciences Research Councils (EPSRC) 'Telling the Tale of Engagement' program that highlights research that has direct impact on the public. Therefore, in the spirit of the original project, it achieves this aim through two novel design interventions that form part of the village's main cultural event, an annual scarecrow festival that takes place in May and has been the main source of the funds that have ultimately enabled the village to lay their own optic fiber connection across local farmers fields to connect them to the main broadband network. The interventions are an interactive digitally enhanced scarecrow, to participate in the festival, and a novel mobile augmented reality (AR) application to allow visitors to experience both the current and the past scarecrow festivals in a playful way (Burnett et al. 2014). In this section, I only consider the design and development of the interactive digital scarecrow known as 'ScareBot' as it can be considered a playful IoT design.

The digital scarecrow was conceived from the drawings and models produced by children at a participatory design workshop held at the 2012 festival as shown in Fig. 10. As many of children's designs featured a robot, this became the basis of the design of the ScareBot who stands 2.5 m tall and is fashioned from red to yellow fluorescent transparent acrylic. ScareBot incorporates a wide range of technologies including an Android tablet, a Raspberry Pi, an Arduino, and LED lighting. People can interact with ScareBot in a number of ways: He blows bubbles from his feet when you send him a text message, and he will also text you back a thank-you message which includes the current date, time, and the weather were he is located; he can play a wide range of sounds placing NFC tokens on a reader that comes out of one of his arms; and you can put your own face on the tablet that makes ScareBot face using the Webcam on his other arm. ScareBot was taken to the festival in 2013 and 2014 and proved a huge hit with the children, as shown in Fig. 11. Although

Fig. 10 Participatory design workshop

the original idea was to leave him in residence at Wray, this playful use of IoT design makes regular appearances around the UK telling the tale of the impact of our University engagement with rural communities and highlights.

Fig. 11 ScareBot at Wray scarecrow festival 2013

6.3 Embodied Meaning in IoT

6.3.1 Physical Playlist

The shared mixtape had an emotional and physical connection for people that digital shared content often lacks. This connection comes from the fact that objects or artifacts often symbolize something more than their intrinsic value, and this is often preserved over the years. Our personal associations with objects often gain subjective meaning based on the memories that we have about them, although such memories are generally hidden and intangible (Csikszentmihalyi and Rochberg-Halton 1981). Writeable CDs came too late, or too close, to the emergence of the mp3 to become a shareable treasured object akin to the mixtape, and it was this realization that produced the initial inspiration for creating a new form of physical playlist that offered this lost tangibility. The project, developed in conjunction with BBC R&D at Media City, UK, created a system that can be used to explore users' experience of a physical shareable personalized object that has digital content embedded within it. Thus, the project differs from those that have used objects as a means of storing memories, such as Memory Boxes (Frohlich and Murphy 2000), as the object itself primarily represents the embodiment of the time and effort the creator took to personalize the gift, thus making it more meaningful than a purely digital playlist.

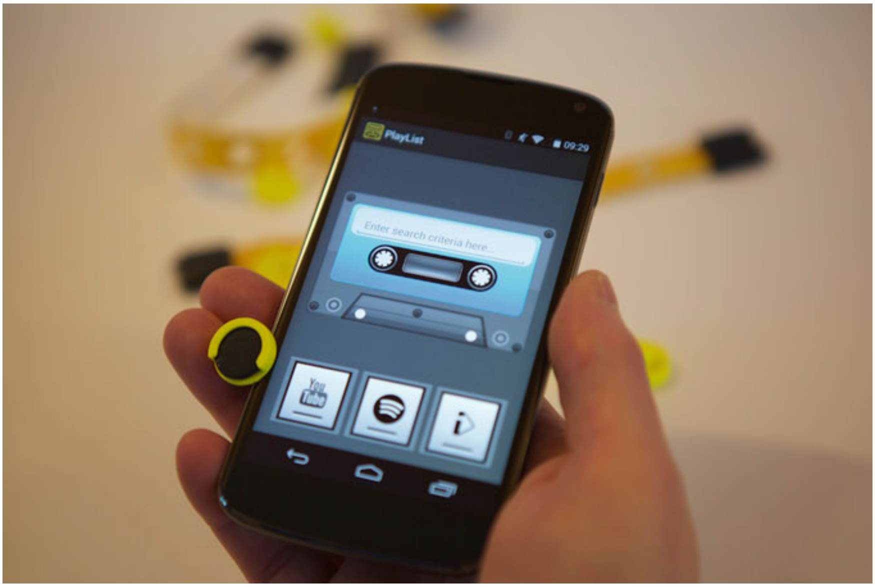

Fig. 12 Physical playlist creation

The results of the project thus far are two elements: the physical shareable objects themselves, and a bespoke media content player that is designed to ensure that the content of the physical playlist is presented to the user in the sequence in which the creator intended. The current physical playlist takes the form of a ‘charm’ bracelet and contains customizable 3D printed widget which houses a small NFC tag. The playlist creator embeds a link to their chosen digital content within a widget using a bespoke Android application as shown in Fig. 12. Currently, the system supports media from BBC iPlayer, Spotify, and YouTube.

The player is shown in Fig. 13 and uses an Arduino to control an NFC reader that moves up and down a rotating rod to read the physical playlist. The playlist is hung on the associated jewelry stand and scanned from top to bottom. The embedded links are sent to a Raspberry Pi which streams the associated media which is played through the attached monitor.

While the mixtape offered elements of personalization, the flexibility of the potential objects that can be combined to form a physical playlist is considerably greater as they can take almost any form. Further, as the playlist is digitally enabled, they can also be made to use other information; for instance, they could be made so that they could only be played on a specific day, such as a Birthday, or at a specific time, or when the weather is warm and sunny, thus allowing the creator to produce a very unique personalized experience.

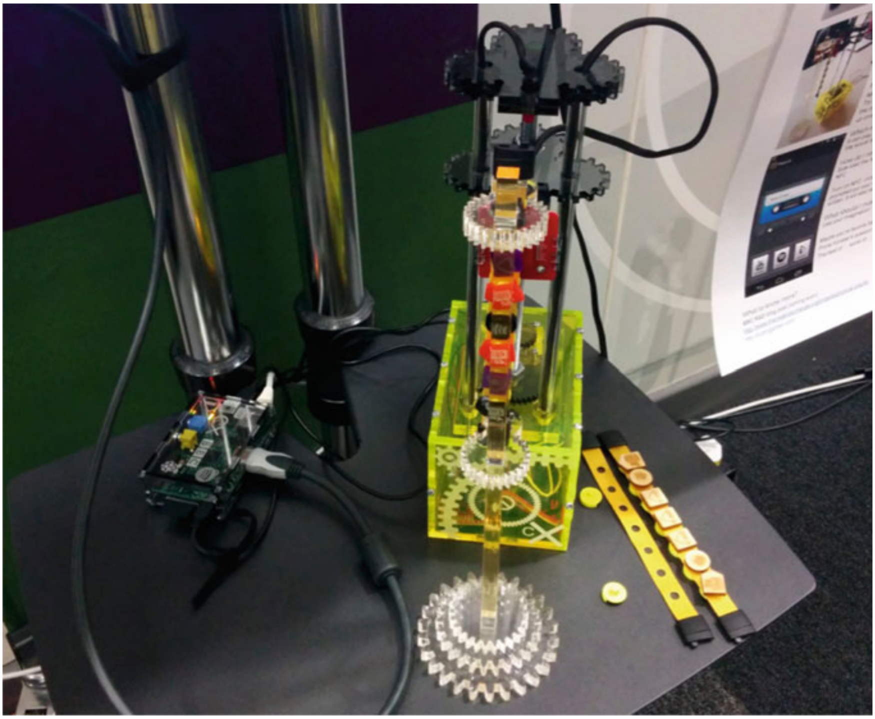

Fig. 13 Physical playlist player

7 Conclusions

While we are undoubtedly in a period where phones and tablets dominate our computing experience, we are already seeing the emergence of a range of connected devices that present an alternate to a flat glass screen and herald the emergence of the so-called IoT. The development of such devices is in some part fueled by advances in 3D printing, open-source operating systems, open hardware, and improved connectivity all of which are now readily available to the designers of playful and gameful systems. While the low barriers to entry of these technologies means they are well within the reach of many designers wanting to create systems that employ physical objects, it requires new considerations to be adopted for interaction design as designers need to combine both digital and physical aspects to provide a unified experience to the user.

Before attempting to design IoT objects and systems, it is worthwhile considering them in relation to the varying human–object relationships they might afford. In this chapter, I drew upon the characterized classes of objects developed by Bruce Sterling in his book Shaping Things and in particular Spimes as tangible objects embedded with extensive and rich informational support.

While the IoT as an amorphous sprawling network of heterogeneous objects is exciting, it is also challenging in terms of current lack of standardization in relation to how these objects can connect to the Internet. While this chapter highlighted the common approaches that currently dominate the connection of these devices such as Web service devices, virtual cloud devices, and peer-to-peer devices, it is important to note that there are other configurations and the main point was to highlight the challenges of developing systems capable of supporting multiple objects simultaneously.

When designing interactions for IoT systems, it is vital that designers understand the role of affordances and how they help users construct coherent mental models from which future tasks and uses can be inferred. However, as discussed, while the affordances of physical objects may be readily perceived through their design, in the case of virtual systems the perceptual information that reveals the affordance needs to be dynamically attributed. This means such information is not simply perceived or not, it exists on a continuum which is often dynamically changed by the designer throughout the interaction.

One of the other challenges for interaction design in IoT is understanding the space in which the interactions take place. A useful framing of this comes from Juul who divided game space into player space, game space, and 3D space (Juul 2009). From this framing, four characterizations for IoT were described as IoT object, IoT objects in player space, IoT object with tablet, and IoT object with screen, as a useful way for designers to consider where the focus of the users' attention may be, and how feedback for a particular interaction is presented to the user.

Finally, I presented a number of examples of playful and gameful interactions that illustrate just some of the possibilities that IoT affords. In particular, the examples illustrate how the tangibility and physicality of the objects present opportunities not only for new interactions and also how IoT may be used to enhance existing media interactions to provide more meaningful experiences.

Finally, I would recognize that further extensive design research is required in this area as it is already apparent that physical and digital design in this context cannot be considered separately and must be combined in the form of new holistic practices which is one of the great challenges for researchers in this area.

Acknowledgments The research presented in this chapter has been made possible through the support of a number of organizations most notably the Arts and Humanities Research Council (AHRC) project The Creative Exchange at Lancaster University and BBC Research and Development at Media City. Along with the co-authors of many of the research papers cited I would like to give special mention to Ian Forrester and Jasmine Cox from the BBC for their enthusiastic support of these projects.

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Part III
Designing Interactions for Arts, Performances, and Sports

Smart Materials: When Art Meets Technology

Fun with Materials to Create Interactive Artistic Installations

Andrea Minuto and Fabio Pittarello

Abstract In this chapter, we will present our approach for the development of young artists. We describe how we helped them to discover new expression methods and methodology. We guided them through the smart material jungle with Arduino as lantern. We will describe the application and use of smart material interfaces (SMIs) in the context of artistic installations. SMIs are interfaces that make use of smart materials and the possibility of changing their physical properties to create interaction. We organised an intensive workshop in the Fine Art Academy of Venice. The students, divided into groups, produced interactive creative works based on cheap traditional materials enhanced with the properties of smart materials. Our idea was to use new materials to augment the degree of freedom of expressivity of traditional media. Through this experience, the budding artists had the possibility to learn new technology and techniques for creating fun new interaction by surprising and amazing the user in unexpected ways. The experience itself stood for a growing point of the students, and it allowed them to give life to their static works. Also, the possibility of augmenting objects with new properties allowed them to convey emotion and feelings, not just information.

Keywords Artistic installation · Arduino actuation · DIY/maker · Smart origami · Smart material interface · Rapid prototyping · Educational workshop

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1 Introduction

In this chapter, we will present our approach for the development of young artists. From the beginning of time, artists have always made and selected most of their tools and materials themselves, from pigments to paint, from canvas to the best marble, and so forth. For newborn modern artistic disciplines, which we can address with the label of *interactive systems*, the artists are only end-users. They use methodologies and algorithms that have been conceived by others. In most cases, these were highly skilled technicians that have nothing to do with arts or similar contexts and purposes. The artists have often no idea of how these artefacts work, nor how they are made. In these conditions, the artists' work is limited to what the artefact (hardware or software) can do, limiting the full extent of potential expression power in their poetic vision.

Thanks to ubiquitous computing, the computing context has shifted focus to real-world tangibles, embedding computation in everyday objects. While some artists have taken advantage of these new opportunities (e.g. *The dangling string* Weiser and Brown (1995), N. Jeremijenko, that materialised the data flux of a research centre), thanks to the cooperation of the technicians, others could not. In most cases, this situation has enlarged the dichotomy between the artists and the possibility of building the tools for their creative work.

The modern movement of makers focuses on do-it-yourself (DIY), often inexpensive, implementations of interactive systems. Thanks to the tutorials and information posted online from this trend, and to the technologies now available at end-user level, the artist can bridge the gap between technology and creativity. He can apply solutions and create everything on his own. He no longer needs the input or the role of technician that was necessary before.

One of the most interesting features of the new maker movement is the pedagogical opportunity of learning what's behind, how things work, and also the tendency to promote low-cost materials. They can learn new concepts through the experience of others, but they do not need to go too deep into the technical details if they do not want to. This allows a lot of people to get a first taste of experimentation with real systems.

We focus our work on a category of (smart) materials that also fit well into the DIY philosophy. We will describe how we designed and conducted a workshop for a class of students of the Fine Arts Academy of Venice. The workshop focused on smart materials and techniques to create interaction in the arts domain. The goal was to make the artists aware of the potential of the new technology, reducing the gap between technology and creativity by empowering their expressivity. Our purpose was for the students to develop interactions in the intersection between arts and technology, by proposing the use of a development platform pair: *Arduino + smart materials.*[1]

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[1]See Sects. 2 and 3 for more details.

In this chapter, we will briefly present smart material interfaces (SMIs) (Sect. 2) and give a description of some relevant related work in the art domain (Sect. 3). We will follow with the objectives and a description of our workshop (Sect. 4). Then, we will present a selection of some of the projects produced by the students (Sect. 5), and we will have a look at the results of the data gathered during the experience (Sect. 6) and discuss it (Sect. 7). We will then conclude in Sect. 8 with our considerations.

2 Briefly About SMIS

Before going ahead, we must give an idea of smart materials and SMIs. A smart material is a material that can change a physical property in a controlled way. The property can vary from colour to transparency, from phase to stiffness or from conductivity to emitting light (and so forth). SMIs are interfaces that take advantage of these materials to promote a new way of interacting with the user. They give the possibility to convey a message in a physical way, for example deforming the shape of the interface to communicate to the user Minuto et al. (2011). Several overviews have been written on interfaces made with smart materials. Among these, Minuto and Nijholt (2013) show how they are used to create interactive methodologies in different ways. Some are cheap and others extremely expensive. In many of the cases, as stated in the article, they are mostly based on cardboard or paper as support materials.

In this chapter, we mention different families of smart materials, such as ferrofluid, shape memory alloy and thermochromic pigments.

Shape memory alloys (SMA) are alloys in which a deformation can be induced through temperature changes, which brings back a previously imprinted shape. In particular, NiTiNOL is a family of SMA that can be used for actuation. One of the most common uses is within the medical tools domain.

Ferrofluid is a liquid which becomes strongly magnetised in the presence of a magnetic field, forming spiked cones in reaction. It is conventionally used in different fields, for example in electronic devices (as ferrofluidic seal), in mechanical engineering (for having localised friction-reducing capabilities), and many others.

Thermochromic materials change in colour, depending on their temperature. In this chapter, most of the thermochromic pigments cited are of two kinds: pigments that have a single threshold over which they become transparent, or liquid crystal-based pigments that have a more precise threshold and can display different colours. They are commonly used in displays and various products both for entertainment and for communicating changes of temperature.

You can find a deeper and broader analysis of the materials with specific characterisation in Addington and Schodek (2005).

3 SMIS and Arts

Many times walking by an installation, we are stunned by the beauty of the artwork we are looking at. It inspires our emotions and feelings. Some artists have headed for the idea of using new materials as part of their artistic experience. They started to play with the aesthetics of the smart materials to communicate their emotion to the visitor. Some of them are from a scientific background and have applied their knowledge within the artistic frame. Sachiko Kodama was the first to start to employ ferrofluid in art installations with *Protrude flow* Kodama (2008) in 2001. The ferrofluid lifts up from a plate and then creates a flowerlike shape balancing the wobbling spikes in between the two spaces. She created several installations, among others: *Morpho Towers—Two Standing Spirals* consisting of two ferrofluid sculptures that move with the music Kodama (2006). Qi Jie gave several workshops, teaching interested people how to make use of SMA and paper, Qi and Buechley (2012). It is also possible to find more online contributions from her and her group, for example on how to make a flapping origami crane Qi (2010). An older work is the *Robotany project* Coffin et al. (2006), Coffin (2008) by Jill Coffin, John Taylor, and Daniel Bauen in which the branches of a living tree are made to sway when someone walks by. Since the SMA wires are completely silent and hidden, the tree appears to be moving in a virtual breeze.

In other cases, smart materials are used just as a bonus to the usual artistic poetry of the artist. The photographer Fabian Oefner is a good example Oefner (2012). With his project *Millefiori*, video and pictures, he broke with his monochromatic tradition by throwing water colours into the mix of ferrofluid and brought some luminosity and playfulness into his work. After him: soap bubbles, ferrofluid, food colouring, and magnets were used in a video called *Compressed 02* by Pimmel (2012). The artist Afiq Omar has also been experimenting with ferrofluid and using the results to create frightening videos (*Ferienne* Omar (2013)). They seem to be mimicking life forms from another world. His experiments have seen him mix ferrofluids with items from the weekly shopping list: soap, alcohol and milk. The Brothers Mueller presents an interactive wallpaper. Their aim is to bring wallpaper back to the foreground. *Viral (STD) Wallpaper* is a damask print with stylised graphic versions of sexually transmitted diseases. By touching the wallpaper, the visitors can trigger the viruses to "infect" the wall. The infection *spreads*, thanks to Arduino (an open hardware platform[2])-connected sensors and thermochromic paint that allow the hidden pattern to appear Brothers (2011). In this case, Arduino plays the controller role for the sequential activation of heating elements that make the paint react. A similar concept is used in the *Chair of Paradise*. The design of the chair is inspired by the mating behaviour of a bird of paradise. This extravagant ritual, which is rather humorous when performed by a bird, becomes nonsensical when it is done by a chair. The chair reacts to the proximity with sounds and pattern changes, thanks to thermochromic paint and Arduino Satomi (2011). There are

[2]Arduino: open hardware platform http://arduino.cc.

other objects that want to communicate with the user, such as tables and benches. Jay Watson of Oxfordshire decided to give voices from the past to his table and bench. He designed them using a thermochromic finish. It reacts to body heat by becoming transparent, temporarily exposing the wood underneath. It leaves an interesting ghostly print of either body parts or dinnerware for a brief amount of time that can stimulate intriguing, playful dinner conversations Watson (2012).

Ferrocious Garehan (2013) is an electronic ferrofluid sculpture that responds to sounds. Different music will cause it to respond in different ways, leaving the ferrofluid jumping and spiking between the two magnets. *Interactive Steampunk Ferrofluid stand* concept, by Geir Andersen (2011), shows how to entertain his spectator with electromagnets and ferrofluid. Here, the aesthetics of steampunk design create all the interaction showing some hint of new perspectives for HCI design Tanenbaum et al. (2012). One last art piece comes from the creativity of Lindsay Browder. She focuses on mind control to show the poetry of changing brainwaves within a ferrofluid flask. The ferrofluid changes shape, grows tiny cones and relaxes again, doing this based on the user's real-time brain activity (*Magnetic Mind* real-time BCI with Neurosky's headset) Browder (2013).

4 The Experience

We organised a workshop at the Fine Arts Academy of Venice that consisted of 5 sessions of about 8 h each. The workshop was held in the context of the interactive systems course for the master's degree in new technologies for art.

The number of students was 14, formed into 7 groups, but only 6 groups reached the final examination. Most of them were aged between 22 and 25, but there was also one of 55 and one of 63. They were all students from the first or second year of the master's course, and only one was from the third year of the bachelor's course. None of the students had any previous meaningful experience with imperative programming. Some of them had partial knowledge of Max/MSP.[3]

The general idea behind the workshop was to give to the students different *bricks of knowledge*, minimal small useful elements of knowledge, to allow them to build new concepts with as few constraints as possible. We offered the students three possible themes to choose from for the projects: *transposition of senses (synaesthesia)*, *object personality*, and *picture feelings*. They were designed to stimulate discussion and allowed a lot of freedom without putting many constraints on their creativity. The *transposition of senses* theme tried to stimulate creativity by making them imagine how, for example, someone could perceive the sense of smell with touch. The *object personality* tried instead to give inanimate objects living qualities and of course personal traits, for example how a chair would behave if it could move freely. The last theme was *picture feelings*, and it focused on how we can

[3]More info about Max/MSP: http://cycling74.com.

transmit the feelings from the perspective of the picture itself, for example, how would a picture frame feel while being watched or laughed at. The students had the possibility to choose one or more themes to fit in.

The main goal, for them, was to develop an artistic working prototype installation of SMI in the context of their theme choice. The only other constraints were to create something tangible or physical that could be interacted with and to possibly make use of smart materials.

4.1 Materials Used

Most of the material for the workshop was given to the students by the researchers (see Fig. 1). Each group received a set of basic electronic components, accompanied by wires and an Arduino. To these was added a paper mounted MOSFET (kind of transistor) circuit, made with conductive tape, to ease the connections to and from Arduino. The students were encouraged to get personalised tools and materials for their future projects. We used Flexinol[4] for SMA actuator, a wire of NiTiNOL[5] that contracts as a muscle. We used thermochromic paint, both ready made and in pigments with the acrylic binder. For making origami models, we used coloured office paper. Each project was characterised by the use of different materials, but all of them included the smart materials and Arduino. The smart materials used here were chosen for their different qualities and characteristics, one for making things move and the other for making colours change. These are also easily found on the market and can be bought from anyone without worrying too much about the expenses. The choice gave us also a very practical and immediate way of interacting with the materials through Arduino (using pulse-width modulation (PWM) and the MOSFETs). This simplifies the creation of any interface that makes use of either NiTiNOL or thermochromic paint.

4.2 Experience and Activity Description

In this section, we will describe the details of the teaching timeline and activities by day, also published in Minuto et al. (2014) with preliminary results.

1st Day: SMIs and Origami. We opened the workshop with an overview of artistic interfaces made with smart materials and about SMIs. Then, we asked the students to fill in an initial questionnaire, about their personal profile, previous knowledge and interests in the workshop. The lesson lasted part of the morning. A few hours were dedicated to the creation of origami models of various kinds and

[4]More info can be found at http://musclewires.com.

[5]NiTiNOL: Nickel–titanium alloy, a family of memory shape alloys.

Fig. 1 In this picture, the main materials used by the students as base for their projects. The different groups added other materials depending on their needs

shapes. The lesson was a step-by-step tutorial. Each origami model was created altogether with the researcher. The origami models varied from basic shapes to more complex action models. The latter are origami models, such as talking fishes or barking dogs, that move if parts of the model are pulled. We then introduced Arduino and basic programming concepts, such as variables, conditional constructs and loops. At this point, the students were divided into groups and several exercises were done.

2nd Day: Arduino. The second day started with the description of the Arduino I/O: the concept of *pin* and the methods to write and read from it. The rest of the session was dedicated to experimenting with Arduino, including hardware tests with LED and the other available components. We did experiments on how to control the properties of smart materials by using pulse-width modulation (PWM). We then presented the three themes for the projects: *transposition of senses (synaesthesia)*, *object personality*, and *picture feelings*. The students could choose one or more themes to fit. At the end of the day, we asked the groups to bring in a conceptual proposal to the next session in the shape of a storyboard that would contain the use of SMI in an art installation within the themes' scope.

3rd Day: Thermochromic pigments. The day started with the students presenting their proposals that were discussed and evaluated. We showed a short demo about SMA and thermochromic paint. The first was an actuated origami barking dog with a distance sensor as activation. The dog barked when the sensor detected an obstacle in its range. We also showed several examples of thermochromic paint applications. We then moved on and explained how to use and how to make the thermochromic paint from pigments. The students applied it to the origami models they had created. As last teaching of the day, we showed the students how it was possible to connect Arduino to social networks (Twitter).

4th Day: Actuators. The students experimented with their first complete SMI. They applied a very small serpentine of resistive wire on the back of their painted origami models. They connected it to Arduino to power it up and make the origami model change colour. Then, they learnt how to create software switches for activating the SMI from Arduino. The students then built a small actuator with wood, NiTiNOL wires and ready-made silicon springs. They connected it to Arduino with a MOSFET paper circuit and realised a light sensor-based movement (to allow them to put in use all the notions learnt till now). At the end of the lesson, we asked them to refine their proposal for the final project and to bring in anything they needed as an external material to realise it. They also filled in the second questionnaire about the characteristics of their projects.

5th Day: Work in progress. In the last session, the students started to work on their projects. All the lesson was focused on the development of the key features for their projects. Each of them had its own peculiarities and different problems to solve, from mechanical to software related.

After the end of the workshop, several checks were made to supervise the development of the projects. The final versions of the works presented in the next section were realised after the end of the workshop, refining the initial idea and completing the technical realisation. During this phase, the students worked mainly alone, but we organised periodic checkpoints for giving additional suggestions and for resolving technical questions (Table 1).

5 Projects

We have selected the best four projects (out of six) as a brief example of the products at the end of the lessons.

5.1 Venezia in fiore

One of the groups chose as theme *object personality* and produced a concept called "Venezia in fiore", translated: Blooming Venice (Fig. 2). It is a small dome covered with fake green leafs and flowers. Every time a user approaches the art installation, or simply passes by, a flower blooms bringing surprise and interest. It will be located in a place without other green elements and just its presence will attract the

Table 1 Description of the experience's timeline

Days	Lesson description	Survey	Main focus
1st	The students filled in the first questionary, and then we taught them about SMIs in general and origami. Introduced basic concepts of Arduino programming	First	SMIs, origami, Arduino
2nd	We taught them Arduino programming and tested it, and at the end of the day, we asked to bring in a conceptual proposal the next lesson. We also assigned themes to help the production of the proposals		Programming, Arduino, electronics
3rd	The students presented their proposals and assisted to a demo session about SMA and thermochromic paint. They then learnt how to make thermochromic paint and to apply it to the origami models created before		Future projects, thermochromic paint
4th	The students experimented with their first SMI, with thermochromic paint activated by resistive wire and then learnt how to connect electronic components and MOSFETs. At the end of the lesson, we asked them to refine the proposal for the final project. The second questionnaire was filled in	Second	Resistive wire, experiments, SMA
5th	The students started to work on their projects		Project
–	The students worked on refining their projects, periodically checked from the researchers		Project
–	After the official presentation of their works, they filled in the conclusive questionnaire	Third	Final thoughts, future

interest of the usual commuters who will be able to see the surprising unusual blooming among bricks and stones. The idea here is to awaken the environmental awareness of the users, by reminding them of the existence of nature, and to give a reward with the flower's blooming. The NiTiNOL wires will create the movements from the inside, and by contracting, they will allow the flower to bloom.

5.2 #holy

#holy is the name of the installation (Fig. 3) designed by a group that chose as theme *object personality*. The project is a picture frame with an origami tessellation inside, designed to be placed in a public gallery. Here, the idea is to invite the visitors to reflect on the concept of holiness and share their reflections on the social networks. The visitor will be invited by a small panel, placed next to the frame, to think about holiness and to tweet their thoughts with the hashtag *#holy*. Using the authors' words, "the cardiac muscle of the icon will contract as a sign of gratitude,

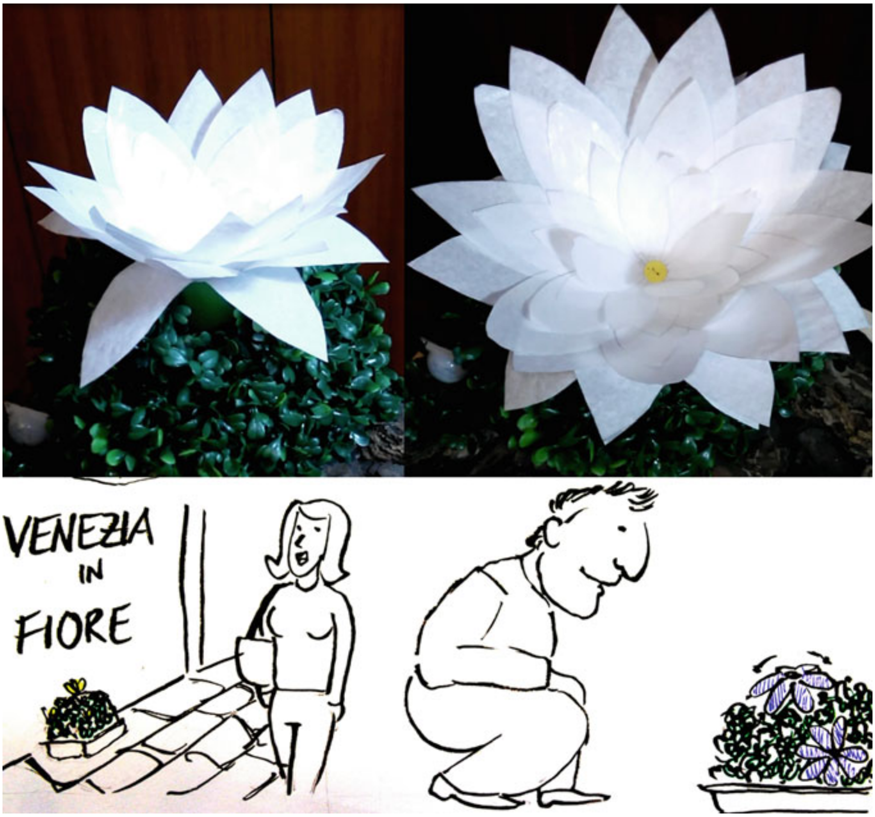

Fig. 2 Development of project *Venezia in fiore*. On the *top*, the final prototype in the two phases, open and closed, and on the *bottom* part, the storyboard sketch for the installation

for indicating that the concept of holiness has come back to life for a while in the hostile modern life". From a technical point of view, the installation involves a number of triggers activated by an Internet connection. NiTiNOL wires create the hidden silent motion from the back of the tessellation.

5.3 *Da mano a mano*

Da mano a mano (translated: from hand to hand) is the title of the installation (Fig. 4) from a group that chose as theme *picture feeling*. It is a small square with hidden drawings and writing. The user will be invited to leave a mark on the installation by placing his palm on the square. As he does the action, the shape of his hand and a sign saying "I was here" will appear out of the dark. The idea is that people want to leave a mark behind them to become immortal. It will be realised

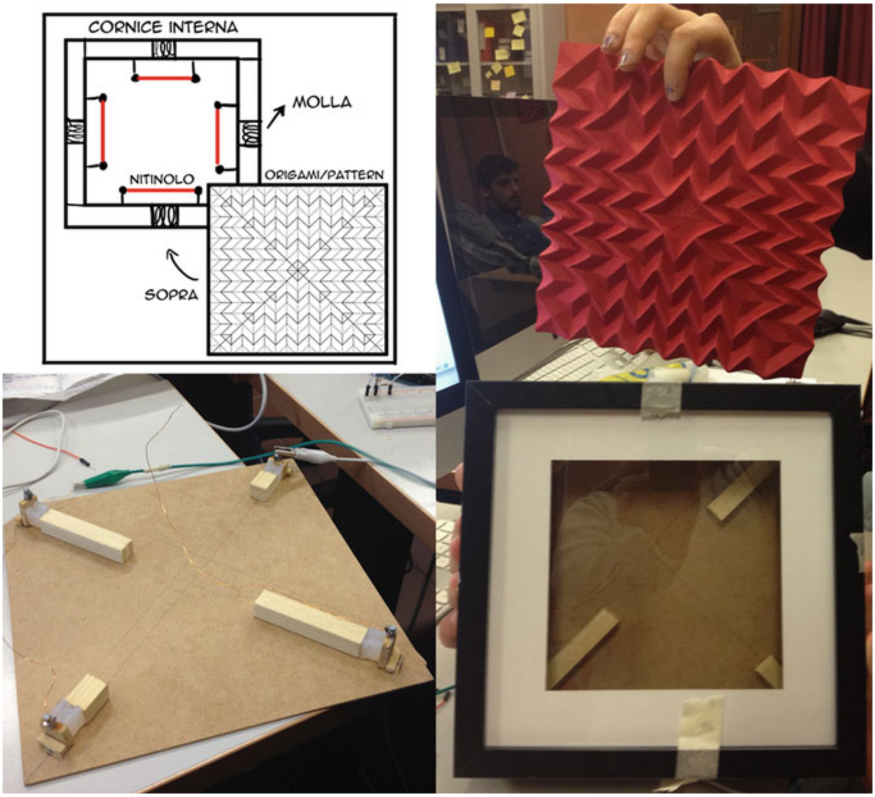

Fig. 3 Development of project *#holy*, from the students' sketches and pictures from the examination. On the *top left*, the initial schematics of the project, and on the other parts, different details of the installation

with thermochromic paint that becomes transparent when someone touches the installation showing up the hidden shapes.

5.4 Art-duino

The last project ***Art-duino*** (Fig. 5) takes inspiration from the theme *transposition of senses (synaesthesia)* and creates a playful interface that takes advantage of the user's attention. This installation has to be located in an art gallery, close to an artwork (perhaps a painting), and is represented by a very long caption in very small size font. The caption fades away when a user approaches the artwork. All the writings are printed (in the case of the prototype hand painted) with thermochromic ink, with resistive wire on the back. As soon as the user reaches the proximity sensor range, the ink starts to disappear, and before the reading ends, there is

Fig. 4 Development of project *Da mano a mano*, from the students' sketches. On the *top*, the concept design and on the *bottom*, picture of the aesthetics and the capacitive hand sensor drawn with conductive ink

nothing else to read. This project is intended to provoke, "the caption is useless, the only important part is the artwork".[6]

6 Questionnaires

As we mention at the end of Sect. 4.2, after the end of the workshop, the students were working independently (excluding the checkpoints) on their own to prepare their examinations. While it was difficult to measure the pedagogical path made by

[6]Cited from the words of the group of students that made it.

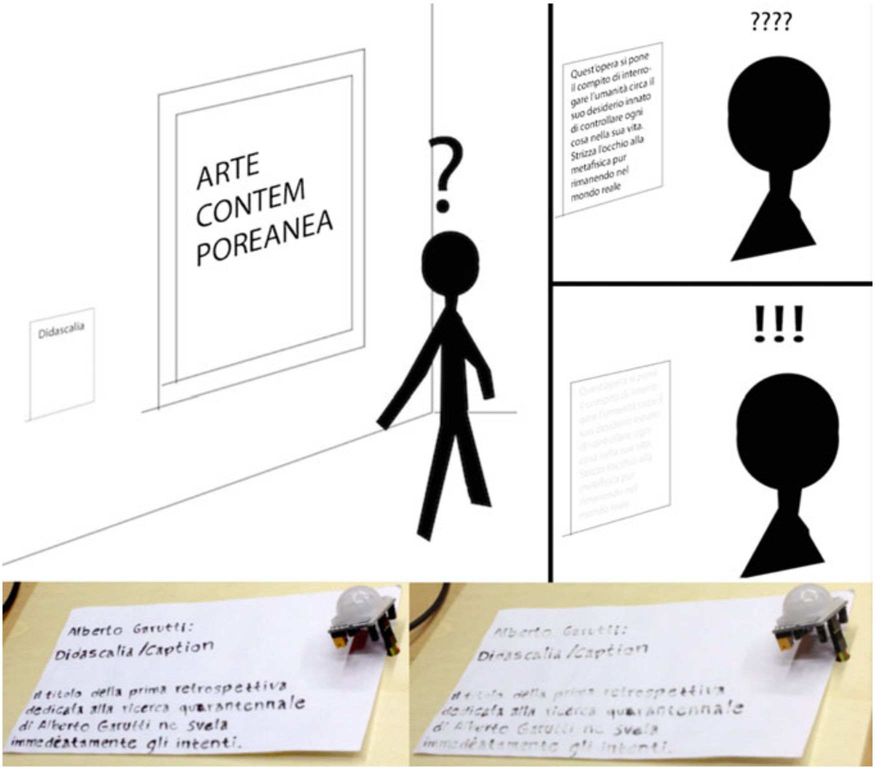

Fig. 5 Development of project *Art-duino* from the students' sketches. On the *top*, the sketches of the student project (*top left* the user approaching, *top right* the user start reading the long description, but before the end, the writings are faded out, *centre right*) and the final prototype, before (*bottom left*) and after activation (*bottom right*), where it is possible to see the ink fading out and becoming transparent

the students from a quantitative point of view, we tried to capture it from a qualitative point of view, through a set of questionnaires. We designed three questionnaires, focused on the initial knowledge of the students, their conceptual elaboration during the design phase and the final thoughts at the end of the experience. For homogeneity, the data displayed in the following tables are related to the twelve students that completed their work and therefore filled in all the questionnaires.

6.1 First Questionnaire

The first questionnaire, presented at the beginning of the experience, included a number of closed questions for capturing the students' initial knowledge about smart materials and their application to the art domains, the Arduino platform and

Table 2 Initial levels of expertise of the students

Parameter	Mean
Level of expertise for assembly electronic components	1.33
Level of knowledge of the Arduino platform	1.17
Level of knowledge of programming language—Java	1.17
Level of knowledge of programming language—JavaScript	1.17
Level of knowledge of programming language—Arduino	1.17
Level of knowledge of programming language—C/C++	1.0
Level of knowledge of programming language—Max/MSP	**1.41**
Level of knowledge of programming language—Processing	1.17

The scores are based on a 5-point scale

Table 3 Applications of smart materials to different domains, highlighted by the students before the workshop

Parameter	Number of instances
Application in artistic context	**6**
Application in architecture	3
Application in everyday objects	1
Application in educational games	2
Application in other contexts	3

The number of instances is the number of students that picked that option, over a total of 12 students

programming languages. Table 2 summarises the answers of the students, related to a 5-point scale. All the students declared a very low level of expertise and skills related to the Arduino platform, both for what concerns programming and the assembling of simple electronic schemes. For what concerns the programming skills, we asked the students about their knowledge of different languages, from traditional languages and scripting to visual programming environments such as Max/MSP. Even in this case, the scores for most answers were very low (i.e. means below 2).

The students had no direct experience related to the manipulation of smart materials, but we wanted to know whether they had at least the opportunity to see them in action. After having illustrated a number of examples in the classroom, we asked the students whether they had seen similar applications. Table 3 summarises the answers of the students, in relation to a grid evidencing the different application domains. As it can be seen in the results, most of the applications were noticed for artistic and architectural contexts.

6.2 Second Questionnaire

The second questionnaire captured their conceptual elaborations with a set of open and closed questions. The students were invited to describe the features of their proposal, putting in evidence the relations with the planned delivery context and the

Table 4 Usage of sensors and actuators for the input and the output interfaces

Sensor/actuator (I/O)	Number of instances
Input: light sensor	2
Input: sound sensor	1
Input: proximity sensor	4
Input: temperature sensor	2
Input: contact sensor	2
Input: Twitter message	2
Output: Paper/wood objects	3
Output: NiTiNOL wire	4
Output: Thermochromic ink	3
Output: Other output (LED/canvas)	2

The number of instances is the number of groups that consider using that particular I/O, over a total of 6 groups

inspiring conceptual sources, if available. The students imagined different social situations (e.g. the road, the art exhibition) where to place their artefacts. For four cases out of six (number of groups), these social situations were considered as essential components of the conceptual proposal. Only in one case was the context considered as unimportant.

In the questionnaire, we also tried to map how the conceptual elaboration was mapped to the acquired technical knowledge, especially for what concerned the definition of the input and the output interfaces. Table 4 summarises these results. For the input interface, the students considered the use of the sensors that were experimented with during the lessons, but they also showed interest in additional sensors capable of capturing additional environmental parameters, such as the sound sensor (microphone not used for speech). For the output, the students demonstrated an interest in the two primary categories of smart materials that were experimented with in the classroom, but even in this case, they also considered the possibility of experimenting with additional components, such as LED lights. Not all of the groups kept the original choices in the end.

6.3 Third Questionnaire

After having completed their works, the students were asked to fill in a final third questionnaire, containing both open and closed questions. According to the definition of engagement of O'Brien and Toms (2010), we tried to capture through the six parameters the different facets of the experience, from the ease of use to the aesthetics. We asked the students to express their evaluation of all the activities of the experience, from the conceptual design to the creation of smart origami with the Arduino-based development. All the scores are based on a 5-point Likert scale. Table 5 displays the overall score and, with the exception of the Aesthetics parameter, the detail for each activity that characterised the workshop.

Table 5 Mean scores assigned by the students to the 6 parameters that define the engagement

Activity	Perceived usability	Felt involv.	Focused attention	Novelty	Endurability	Aesthetics
Origami	4.00	3.58	3.25	2.17	2.42	n.a.
Arduino (electronics)	2.83	3.67	4.00	4.67	3.50	n.a.
Arduino (programming)	2.58	3.42	3.67	4.75	3.17	n.a.
SM (NitiNOL)	3.67	4.25	4.17	4.83	3.67	n.a.
SM (therm. ink)	4.25	3.92	4.08	4.75	3.83	n.a.
Project concept	4.08	3.92	4.3	3.58	3.83	n.a.
Project development	3.17	4.08	4.17	3.92	3.83	n.a.
Overall	3.51	3.83	3.95	4.10	3.46	3.94

The scores are based on a 5-point scale. The table displays the overall score and, with the exception of the *Aesthetics* parameter, the detail for each activity

Concerning the *perceived usability*, we registered a positive result (mean 3.51) with higher scores for the activities related to the manipulation of smart materials, the conceptual elaboration and, of course, the origami creation. The activities related to Arduino resulted more difficult, as underlined by the scores assigned to the realisation of the electronic scheme (mean 2.83) and programming (mean 2.58). The latter result is consistent with an additional question of the questionnaire (not displayed in figure) focused on the perceived level of acquired knowledge of the Arduino platform (mean 2.25). The students enjoyed performing the activities related to the project, as can be seen from the score assigned to the *felt involvement* (mean 3.83). Again, the activities related to the manipulation of smart materials and conceptual elaboration gained higher scores. However, in this case, the other activities were also rated rather high, i.e. above 3.5. The *focused attention* parameter, measuring the cognitive interest, gained even better scores with mean values above 4 for the activities related to the manipulation of smart materials, the conceptual elaboration, the project development and the creation of the Arduino-based circuitry. Unsurprisingly, the origami model creation gained lower scores (mean 3.25). Most of the activities that were part of the project were perceived as novel (*novelty* parameter mean 3.46), with values above 4.5 for those ones related to the manipulation of smart materials and to Arduino (both programming and creation of the circuitry). Again, the origami model creation scored rather low (mean 2.17). The students showed a positive attitude towards the possibility of performing the project activities again (*endurability* parameter mean 3.46), with a particular interest for the activities related to the smart materials' manipulation, the conceptual elaboration, the project development and the creation of the Arduino-based circuitry. Concerning *aesthetics*, we asked all the participants to express, through an anonymous vote, their opinion about the value of the works of art. The mean score, 3.94, shows a high degree of appreciation for the aesthetic qualities of the works of art.

The final questionnaire included an additional set of open questions that gave interesting results. The participants were asked to express their opinion about the usefulness of the experience in respect to their future artistic activities. Four out of twelve participants declared that the experience was useful for their artistic future. Only one participant declared explicitly that the experience would not have any impact on his artistic activity. The rest of the participants (seven students) declared that while they were thinking to direct their activities towards other technologies, the experience was useful for showing additional points of view on the possibilities of materials, circuitry and programming.

The participants were also asked whether the experience had changed their opinion about technology. While half participants declared that they were already aware of the importance of the technology, the rest of the participants stated that the experience was important for improving their awareness.

7 Discussion

The answers from the questionnaire seem to capture a positive pedagogical path. The students started from a situation of zero knowledge and arrived at the development of meaningful design and the final perception of the importance of the work done.

During the experience, the students acquired new skills such as using previously unknown materials and components, soldering and programming. While at the beginning the students were guided, most of them demonstrated a good level of autonomy in using their new skills, when they worked on their projects.

We supported them with periodic checks in person or through videoconference conversations. The level of support never went beyond the suggestion of how to operate to solve a specific problem.

All the design and practical operations were done by the students themselves. Most students described reasonable hypotheses for the technical realisations. They went beyond the set of sensors and actuators that they could experience directly in the previous days. Many groups demonstrated that they had acquired a methodology of work, visible since the selection of the components used in their projects. The students introduced capacitive sensors for the input and traditional canvas as a support for thermochromic paintings, experimented with new electrical circuits for composing their creations, seeking information on the Web or asking teachers for advice. The students were not afraid of technology, and they tried new solutions for implementing their concepts.

The conceptual elaborations were made possible, thanks to the knowledge of the technical mechanisms explained and experimented with in the workshop. The single technical mechanisms were in many cases creatively composed in the conceptual definition of the students' work, going beyond the schemes that had been used in the workshop, at the service of the expressivity of their work.

According to our initial expectations, the students shifted from the role of users to the one of makers. They imagined different contexts where to place their artefacts. These social situations were often the primary component of the conceptual proposal that required a physical or a virtual presence as in the case of the use of the social network Twitter.

The students interpreted the relation between *materiality* and *digitality* in different modalities. Often the digital part of their proposal was hidden under the hood for the visitor, presenting the experience as a *magical* interaction between different materialities (the components of the installation and the user), for example, in the *Da mano a mano* installation. Of course these conceptual proposals would not have been possible without the acquired knowledge about the sensors and actuators of a digital system. In other cases, students mixed the materiality of origami models with the digital social world, imagining a sentient framed origami model reacting with a pulse to the messages received from the associated Twitter account. The practical demonstration of the properties of the materials triggered a positive interest towards the search for new components that could react to additional environmental variables, for augmenting the expressivity of the projects' design.

The final recap questionnaire captured good results for what concerned the engagement. As stated in the previous section, the parameters that characterise the engagement capture different complementary aspects of the experience, from the *traditional* usability to the cognitive and emotional involvement and to the aesthetic values, particularly important for the specific educational context in which the workshop was organised. We obtained positive scores for all these parameters, as evidenced in the previous section (and in Table 5). For all the parameters, the highest values were registered for the smart materials' manipulation. Also, the Arduino-based activities gained good scores, with a preference for the activities related to the *concrete* realisation of the circuitry rather than to the *abstract* programming. The results are coherent with the tradition of the Fine Arts Academies in Italy that emphasises the importance of the practical experimentation with physical materials versus the theoretical speculation.

The answers to the open questions show that the experimentation contributed to enlarge the possibilities of artistic expression, leading in a significant number of cases to identify the use of smart materials as a possibility for the future activities of the students. The answers to the questionnaire show also that while in a number of cases the students were already aware of the importance of technology, the realisation of the workshop had a positive pedagogical role for increasing the perception of its role.

8 Conclusions

For the workshop ideation, we followed the traditional educational path of the Fine Arts Academy, directed to the production of works of art rather than to mere theoretical speculation. We introduced new technologies and allowed students to manipulate new materials, with the final goal of stimulating them towards new forms of artistic expression.

At the end of the project, we may conclude, both from the observation of the work done and from the comments expressed in the questionnaire, that we succeeded in reaching this goal. The students successfully took the lead and reinterpreted the technological bricks we gave them for their own purposes, making the new knowledge part of their own creational process. The workshop was also a confirmation of the role that smart materials and low-cost programmable platforms may have for expressing creativity in new shapes. The organisation of a small art exhibition, discussed with the students at the end of the experience, might be an additional occasion for disseminating the knowledge about SMIs and DIY, displaying the results in terms of creative solution, collecting the visitors' opinions and stimulating the students to shift from the status of users to that of makers.

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MindMusic: Playful and Social Installations at the Interface Between Music and the Brain

Tim Mullen, Alexander Khalil, Tomas Ward, John Iversen, Grace Leslie, Richard Warp, Matt Whitman, Victor Minces, Aaron McCoy, Alejandro Ojeda, Nima Bigdely-Shamlo, Mike Chi and David Rosenboom

Abstract Single- and multi-agent installations and performances that use physiological signals to establish an interface between music and mental states can be found as early as the mid-1960s. Among these works, many have used physiological signals (or inferred cognitive, sensorimotor or affective states) as media for music generation and creative expression. To a lesser extent, some have been developed to illustrate and study effects of music on the brain. Historically, installations designed for a single participant are most prevalent. Less common are installations that invite participation and interaction between multiple individuals. Implementing such multi-agent installations raises unique challenges, but also unique possibilities for social interaction. Advances in unobtrusive and/or mobile

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devices for physiological data acquisition and signal processing, as well as computational methods for inferring mental states from such data, have expanded the possibilities for real-world, multi-agent, brain–music interfaces. In this chapter, we examine a diverse selection of playful and social installations and performances, which explore relationships between music and the brain and have featured publically in Mainly Mozart's annual *Mozart & the Mind* (MATM) festival in San Diego. Several of these installations leverage neurotechnology (typically novel wearable devices) to infer brain states of participants. However, we also consider installations that solely measure behavior as a means of inferring cognitive state or to illustrate a principle of brain function. In addition to brief overviews of implementation details, we consider ways in which such installations can be useful vehicles, not only for creative expression, but also for education, social interaction, therapeutic intervention, scientific and aesthetic research, and as playful vehicles for exploring human–human and human–machine interaction.

Keywords Brain–computer music interface · Wearable EEG · Physiological computing · Affective computing · Music cognition · Digital music instruments · Interactive media installation · Virtual reality · Experimental music · Neurogaming

1 Introduction

Musical performance and perception are tightly bound with the immediate environment. If we adopt an ecological perspective (Gurevich and Fyans 2011), we can consider musical experience to be contextualized with respect to a system

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comprising performers, their instruments, and the audience. This musical ecosystem gives rise to a complex set of interactions that drive the performance–perception dynamics. For example, it has been demonstrated in the acoustic setting that musicians adapt their performance based on environmental settings through closed-loop acoustic-to-sensorimotor mechanisms (Ueno et al. 2010). Similarly, the audience is attuned not only to the performance environment (DeNora 2000) but also to the performer intention (Broughton and Stevens 2009), expressiveness, and even social context. This sensitivity to social context extends even to that of the performers themselves—a finding supported by recent studies which have shown that a listener's perception of musical expressivity is influenced by whether the musician observed is playing solo or in an ensemble (Glowinski et al. 2014). The concept then of an ecological approach to musical performance with all the social, emotional, cultural, and perceptual complexities that such a viewpoint entails is a natural capture of such observations and provides a suitable framework within which to discuss the musical interfaces highlighted in this chapter.

The advent of digital music has led to the creation of new disruptive musical ecologies such as DJing or listening to music privately in public spaces (Gurevich and Fyans 2011). These have provoked fresh thinking regarding the nature of musical interaction, and the emerging synthesis is that digital musical ecologies are ushering in a world of hitherto unavailable musical experiences, which we are only now beginning to explore and understand. At the vanguard of this enquiring, speculative movement are multi-agent installations and performances that use physiological signals to establish an interface between music and the brains and/or bodies of performers and their audience (Miranda 2014; Nijholt 2015). Such instruments have a surprisingly long history and can be traced back to the development of the electroencephalophone by Drs. Furth and Bevers circa 1943 at the University of Edinburgh (Henry 1943). This device performed sonification of electrical measures of brain activity (the electroencephalogram or EEG) for the purposes of neurodiagnostics and demonstrated for the first time that brain state could be used to generate sound—a precursor to a brain-driven musical interface. The volitional modulation of such sonified brain activity—in effect creating a musical instrument—was subsequently first demonstrated in a significant way by Alvin Lucier in his piece "Music for Solo Performer" in 1965. This electroencephalophone used alpha band EEG measured across the temples to drive percussive instruments. Lucier would intentionally alter his level of alertness and hence modulate alpha band power to alter the sound levels produced and the musical expression obtained (Loui et al. 2014). This approach was developed further by others including early brain music pioneer David Rosenboom who drew acclaim for a number of significant experimental music compositions using such methods in the 1970s (Rosenboom 1999). Since then, the idea of using direct coupling between brain state and music generation has been explored in many contexts, typically under the broad definition of brain–computer music interfaces (BCMI) (Miranda 2014). However, the complexity and cost of the technologies involved have limited installations primarily to single participants. Recently, however, inexpensive wearable physiological sensors including EEG systems have become available. These devices, together with robust, wireless networking technologies, are facilitating the creation of new distributed musical experiences, which can for the first time relatively easily couple performers and/or their audience in direct brain-to-music interactions.

In this chapter, we examine a diverse selection of playful and social installations and performances, exploring relationships between music and the brain. These have all been featured publically at Mainly Mozart's annual *Mozart & the Mind* (MATM) festival in San Diego (Fig. 1), which combines scientific and artistic presentations, performances, and concerts, and interactive exhibitions to explore the impact of music on our brains, health, and lives. Several of these installations leverage neurotechnology (typically novel wearable devices) to infer brain states of participants. However, we also consider installations that solely measure behavior as a means of inferring cognitive state or to illustrate a principle of brain function.

We first describe three installations exploring relationships between musical rhythm and cognitive function: *Interactive Gamelan*, by Alexander Khalil, Victor Minces, and Andrea Chiba, examines the relationship between attention and interpersonal synchrony in a group music setting. *Brain/Sync*, by John Iversen and

Fig. 1 Mainly Mozart's *Mozart & the Mind* festival, held annually in San Diego, California, is a series of presentations, performances, and interactive expositions exploring intersections between music and neuroscience, cognitive and social sciences, and health

Tim Mullen, explores parallels between rhythmic synchronization within a group ensemble and synchronization in the brain; *NeuroDrummer*, by Matt Whitman, explores novel closed-loop cognitive therapies via an immersive virtual reality rhythm game. Next, we describe *The Floating Man*, by Alejandro Ojeda, Nima Bigdely-Shamlo, Aaron McCoy, and Tomas Ward, which explores the use of an EEG-based measure of engagement for real-time navigation of a streaming musical service. Finally, we describe three multi-person installations and performances leveraging EEG-based measures of cognitive and affective state within a musical performance context: Richard Warp's *Spukhafte Fernwirkung* is a compositional duet combining brain-driven, algorithmic music generation with live musical improvisation. *MoodMixer*, by Grace Leslie and Tim Mullen, composes new music based on the combined cognitive and/or emotional state of multiple participants. *Ringing Minds*, by David Rosenboom, Tim Mullen, and Alexander Khalil, explores novel concepts in neural hyper-scanning and active, imaginative listening to create a unique performance in which the collective brain responses of four individuals interact with a spontaneous electroacoustic musical landscape. Throughout the chapter, we briefly describe implementation details of each installation, and we explore their utility as playful vehicles for creative expression, education, social interaction, therapeutic intervention, scientific and aesthetic research, and as new media for human–human and human–machine interaction.

2 Interactive Gamelan

Gamelan is a type of traditional music found in many parts of Indonesia. The word "gamelan" literally means "percussion" and also refers to a type of orchestra that features mainly metallophones (metal-keyed pitched percussion instruments) along with various drums, gongs, and occasional string or wind instruments. Gamelan music of all types and genres highly emphasizes synchrony among players. We use synchrony to describe not simply moving together in rhythmic unison but rather as the coprocessing of time: a shared sense of the passage of time that facilitates tight coordination. This is commonly expressed in Gamelan music as a single melody distributed between multiple players. The Interactive Gamelan, developed by Alexander Khalil, Victor Minces, and Andrea Chiba, is an installation based on techniques and methods developed for experimental measurement of synchronous human interaction in a musical context. Gamelan is for us both a metaphor for interpersonal synchrony and an efficient method of collecting data. The Interactive Gamelan provides a real-time visualization of temporal relationships within and across multiple nested timescales between players in an ensemble. In spite of the complexity of these relationships, the visualizations are simple enough that players can immediately use them to improve synchronous playing or to explore rhythmic relationships.

2.1 Installation Design

Interactive Gamelan is based upon work that examines the relationship between interpersonal synchrony in a group music setting and other cognitive characteristics, especially the ability to focus and maintain attention. The methodology that underlies Interactive Gamelan was developed to collect data in the ecological, or "real-world," setting of a music class as students attempt to synchronize with an instructor as well as—and sometimes in spite of—each other. This idea is more than simply an ecological version of tasks that involve tapping with a metronome because it affords insight not only into individual differences in performance that may underlie aspects of cognition important to learning but also into group temporal dynamics.

In order to make such measurements, we constructed a set of pitched percussion instruments modeled after a traditional type of Gamelan from the island of Bali, known as angklung (Fig. 2). Gamelan angklung is perhaps the most simple form of Gamelan, featuring an orchestra of bronze-keyed metallophones tuned to a four-tone scale. Affixed to each key of each instrument were contact microphones that allowed each keystroke of each player to be recorded in isolation during a group session (Fig. 3). Signals from each keystroke were recorded via an audio digital converter into a computer. Each player's level of synchrony was assessed according to vector strength (Goldberg and Brown 1968). The resulting synchrony score for each player was then correlated against his/her performance on measures relating to attention. A significant correlation was found across all measures. This indicates that the cognitive processes that underlie the ability to synchronize may also underlie attention and learning (Khalil et al. 2013). The fact that it is possible to improve a person's ability to synchronize through rhythm training suggests that such training may have an effect on ability to attend. Currently, this project is directed toward long-term experiments that investigate this possibility.

Fig. 2 Children playing the Balinese Gamelan angklung instruments upon which Interactive Gamelan was designed

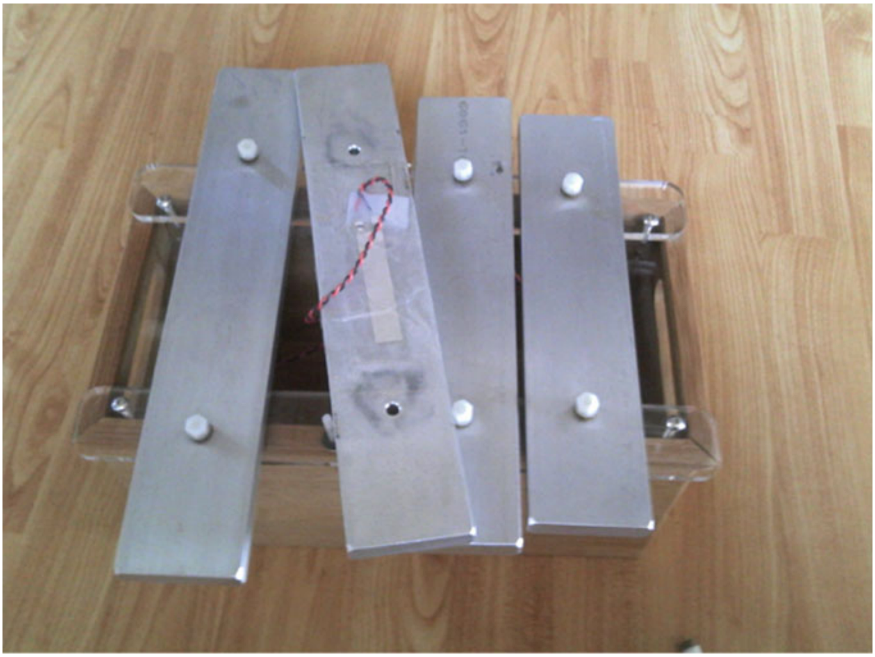

Fig. 3 An Interactive Gamelan instrument with contact microphone

2.2 Synchrony Visualization

Interactive Gamelan features the methodology described above with the addition of a real-time visualization that can be used for training or exploration. Up to sixteen players may participate at one time. In Interactive Gamelan, the beat is visualized as a circle. Each beat played by a lead player is represented by a white line sweeping around the display, giving the impression of a radar console. The display also features concentric rings of various colors. Each of these rings represents one player. Each time a player strikes their instrument, a dot is displayed on the corresponding ring. If a player strikes at exactly the same time as the lead player, the dot will appear at the 12:00 position of that player's ring. If he/she strikes ahead of the lead player, the dot will appear to the left of 12:00, and if he/she strikes after the lead player, the dot will appear to the right. Each key of each instrument is represented by a dot of a different color: light blue = G−; purple = A+; red = B−; and pink = D. These colors were selected simply because they appeared to the authors as easy to differentiate from each other (see Fig. 4).

The display simultaneously represents the rhythmic performance of players across three nested timescales. At the scale of tens of milliseconds, the timing of strikes between players is represented as the relative distance between dots on the screen (see Fig. 4). At a timescale of hundreds of milliseconds, the timing of the

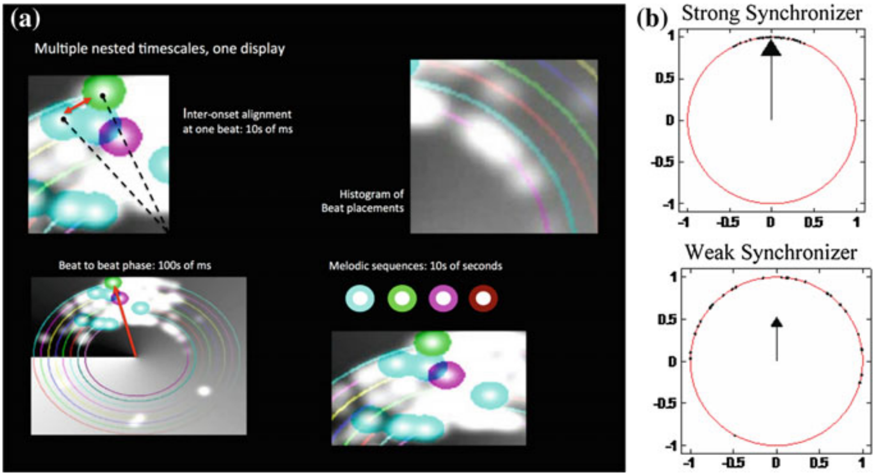

Fig. 4 **a** Details of the multiple nested timescales depicted in Interactive Gamelan's "radar display." The full "radar display" is shown in the *lower left corner*. The outermost ring represents the lead instrument with its onset indicated by a *green dot*. The other rings each represent a different instrument. The *blue dots* indicate they are playing the note G−. **b** Example of a good synchronizer (*top*) and a weak synchronizer (*bottom*). The *black dots* comprise a histogram of phase relationship for each onset in relation to the beat of the leader. The size of the *arrow* indicates overall vector strength

interval between consecutive beats is represented by the relative position between dots in a sequence. At the largest timescale, melodic sequencing of notes is displayed by the color sequence of dots. Beyond this, each dot leaves behind a white trace. These traces remain on screen throughout each session. The spread of these traces can indicate how consistent a player is in relation to the beat.

At any point, the lead player can stop the session by tapping out 4 beats in quick succession. This will freeze the display and a new window will open displaying a graphic that provides feedback regarding consistency of synchrony with the leader and on average whether they tend to play ahead of or behind the beat. In this way, Interactive Gamelan can give real-time, immediate feedback and can also give feedback at the conclusion of a session. Players may choose to watch the screen and adjust accordingly or focus only on playing and receive feedback when they have finished, or both.

The Interactive Gamelan was deployed as an installation at MATM in 2013. Guests were invited to try traditional gamelan pieces with a teacher and also to experiment on their own. Players quickly learned to read the radar screen at a glance and used it in order to try and improve their synchrony. Notably, very many players first tried to identify themselves on screen by playing intentionally "off" the beat, often commenting something like "look, that's me!" Many players were at first wary of receiving negative feedback, but quickly they began to explore the potential of the system. Some did so by trying different rhythms to see how they would be

Fig. 5 *Mozart & the Mind* participants trying Interactive Gamelan with gamelan instructor I Putu Hiranmayena

represented on the display. Naturally, these efforts involved a collaborative effort in which participants would have to work together to produce group rhythms. I Putu Hiranmayena, a Balinese Gamelan instructor, was on hand not only to help teach Balinese rhythms but also to facilitate these group interactions, suggesting rhythms and sequences and helping people stay on the beat (see Fig. 5).

Interactive Gamelan is not based on absolute latency—whether players are striking their instruments at exactly the same time as the leader—but rather on consistency in relationship to the leader. This means that Interactive Gamelan is well suited for the Internet, where some latency is unavoidable but phase relationship can be maintained. A version could be developed that could be played by multiple players online interacting in a virtual rehearsal or concert space.

Immediate plans for Interactive Gamelan involve using it in the context of multiplayer EEG recording. Such recordings afford many advantages in terms of collecting data in an educationally relevant setting. For example, a classic EEG paradigm would feature a sequence of expected and unexpected events. One would predict that the unexpected events would elicit a different brain response. In multiplayer Interactive Gamelan recording, players create their own unexpected events by occasionally losing the beat. These naturally occurring events are much more data-rich than contrived ones. Aside from brain response to these events, peri-event brain states could be analyzed. In this way, as Interactive Gamelan seeks to represent interpersonal rhythmic dynamics, the addition of multi-player EEG recording would allow these dynamics to be explored at the neural level.

3 Brain/Sync: Making Synchronization Come Alive

One of the most exciting areas of neuroscience is the study of connections within the brain. Advances in our ability to trace neural pathways and examine how remote brain regions coordinate their activity have emphasized the importance of brain networks for understanding the richness of human behavior (Alivisatos et al. 2012; Hagmann et al. 2008; He et al. 2009). In particular, synchronization is a central mechanism in both the brain and our interpersonal interactions (Patel and Iversen 2014). In the brain, groups of neurons can become synchronized to form flexible and powerful neural circuits. In music, synchronization between performers is crucial, while the synchronized movements of dance are found in every culture and have been hypothesized to play a central role in interpersonal communication (McNeill 1997).

Brain/Sync was originally developed, by John Iversen and Tim Mullen, to follow and reinforce a MATM talk by John Iversen, Anirrudh Patel, and Aiyun Huang called "Rhythm, Music, and the Brain: A Dialog on Neuroscience and Percussion." The talk included discussion of the neuroscience of rhythm and synchronization, as an important organizing principle of brain function. Brain/Sync was designed to make these concepts come alive for participants by providing them interactive, visceral insight into concepts of synchronization—both in music and in the brain—as they create rhythms together and form a network of communication through data analysis of the same type we use to understand synchronization in the brain.

3.1 Installation Design

Brain/Sync was built around a system previously used in our experiments on human interpersonal synchronization (Iversen and Patel 2008). Figure 6 illustrates the system design. A set of six piezoelectric handheld drum pads (Pulse BD-1) provided an input surface that participants could hold and tap or slap on. Pads were wired through a trigger to midi converter (Roland TMC-6) and routed to custom software, created in Processing,[1] for analysis and visualization of phase synchrony between participants' rhythms. A rhythm network was visualized as a ring of colored circular nodes, each corresponding to an individual. Input to each drum pad

[1]Processing code available at (http://www.openprocessing.org/sketch/174919) and was adapted from the sketch "Network Excitation" (http://www.openprocessing.org/sketch/63796).

Fig. 6 *Left* System diagram. *Bottom to top* Rhythmic input from six drum pads (plots below each pad show time series of beats) is converted to MIDI with phase relationships quantified and visualized in processing. The network plot (*top*) shows each drummer as a circular node and displays links between participants who are creating synchronous rhythms, as quantified by a low standard deviation of relative phase. *Right* Participants engage with Brain/Sync at *Mozart & the Mind* 2013

caused the associated node to pulse, providing visual feedback. Audio feedback, with a different instrument sound for each pad, was also provided. Participant tapping time series were analyzed using circular statistics (Fisher 1993). Tap times were first converted to relative phase with respect to each of the other participants. Relative phase is a normalized measure of the time of each tap relative to the nearest taps of another individual. Synchronization between each pair of performers was calculated using the circular standard deviation of their relative phase over a sliding 5-second window to quantify the stability of timing between each pair of performers. Low values correspond to performances that have a consistent phase relationship, and thus high synchrony. The real-time status of the network was visualized using dynamic links between performers who were in sync. The circular standard deviation was mapped to the width and “excitation” of each line, whereby greater coupling was displayed as wider, more dynamic links. The network state in Fig. 6, for example, represents a transient network created in a group of six participants, three of which are tapping in sync.

3.2 Discussion

Participants seemed to greatly enjoy interacting with the installation. After tentatively creating their own rhythms, synchronization sometimes arose spontaneously, and other times, it had to be suggested by the experimenter. The participants were coached to try to create two independent sub-networks by tapping in time with a group of three people, while trying to be as unsynchronized as possible with the other group of three. The experience usually ended with everyone coming in sync and creating a fully connected network graph. Perhaps most importantly, it became a natural environment to discuss the concepts of synchronization and networks, as well as ask questions about the preceding experiment.

Brain/Sync has many applications beyond its initial incarnation and would benefit from being examined more generally as a novel interface for interactive education, group rhythm training, and as a tool for current and future cognitive experiments studying the impact of rhythm on the brain. For example, to deliver a more technical understanding of synchrony, such as in a neuroscience class, different candidate measures of synchrony in real brains could be compared, such as phase synchrony, or a measure of causality, with each participant acting as a single "neuron" or neuronal group in the larger brain. Brain/Sync could be embedded in a larger context, with sensory input and motor output to create a proto-brain able to discriminate sensations and create actions. In music, it could be configured as a way to examine group social and temporal dynamics among an ensemble of performers, which could have artistic and pedagogical applications. Synchrony is a fundamental language of the brain, and of human culture, and its exploration deserves to be brought to a wider audience.

4 NeuroDrummer

NeuroDrummer, by Matt Whitman, was a bold interactive dive into virtual reality (VR), live rhythm performance and visualization, and demonstration of closed-loop neurotherapeutic gaming. Here, we explored the intersecting passions of UCSF neuroscientist Dr. Adam Gazzaley and Grateful Dead Rhythmist Mickey Hart within the unifying theme of "Rhythm and the Brain." Music and rhythm training have been shown to significantly affect brain plasticity and may remediate specific age- or disease-related impairments in cognitive and motor function (Herholz and Zatorre 2012). Additionally, interactive cognitive games are now being seriously investigated as an alternative to pharmacological neurotherapeutic interventions. A recent study, published in *Nature* by Dr. Gazzaley and colleagues, demonstrated that playing an interactive game, which incorporated an adaptive multitasking component, resulted in sustained, transferrable improvement in multitasking, attention, and working memory in older adults (Anguera et al. 2013).

NeuroDrummer was conceived as a prototype of near-future, playful interfaces for neurotherapeutic intervention as well to illustrate rhythm and cognition experiments now underway at the UCSF Neuroscape Lab. Furthermore, it served as a novel VR-based musical and artistic performance medium for live performances by Mickey Hart throughout 2014, concluding with Mainly Mozart's MATM festival in La Jolla, CA. To our knowledge, these represented among the first live musical performances from within VR.

4.1 Installation Design

The NeuroDrummer game environment (Fig. 7) consisted of a fully 3D virtual environment and rendered using an Oculus Rift VR headset. The primary interactive controller was a Roland HPD-20 digital MIDI hand drum, featuring 13 programmable interactive regions within four quadrants and an infrared MIDI trigger. Gameplay/performance occurred along a predetermined path through an extraterrestrial universe. Therein, Grateful Dead-inspired psychedelic visuals and colored projectiles were continually generated in response to Mickey Hart's drum performance and the specific pressure applied to the regions of his MIDI drum. A dynamic electronic music track, composed by Mickey Hart and Jonah Sharp, provided a constant musical texture over which Mickey rhythmically improvised.

Fig. 7 *Top* Live performance at Dr. Gazzaley's Nvidia GTC keynote address, San Jose 2014. Mickey Hart performs with NeuroDrummer (*left display*), while Tim Mullen navigates a real-time "Glass Brain" model of Mickey's active brain in VR (*right display*). *Center-left* Mickey Hart wearing Oculus Rift, Cognionics EEG Cap, Oculus Rift, and earlobe heart monitor. *Top-right* Stereoscopic Gameplay. *Bottom* NeuroDrummer and Glass Brain performance at *Mozart & the Mind* 2014

NeuroDrummer incorporated a playful multitasking component requiring Mickey to repeatedly switch between two behavioral tasks throughout the game. As Mickey maintained his rhythmic, improvisational, groove (Task 1), the game determined suitable time points to interrupt this task by launching what he perceived as massive 40-ft asteroids, flying straight toward him from universes beyond. Mickey's goal (Task 2) was to, as rapidly as possible, detect and shatter the asteroid, by swiping his arm through it in virtual space. To achieve this physical interaction, we used the vertically emitted infrared "D-Beam" trigger featured on the HPD-20 drum. The intersection of the forward arm motion with the D-Beam provided a MIDI trigger to the game, closing the interactive loop.

4.1.1 Creative Decisions

A key challenge was to make NeuroDrummer a truly immersive and enjoyable world wherein Mickey could creatively express himself. Creating a VR environment suitable for a live performance presented its own unique challenges. VR is infamous for its tendency to induce nausea. A possible cause for this is mismatch between visual and vestibular (proprioceptive) sensory input (Hettinger et al. 1990). Our design solution was to provide as close a match between what Mickey was seeing and what he was experiencing proprioceptively, at all times. For instance, rather than allowing for free movement and dynamic acceleration, gameplay occurred along a predetermined path with a constant forward velocity. Head motion was unrestricted allowing for active exploration of the local environment. This allowed rich dynamic visuals to continually emerge around Mickey as he "moved" through space, while also maintaining a neutral acceleration profile. This is much like watching passing scenery while standing inside a train moving straight at a constant velocity: If motion is smooth enough, it all can feel as stable as one's living room.

The visuals within the generative universe were all based on Mickey Hart's artwork, developed over the years. His legendary drumhead paintings became planet textures, murals became textured entrances to four-dimensional space tunnels, and planetary-scale representations of the iconic Grateful Dead skeletons danced playfully with the beat. To create an engaging and surreal environment, we explored interesting visual concepts such as multi-dimensional hypercube projections, something that can only be done properly in VR as a 4D to 3D projection. The trajectories of colorful projectiles, generated in response to drum interaction, were determined by 3D head orientation such that they appeared to emanate from the player, providing another dimension of creative control and immersion.

Other design choices were intended to increase presence and even elicit an "out of body" experience within the VR domain. A recent study (Aspell et al. 2013) demonstrated that integration of exteroceptive and interoceptive signals within a virtual environment, specifically synchronous visualization of one's heartbeat on a virtual body, increased self-identification, self-localization, and tactile localization toward the virtual body. To explore this, we modified an open-source Arduino-based earlobe pulse oximetry heart rate monitor (SparkFun PulseSensor) to provide a real-time heartbeat signal to the game. When Mickey looked down at his virtual avatar (represented as a skeleton), he was able to see a real-time 3D representation of his heart pulsing within his chest. The other dancing skeletons' pulsing hearts were also synched to Mickey's heartbeat. Back in physical reality, an LED necklace worn by Mickey, pulsed in synch with his heartbeat.

4.1.2 Closing the Brain–Body Loop

NeuroDrummer performances were complemented by an immersive live brain visualization called *The Glass Brain*, led by UCSD/SCCN/Syntrogi neuroscientist Tim Mullen with Dr. Gazzaley and colleagues at UCSF. This applied advanced real-time brain mapping techniques developed by Mullen and Kothe (Mullen et al. 2014; Mullen 2014), to electroencephalography (EEG) data recorded from Mickey's brain during gameplay using a novel 64-channel wireless EEG system (Cognionics Inc., San Diego, CA). Spatiotemporal reconstructions of brain activity and information transfer (connectivity) were superimposed in real time on a 3D structural model of Mickey's brain tissue and fiber tracts, obtained previously from MRI. This "4D" model of Mickey's active brain was rendered in a separate VR environment and could be navigated in real time by a second participant using a gamepad.

Ongoing work is focused on adapting gameplay in response to these real-time measurements of brain activity related to cognitive control, as well as behavioral task performance. The ultimate goal is to restore and enhance cognitive function impaired by age or by disorders such as ADHD.

NeuroDrummer represented an exciting prelude into experimental studies now underway. In developing this project, we gained a deeper understanding of the available tools and possibilities for future immersive neuroadaptive interfaces that produce healthier brains and minds as well as provide novel vehicles for playful, creative expression.

5 The Floating Man

The Floating Man installation was developed by Alejandro Ojeda, Nima Bigdely-Shamlo, Aaron McCoy, and Tomas Ward. The installation presented an interactive musical experience that experimented with emerging inexpensive EEG-based neural interfacing technology, novel processing infrastructures, and computationally lightweight brain-state estimation algorithms to explore alternative means of navigating a streaming musical service.

In recent years, there has been a dramatic shift in how people access music. Where previously people would buy a copy of the music for private playback, which is the case when buying a compact disk or downloading an MP3, a more popular approach is to subscribe to an on-demand musical streaming service. In this latter case, the listener does not necessarily purchase a file for download. These streaming services (e.g., Spotify, Pandora, Grooveshark) often offer a personalized listening experience where, based on a listeners likes and dislikes, and crowd-sourced knowledge, ever better suggestions are offered in terms of matching the musical preferences of the listener. The process, which drives this personalization activity, begins at the level of the individual and is measured by offering the listener an opportunity to tag the current music with “like” or “dislike” labels. These data are processed by a recommender engine in order to better refine future musical offerings (Song et al. 2012).

This Floating Man, presented as an installation at MATM in May 2014, was developed then to explore how wearable neurotechnology might be used to make the necessary feedback mechanism less reliant on conscious effort on the part of the user. Furthermore, in an effort both to experiment with socialization concepts through which internal state could become a shared experience and to translate musical experientialism into engaging visual metaphors, a dynamical graphical representation was created to complement the installation.

5.1 Installation Design

From a technical perspective, the installation was built around concepts in pervasive and ubiquitous computing (Greenfield 2006) and in particular the idea of detecting music listening preferences through neural interfaces. In this case, a wearable computer comprising a set of EEG electrodes on the scalp (providing input), an integrated analog front end, and a custom preprocessing stage implemented as an embedded system (Cognionics Inc., San Diego) was used to extract and digitize physiological signals bearing brain-state information. The wearable system terminated in a radio link (Bluetooth) which conveyed the resultant measures of neural activity to a localized, distributed, processing architecture (Syntrogi Inc, San Diego). These signals—derived from a 4-channel electroencephalographic montage—carry in a very coarse manner, aspects of cognitive user state. Through the use of algorithms available in the neuroscience literature which tentatively suggest that attention-related states can be discerned from such a low-density electrode array, a basic neurorecommender engine was created over a small set of music. Music presentation began with a random choice from the available set and was played until the measure of attention fell below an adjustable threshold value for an extended period. Once this happened, the music player advanced to another piece from the available set.

The interaction dynamics was based around a simple state transition algorithm illustrated at a high level in Fig. 8. The user, while attentive to the music being played, retains the floating man at a “ground level” between the two hemispheric measures of EEG. As this attention level drops, the character, which can be

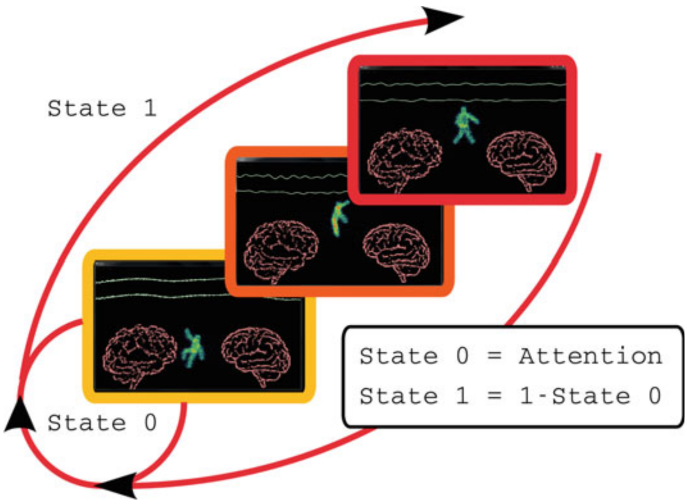

Fig. 8 Top level state transition illustration for gameplay

considered an avatar, rises and floats away from the ground state. As this less attentive state persists, the avatar will rise to a point high on the screen triggering a transition to a new musical track and a reset to State 0 which is assumed attentive at the beginning of each track. The process repeats to reveal a measure of musical interest across the set of tracks.

5.2 Discussion

The Floating Man installation evoked interest and comment from all who interacted with it. The idea that music and cognitive responses could be coupled through a very visual experience elicited a range of opinions regarding sense of agency, interactive enjoyment, affective awareness, and experiences. As a novel form of interaction with a music streaming service, it demonstrated a basic proof of concept that is clearly a harbinger of things to come. Perhaps most interesting is the glimpse given of the potential that wearable sensing and pervasive, ubiquitous computing systems may offer in improving everyday living. In particular, the distributed computing platform, which here processed the data, stored intermediate results, and in the local (client-side) application produced an interactive visual experience, is an example of an emergent class of computing services which can in the future understand who we are as individuals, anticipate our needs, react to changing moods, and ultimately enhance our quality of life.

6 *Spukhafte Fernwirkung* (Spooky Action at a Distance)

It is certainly not out of a particular bias toward the German language that the name for this work was chosen. It is more out of identification with the idea of "spooky action at a distance," a term once used by Einstein to describe quantum entanglement. This theory deals with the idea of conjugate variables—in our case, the mind and the body, and the fact that observing one necessarily means that the other will be less accurately observed, due to the special, symbiotic nature of their relationship. *Spukhafte Fernwirkung*, developed by composer Richard Warp, is described here as a musical installation for two performance partners, one wearing an EEG headset and the other seated at a piano. However, this work has also been formulated as a solo performance, where the pianist also wears the EEG headset and "plays both parts."

6.1 Installation Design

In *Spukhafte Fernwirkung*, which debuted at MATM in May 2013, we explore biofeedback using the Emotiv EPOC 16-channel EEG headset worn by an audience member (the "performance partner"), which communicates with a custom Max/MSP interface to generate stochastic musical patterns that are blended with improvisations by a pianist. There is no prewritten score—the experience is an exploratory one. The performance partner learns to re-evoke each separate trained thought, using the neutral state as a baseline, while Emotiv's proprietary machine learning algorithm optimizes the detections of these patterns. While it is not clear how accurately the software's training module correlates with the user's actions and intentions, the sensor hardware has been judged to be of acceptable quality for non-medical applications (Duvinage et al. 2012), indicating that any analysis being performed is using relatively reliable source signals. Setup and training last approximately 10 min, after which the performers engage in a live session.

Data from the performance partner's incoming brain signal are sent from the headset as Open Sound Control (OSC) data packets into Max/MSP, where the data are received via UDP and processed into musical output.

In the Max/MSP patch, the "musical material" and "register" cognitive values are routed to an array of probability tables that determine if a note is to be played or not, then to a weighted random number generator constrained to 12 pitch classes, and the output fed into a 16-step sequencer. The random intervallic range narrows as the strength of the cognitive command increases such that, while still random, it is constrained at the upper limit to perhaps just between a few notes. The resulting musical effect is one of a "shimmer" at higher intensities, and a more sporadic, distantly intervallic sequence at lower intensities. The values from the sequencer output are converted to MIDI and sent to a piano keyboard for playback (Fig. 9). The pianist's role in this installation could be described as interpreter/improviser,

Fig. 9 Richard Warp (*right*) improvises on the keyboard in response to musical patterns generated by a guest performance partner (*lower left*), wearing an EEG headset. *Mozart & the Mind*, 11 May, 2014

whose goal is to support and highlight the musical patterns being generated by the performance partner through intelligent and sensitive improvisation.

The orthogonal "register" command shifts all selected pitch classes up by up to three octaves (C3–C5) according to intensity of the signal. An auto-regression function is applied to the "musical material" signal that ramps down otherwise-spiky signals over time, thus allowing for overlap of the "register" signals in order to pitch shift the note choices.

Emotiv's Affective Suite values are being used in this installation to modify harmonic content, dynamics, and tempo. A harmonic filter is applied in Max/MSP to the prevailing affective state, drawn from Emotiv's proprietary indices for "meditation," "Frustration," and "Excitement." Excitement remaps notes generated to neighboring intervals in the major scale, Frustration to the minor and meditation to the Whole-tone scale. Tempo operations also respond to the dominant affective state, where excitement is mapped to 130 BPM, Excitement to 90 BPM and Frustration to 100 BPM.

Finally, playback dynamics of selected notes are determined according to the affective state, using velocity and envelope to shape note choices. An excited state, for example, would shift the envelope to have a fast attack and release with high velocity (volume) while a meditative state would effectively hold the sustain pedal while decreasing the velocity, creating a gentle wash of sound.

6.2 Discussion

Each of the dozen or so participants' response to the system during the MATM installation being unique, whether due to the level of overall control over the signals or the focus on one particular signal type over another, the overall musical experience would be inevitably different each time. Further, since the performance partners in the demonstration piece were essentially immobile and it was impossible to read any visual or body clues, there was an immediacy about reacting to the sound on the part of the pianist that goes beyond the usual group improvisation cues that one might find in, say, Jazz. Finally, it was found that there was a palpable difference between expression and intention on the part of the performance partner. When talking to the participants after the event, the question of "how good a level of control did you feel you had over the system" often elicited a response along the lines of "at times, when I meant to do something, it did the opposite." This distinction between intention and expression is a crucial one, since the pianist is predominately reacting only to the expression, and has no way of knowing the goals of the participants once they become familiar with the equivalence between their mental state and the resulting musical output. It is presumed that they will attempt to manipulate the output as part of the performance, but there is no outward physiognomic analogue, whereas in normal improvisation situations one can glean the intention from gestural, facial or contextual cues.

The ongoing development of this work from the relatively simple "sandbox" installation at MATM into an aesthetically compelling contemporary work for piano is a challenging one. The compositional interface was designed to be "plug and play" with minimal training on the part of the performance partner—however the piano performance/improvisation element necessarily requires the skills of an expert musician. Furthermore there is a certain amount of risk assumed on the part of the designer of the system that a particular biofeedback signal can be sustained long enough for a meaningful interaction—an unpredictability that must be factored in and tested at the earliest stages of the work.

It is worth noting at this point that much of the architecture and execution of *Spukhafte Fernwirkung* is predicated on one core assumption—namely that the signals being received from this particular EEG device are valid representations of the mental states that are claimed to be detected. There is much discussion in the neuroscience community regarding the relatively recent influx of Brain Computer Interface devices into the consumer market, the consensus being that while these may be entertaining playthings, they hold no particular scientific value. While this is undeniably true, their potential for use as a new interface for musical expression should not be underestimated. To the extent that it is possible to consciously modulate labeled parameters in real time by "behaving" in a certain way, such devices may pave the way for a new generation of musicians (and non-musicians) to explore new dimensions of music making and artistic expression.

Marshall McLuhan coined the term "the medium is the message" in 1964. In an age of scientific, technological and artistic convergence such as we find ourselves in today, one could employ the corollary of "the interface is the work." The creation of new musical works increasingly implies and requires the creation of the contextual vessel in which to carry them. Hacker culture, ubiquitous computing and social media are all feeding into a new paradigm of creative expression that is both highly specific and almost scientific in its execution, yet capable of achieving global reach.

7 MoodMixer (2011–2014)

The MoodMixer installation project is an ongoing collaboration between Grace Leslie and Tim Mullen exploring new possibilities for playful collaborative BCMI that respond to the mental state of multiple participants. Three distinct versions of MoodMixer were created. Each incorporates both active and passive approaches to real-time EEG-based music generation, and a multi-user design that promotes social collaboration in the experience of the installation. MoodMixer was first presented at the New Interfaces for Musical Expression conference in Oslo, Norway in 2011 (Leslie and Mullen 2011), with subsequent realizations presented at the 2012–2014 MATM festivals in San Diego, CA, USA.

7.1 Installation Design

The MoodMixer system has been presented in three iterations, each with modifications to the EEG hardware, software, or audiovisual feedback. The overall technical architecture is depicted in Fig. 10. Two participants wear wireless EEG headsets. From each user's EEG data, two normalized mental state indices are calculated. These define coordinates within a 2D mental state space, explored simultaneously by all participants. Real-time feedback on each user's position within the state space is provided by a simultaneous visual display and spatial quadraphonic generative music composition. These and other version differences are reviewed in the next sections.

7.1.1 MoodMixer 1.0 (2011)

The first version of MoodMixer used the single-channel NeuroSky Mindset, a relatively low cost, commercially available EEG system. The system featured a headphone design with an additional, moveable arm that placed a single active dry (gel-free) electrode over left or right prefrontal cortex. Reference and ground electrodes were incorporated into the earpads of the headphones. The raw EEG data measured with the electrode, and indexes for "meditation" (relaxation) and "focus" (arousal) calculated directly on the NeuroSky hardware, were streamed via

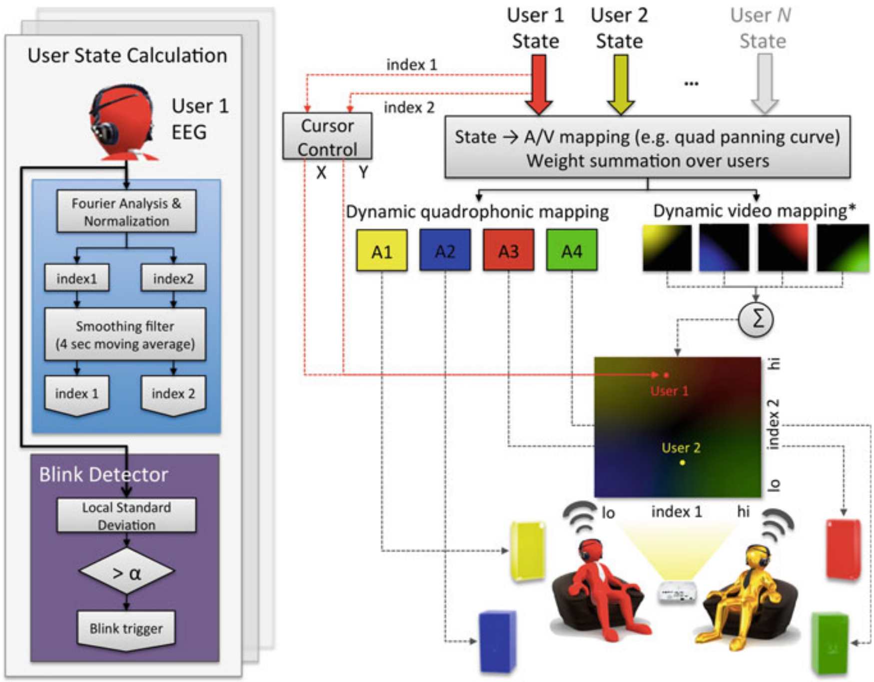

Fig. 10 Architectural diagram of the MoodMixer installation and its typical dual-user quadraphonic instantiation at *Mozart & the Mind*. A two-dimensional mental state space (comprised of two cognitive/affective indices) is explored simultaneously by pairs of MoodMixer users. *A1–A4* represent four dynamically mixed audio tracks each composed to reflect an extremum of the state space. For MoodMixer 1.0 and 2.0, the users' position in the state space is visually represented by a moving dot superimposed on a weighted sum of four-colored spatial gradients. For MoodMixer 3.0, this video mapping was replaced with dynamic blending of video footage from *Four Stream Mind*

Bluetooth to a Max/MSP patch using an external by Kyle Mahulis (www.nonpolynomial.com).

The meditation and focus indices were smoothed using a 4-second moving average filter, and then, a 4-way panning curve was used to dynamically balance amplitudes of a four-channel music composition. Each channel of the mix was composed to represent an extremum of the two-dimensional mental state space, i.e., high relaxation and low arousal were reflected by a soothing zero-beat ambient track, and low relaxation and high arousal introduced a frenetic experimental jazz track. Thus, dynamic amplitude balancing of each track spatially represented the participants' state at each moment.

The meditation and focus indices of each participant were mapped to, respectively, normalized x- and y-coordinates of a colored dot superimposed on a 2D background plane. Four-colored gradients (red, yellow, green, blue), each reflecting an extremum of the state space, were placed in the corners of the plane. Each participant's state additively determined a weighted mixture of the gradients such that a corner glowed proportionately more intensely as both participants' state converged on the respective extremum (e.g., low meditation with low focus, or high meditation with high focus). We found this simple dot + gradient visualization afforded both aesthetic and intuitive feedback regarding each participant's local state and trajectory, as well as the combined states of all participants.

Participants could also optionally generate audiovisual effects by eye blink-driven "gestural control." A blink event was triggered when the relative local standard deviation of the raw EEG signal (over a sliding 200 millisecond window) exceeded a predetermined threshold. Single blinks triggered a short audio sample (e.g., an electronic bass drum stroke) and a brief additive gradient luminance increase. A sequence of three eyeblinks (one per second) triggered a longer musical sequence composed to blend with the 4-channel music mix. Different musical samples could be assigned to each participant's blink gestures.

7.1.2 MoodMixer 2.0 (2012)

The second version of MoodMixer preserved the overall user interaction design, but changed the EEG hardware and analysis, and generative music system. Single-channel NeuroSky headsets were replaced with Mindo 4s headsets, which recorded 4 channels of EEG over the participants' foreheads. *Meditation* and *focus* indices were replaced with *valence* and *arousal* indices. A 2010 study by Lin et al. (2010) demonstrated that positive emotional valence in response to natural music listening was associated with delta (1–3 Hz) power decreases and beta (12–30 Hz) power increases measured at frontal EEG locations, whereas positive changes in arousal was accompanied by increases in both delta and beta power. Thus, a *valence* index was calculated by measuring the ratio of beta to delta band power, and an *arousal* index was calculated by measuring the overall increase in delta and beta proportional to the total mean power across the typical EEG spectrum (1–30 Hz). Spectral band power estimates were obtained using a multi-taper decomposition, followed by $1/f$ normalization. Valence and arousal indices were z-transformed using exponentially weighted moving estimates of mean and variance and finally logistically transformed to produce [0, 1] bounded measures.

A custom Max/MSP patch generated MIDI events for 4 musical instruments (2 pianos and 2 ambient electronic instruments), creating a minimalist-style piece reminiscent of the piano piece *Phrygian Gates* by the composer John Adams. One instrument played out of each of the 4 channels of the quadraphonic mix. As the calculated valence index for one participant surpassed various predetermined thresholds, the mode of the piece (Lydian, Phrygian, etc.) cycled. The calculated arousal index of the other participant was mapped to the tempo of the piece, so that higher states of arousal were interpreted as faster musical tempi. The visual feedback remained unchanged from the previous MoodMixer version.

7.1.3 MoodMixer 3.0 (2014)

MoodMixer 3.0 used new Mindo 4H EEG headsets and replaced the previous audio and visual feedback with *Four Stream Mind*, a 4-channel audio and video installation by Grace Leslie and Maxwell Citron. As in the first version, a 4-directional equal-loudness panning curve mixed a 4-channel electroacoustic music piece that was composed to represent the extrema of the 2D valence–arousal state space. The sum of the valence and arousal indices for both participants controlled a video mixer playing back modified footage of recorded nature scenes from multiple elevations, from deep under the ocean's surface, to high-altitude clouds. As participants' combined valence–arousal increased, the visual feedback gave an effect of rising up in space, and vice versa. The music feedback incorporated field recordings from each of the locations where this footage was recorded.

7.2 Discussion

Brain–computer interfaces have been classified as active or passive (Zander et al. 2010) according to the level of conscious control the participant takes over their experience. The MoodMixer user experience design could be classified as active or passive depending on the experience level of the users. For the inexperienced, a passive design involved unobtrusively monitoring the users' cognitive state and producing an audiovisual representation of that state without any attempt by the users to influence it. This approach was taken by Steve Mann, James Fung, Ariel Garten, and Chris Aimone in the 48-participant *Regen* concert series (Mann et al. 2007), where the alpha rhythm activity of each user was directly mapped onto parameters controlling a jazz music performance. The *Ringing Minds* installation described in this chapter provides another example of a passive collaborative BCMI.

Alternatively, for the experienced MoodMixer participant, the musical mix could be controlled by manipulating cognitive and affective state. Users learned over time how each manipulation maps to a change in the musical feedback produced. A 2D visual representation of the measured cognitive state aided the participants in learning how to manipulate these dimensions to create the desired musical effect. This "active" brain–computer interface (BCI) system, where brain activity is consciously controlled by the user, follows in the vein of Alvin Lucier's *Music for Solo Performer*, widely considered the first live musical brain wave performance. In *Solo Performer,* brain waves in the alpha (8–12.5) band were used to drive percussion instruments, and sound was created only when the participant actively increased his or her level of alpha activity: "the piece…demanded that a solo performer sit in front of an audience and try to get in that alpha state and to make his or her brain waves come out" (Lucier 1995). MoodMixer's design invited deliberate control of mental state by providing clear visual and musical feedback designed to aid the learning of these brain-to-music mappings.

MoodMixer's multi-user design also adapted to both solo and collaborative interactions. The mapping of cognitive state to musical parameters (and the visual feedback provided) was clear enough to allow deliberate control, even in a collaborative setting. In most BCMI designs, there exists an interaction between the active–passive and solo–collaborative dimensions: The musical feedback complexity for systems with a large number of participants typically renders each individual's "control" of the musical mix impossible. Typically, the more users that are added to a brain–music system, the less deliberate each individual's control becomes. MoodMixer's multi-user design, combined with the visual representation of cognitive state, allowed users autonomy over their musical decisions, while inviting a collaborative musical experience.

8 Ringing Minds

One-brain to N-brains! Creative Brain Computer-Art Installations (BCAIs) and brain–computer music interfaces (BCMIs) have been investigated over several decades with both playful and systematic intentions (Miranda 2014). The majority of such systems involve a single individual interacting with the system in isolation. Less common are *collaborative* systems, which respond to the brain states of multiple individuals simultaneously interacting with the system. A historical review of collaborative (and competing) BCI systems is presented in Nijholt (2015). Earlier, well-known examples of such systems include one co-author's (Rosenboom's) interactive installation for multiple participants, *Ecology of the Skin* (1970), performing groups like his *New York Biofeedback Quartet* (1971) and compositions like *Portable Gold and Philosophers' Stones* (1972) (Rosenboom 1976). His interactive installation, *Vancouver Piece*, created for the Vancouver Art Gallery's 1972 show, *Sound Sculpture*, took this a step further (Grayson 1975). Characteristics of phase synchronous alpha waves detected across the EEGs of two individuals were used to modulate lighting effects shone on them, while they faced each other on opposite sides of a two-way mirror. As high-amplitude alpha waves from the participants shifted their phase relationships, the two faces would seem to shift positions, back and forth, off and on each other's shoulders. The result was a blurring and merging of the participants' physical identities that was related playfully to their individual and collective states of consciousness. These and more examples are discussed and can be heard in: Rosenboom (1976, 1997, 2000, 2003, 2006). Recently, this kind of work has resurfaced, energized significantly by advances in increasingly accessible technology and significant progress in methods for analyzing brain signals.

The most recent example is a new, collaborative installation work by David Rosenboom, Tim Mullen, and Alexander Khalil called *Ringing Minds*. The installation premiered on 31 May, 2014, at Mainly Mozart's MATM festival in La Jolla, California. Here, the focus was on taking another exciting step: treating the brains of several musical listeners as if they were part of a single "hyper-brain" responding to, and driving, a live musical performance.

Within the cognitive neurosciences, "hyper-scanning" methods have recently emerged for studying simultaneous, multi-person, brain responses that underlie important social interactions, including musical listening and performance (Montague et al. 2002; Yun et al. 2012; Sänger et al. 2012). For instance, significant intra- and inter-brain synchrony has been observed between guitar musicians performing together and (to a lesser degree) when one is listening to and the other perform (Müller et al. 2013; Sänger et al. 2012). It is reasonable to posit that shared neuronal states may be decoded from the collective brain activity of multiple participants engaged in active, imaginative listening of a live performance.

Numerous studies (reviewed in Koelsch and Siebel 2005; Koelsch 2011) have established correlations between EEG measurements, such as event-related potentials (ERPs) and oscillatory activity, and musical features (e.g., pitch, amplitude, rhythm, context, and other structural features in musical forms) as well as cognitive and behavioral aspects of a listener (e.g., engagement, attention, and expectation, musical training and active listening skills). While such studies typically average brain responses from a single individual over multiple repetitions of a stimulus, recent BCI studies have demonstrated robust single-trial ERP detection by averaging simultaneous evoked responses from brains of multiple individuals engaged in the same task (Wang and Jung 2011).

Ringing Minds uses real-time hyper-scanning techniques to decode ERPs and dynamical properties of a multi-person hyper-brain as it responds to, and subsequently influences, a live musical composition. The installation explores concepts of "audience-as-performer," complexity and structural forms in music and the brain, and resonance within and between listeners and performers.

8.1 Installation Design

The *Ringing Minds* installation, as realized at *Mozart & the Mind*, is depicted in Fig. 11. This consisted of (1) four participants wearing EEG headsets, (2) signal processing software, (3) visual feedback display, (4) a custom software-based electronic music instrument driven by the hyper-brain, (5) musicians with violin and lithophone, and (6) five-channel spatial audio output.

We designed and constructed wearable single-channel EEG headsets combining a novel flexible headband design with dry sensors and miniaturized bio-amplifiers provided by Cognionics Inc. (San Diego, CA). In order to maximize the likelihood of measuring single-trial evoked responses to changes in musical and rhythmic structure and context, such as MMN, P600, and N400 ERP components, the active electrode was positioned above central midline cortex near 10/20 location Cz. Reference and ground were at left and right mastoid.

Data processing took place on a laptop. In order to minimize latency differences between EEG amplifiers, we relied on wired serial USB data transmission.

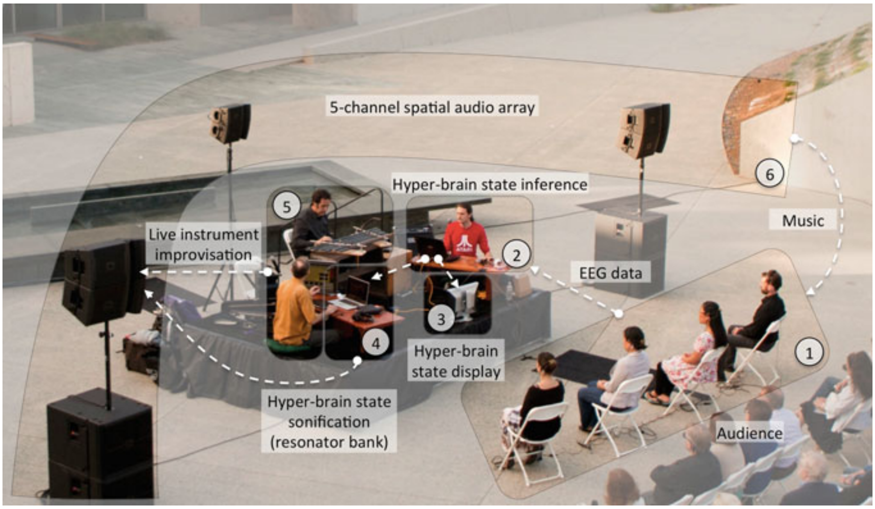

Fig. 11 *Ringing Minds* installation with (*1*) four-brain EEG BCMI participant group, (*2*) signal processing software for POP and ERP analysis operated by Mullen, (*3*) visual feedback display, (*4*) custom electronic music instrument sonifying POP/ERP features, (*5*) Rosenboom and Khalil on violin, electronics, and lithophone, and (*6*) five-channel spatial audio output. *Mozart & the Mind*, 31 May, 2014

Streaming data were acquired from each EEG headset at 512 Hz using the open-source Lab Streaming Layer, concatenated into a single 4-channel time series, down-sampled to 128 Hz, and processed in MATLAB using a custom real-time pipeline using freely available BCILAB and SIFT toolboxes (Mullen 2014).

The EEG analysis pipeline builds on multivariate principal oscillation pattern (POP) analysis methods for identifying oscillatory characteristics of a time-varying dynamical system. Mullen previous applied such methods to multi-channel intracranial electroencephalogram (iEEG) data from individual epileptic patients with the goal of identifying characteristics of spatiotemporal oscillatory modes emerging during a seizure (Mullen et al. 2012). For *Ringing Minds*, each participant's single-channel EEG time series was instead taken to be generated by a common multivariate dynamical system—a hyper-brain sampled by 4 sensors. A sparse vector autoregressive dynamical model was fit to this 4-channel time series within a short (1 second) sliding window. This model was decomposed into a set of parameterized POPs (*eigenmodes*), each of which reflects an independent, stochastically forced, damped harmonic oscillator or relaxator. The dynamics of a POP are equivalent to an idealized string "plucked" with a specific force plus additive random excitation. Alternatively, each POP may be regarded as a spatially extended neuronal process (e.g., a coherent network), oscillating and/or exponentially decaying in response to an excitatory input. POP analysis provides solutions for the frequency, initial amplitude (excitation), decay (damping) time, and other dynamical properties of each POP. In *Ringing Minds*, a POP can extend across brains, reflecting a resonant/

Table 1 Mappings from POP parameters and ERP, obtained within a 1-s sliding window, to a software-based electronic music instrument

Param..	Mapping from (POP/ERP analysis)…	Mapping to (electronic music instrument)…
K	Index number for a POP	Index number for corresponding resonator
F_k	Frequency of the *K*th POP	Index into a table of scale gamuts from which the pitch of the *K*th resonator is obtained
D_k	Damping time for the *K*th POP	Decay time for the *K*th resonator
A_k	Excitation of the *K*th POP	Amplitude for the *K*th resonator
OR_k	Binary value indicating whether the *K*th POP is an oscillator or a relaxator	How an exciter circuit "rings" the *K*th resonator. For oscillators, the exciter applies an impulse function, with controllable rising and falling slopes. For relaxators, the exciter function injects a noise burst with exponential decay
S_k	Stability of the *K*th POP	Variance of a controlled random modulation of the pitch assigned to the *K*th resonator
W_k	Dispersion (variance) of energy of the *K*th POP across all brains	Spatial positioning of the *K*th resonator output in the multi-channel, surround-sound field
ERP	Detrended, single-channel EEG averaged across all brains	Sonification of ERP via pitch modulation of all resonators active in the instrument at that time

synchronous state of the hyper-brain. *Ringing Minds* measured 40 POPs, spanning the EEG spectrum, each of which was characterized by 7 dynamical parameters. Table 1 lists these parameters and their mappings onto an electronic music instrument, described below. Within 1-second windows, hyper-brain ERPs were obtained by averaging simultaneous evoked responses, across all brains, instead of across multiple repetitions of a stimulus, as would normally be done with a single brain.

To sonify the hyper-brain's evolving dynamical structure with musical sensibility, Rosenboom built a software-based electronic music instrument, the central core of which is a very large array of complex resonators. These respond to the POP and ERP data in a way that generates a vast, spatialized sound field of ringing components, analogous to ways neural circuits might also "resonate" and sustain modes of behavior within and between individuals. POP-to-resonator mappings were chosen to produce an aesthetic interpretation of the precise meaning of oscillator/relaxator for POPs. Periodically, the shapes and temporal positions of important peaks in the ERPs were applied to modulate the resonant auditory field, sounding as if a stone had been tossed onto the surface of a sonic lake.

Manual controls for each resonator were available for fundamental frequency, harmonic series numbers applied to the fundamental frequencies, resonance time, amplitude, and an on/off switch. POP indices (K) could also be used to scan pre-composed pitch gamuts and apply the results to the resonator bank. This feature, plus the ability to choose harmonic number relationships for groups of resonators, enables one to compose particular musical tonal spaces within which the hyper-brain-to-music mappings will unfold. The exciter circuits also have manual controls for attack, decay, noise center frequency, overall amplitude, noise amplitude, and crossfading between impulse and noise sources. Finally, the instrument can also be played via MIDI and/or OSC inputs. The control parameters of the instrument could be varied in real time, which facilitates developing performances as well as installations. The instrument becomes, in effect, a *compositional model* inspired by the *analytical model* working on the EEG signals from the multi-brain participant group. The *model* thus becomes an *interactive instrument*.

Two musicians improvised over the hyper-brain sonification. Rosenboom played electric violin and electronics, and Khalil played an instrument of his creation, called a *lithophone*, resembling a stone xylophone with piezoelectric pickups. Much like throwing stones of various shapes and sizes into a lake and watching the ripples propagate through the medium, by manipulating musical structure and expectation, the musicians sought to generate musical events which evoked ERPs and oscillatory shifts in the collective neuronal state of the listeners. The subsequent sonification of these responses closed the feedback loop and offered both musicians and audience insight into the collective neuronal state of the listeners, while creating unique opportunities for improvisation.

8.2 Discussion

Ringing Minds investigates many things. Among them are complex relationships manifesting among the components of a sound environment—the resonator field—and a group of individuals, who may interact with this environment via natural listening patterns and possibly make use of biofeedback techniques to try to influence that environment. Projects such as *Ringing Minds* can also extend possibilities for interactive, intelligent musical instruments, in which relationships among the complex networks of performing brains and adaptive, algorithmic musical instruments can become *musical states*, ordered in compositions such as notes and phrases (Rosenboom 1992). With careful, *active imaginative listening* to the results of this fine-grained resonant field, one can witness both local and global processes interacting and perceive small-scale events zooming out into larger-scale arenas of human perceptibility.

9 Conclusions

The selection above from Mainly Mozart's MATM festival is a contemporary snapshot illustrating the diversity of musical interfaces leveraging information from brain and behavior. In *Interactive Gamelan*, the installation exploited a group music setting to explore interpersonal synchrony and other cognitive characteristics such as the ability to focus and maintain attention. Real-time feedback of synchrony performance was presented through digital means allowing people to visualize their immediate performance in new and playful ways. *Brain/Sync* similarly explored temporal structures in a musical context and presented performers with group measurement of phase synchrony visualized through rhythm networks that emphasized dynamic coupling across performers. Users harnessed this information to explore different rhythmic textures in a social setting that encouraged experimentation and learning. *NeuroDrummer* presented a rich immersive VR experience that served to close the brain–body loop in a drumming performance. This demonstrated future possibilities for closed-loop interactive games for restoring or enhancing brain function. *Spukhafte Fernwirkung* presented a duet comprising brain-driven, algorithmic music generation which utilized a stochastic mechanism to produce novel musical patterns which were interpreted and improvised upon by an accompanying pianist. A pure exploratory experience, it demonstrated how a hybrid musical composition combining both brain and behavior can give rise to novel, thought-provoking musical journeys and musical improvisation. The *Floating Man* installation presented another facet of brain–music interaction. Rather than using brain activity for composition, instead the interface was used to measure the ability of music to hold one's attention. With such a measurement used in a real-time capacity, a closed-loop system was developed which could allow, in principle, the user to continue listening to a favored piece of music among an otherwise shuffled set of tracks. *MoodMixer* demonstrated collaborative BCMI paradigms for dynamic music composition based on real-time EEG-based measurements of multiple individuals' cognitive or affective state. Finally, *Ringing Minds* presented a unique collaborative musical system that responded to the brain states of multiple interacting individuals simultaneously using hyper-scanning methods. Through harnessing event-locked brain activity and the dynamics of the "hyper-brain" derived from the participants, a closed-loop musical performance emerged. These unique musical artifacts represent arguably an entirely new musical ecosystem—one in which the roles of audience and performer are not assigned to individuals in the conventional manner but are instead distributed across all participants to varying degrees.

In summary, what is perhaps most exciting from the above selection is the expanded use of neurotechnology within a musical performance or installation to encompass many agents, both performers and listeners, and the blurring of the boundaries between the two (Rosenboom 2003; Miranda 2014). Such collaborative (or competitive) systems introduce fascinating new possibilities for the use of neurotechnology within increasingly social and ecological contexts (Nijholt 2015). While many of the installations were designed as examples of novel modes of musical expression, they also served a dual educational purpose, provoking conversation around notions of musical perception, neuroscience, performance, and interaction within a social, playful, and exploratory context.

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Enhancing Remote Spectators' Experience During Live Sports Broadcasts with Second Screen Applications

Pedro Centieiro, Teresa Romão and A. Eduardo Dias

Abstract When fans attend live sports events, they usually engage in social experiences with friends, family members, and other fans at the venue sharing the same affiliation. However, fans watching the same event through a live television broadcast end up not feeling so emotionally connected with the performers and other fans, as they would if they were watching it live together with thousands of other fans. With this in mind, we seek to create mobile applications that deliver engaging social experiences involving remote fans watching live broadcasted sports events. Taking into account the growing use of mobile devices when watching TV broadcasts, these mobile applications will explore the second screen concept, which allows users to interact with content that complements the TV broadcast. Within this context, we present four second screen application prototypes developed to test our concepts, the corresponding user studies and results, as well as suggestions on how to apply the prototypes' concepts not only in different sports, but also during live TV shows and electronic sports. Finally, we also present the challenges we faced and the guidelines we followed during the development and evaluation phases, which may give a considerable contribution to the development of second screen applications for live broadcasted events.

Keywords Sports fans · Live sports · User experience · Touch-based mobile devices · Second screen applications · Entertainment · Real-time remote interaction

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1 Introduction

Sports. This competitive physical activity has extended as far as the existence of humanity, with evidence dating back from the Neolithic age of 7000 BC showing a wrestling match surrounded by crowds (Cooper 2013). It is this natural human drive to compete that has always pushed the athletes forward. Rivalries have been born, records have been shattered, and history has been written, only because athletes had a single goal in mind: to be the best of the best. Ali and Frazier, Prost and Senna, Armstrong and Ullrich, Bolt and Gay, Federer and Nadal, and Ronaldo and Messi. These are some of the greatest rivalries that helped to create new standards in different sports for years to come.

Although not everyone practices sports regularly, watches live or broadcasted sports events frequently, or is aware of the latest sports achievements, the value of sports cannot be denied, because sports often have a great impact on people's lives. They affect people's mood. They cause emotions. They create memories. In particular, when people attend live sports events (Gordon 2013). The stadium atmosphere involves sports fans in a unique experience, where the specific environmental features of the venue and elicited affective responses of the spectators act together to create amazing vibes, strong emotions, goose bumps, and general euphoria (Uhrich and Benkenstein 2010). Unfortunately, sometimes sports are haunted by "fans" that go too far in their "support". Within football fandom, hooliganism is often associated with the clubs' organised groups of fans called the "ultras". These groups may have a positive impact when supporting their clubs during matches, but they can also have a strong negative impact by inciting members to violence and brawling. This violent behaviour is often associated with keeping fans with families away from the venues, especially when there are important matches between rivals. Of course that it is not our goal to promote this kind of actions, but rather to promote positive feelings for fans watching a sport event.

In fact, most fans do not have the chance to go to the venue due to factors such as the above-mentioned violent behaviours, ticket price, distance or the limited number of seats available. And when fans watch a sports event on TV, they do not feel so emotionally connected with the performers and the in-venue fans, as if they were watching it live where the event takes place. Furthermore, since there are usually much more spectators watching a match through television than at the live venue (see (CNN 2009), for example), we see this is as a prominent area that should be taken into account by the entertainment computing community to create innovative and exciting experiences. With the help of sports researchers and psychologists, computer scientists can acknowledge what motivates fans to support their team and ascertain what emotions in-venue fans and remote supporters feel while watching live sports events. This way, computer prototypes can be built that contribute to enhance the remote spectators' experience during broadcasted live sports events, like the venue atmosphere helps to improve the fans' immersion and emotional levels during the live sports events.

We chose to develop our study within the mobile computing area, with a strong emphasis on the second screen concept. This concept provides several functionalities that improve the viewer's experience, usually by providing additional show-related information, access to social networks, and interactive experiences synchronised with the programme content, such as polls or quizzes.

In this chapter, we show how second screen interactions can be designed to enhance the remote spectators' experience, in particular during broadcasted live sports events. In this context, we developed four different prototypes that seek to enhance the users' experience during a soccer match in different ways, either through applauding on key moments, making live predictions, and sharing opinions and emotions with friends. Finally, we also suggest how the prototype concepts can be applied in different sports, TV shows, and even electronic sports, which has seen a rise in popularity in recent years (OnGamers 2014).

2 Bridging the Emotional Gap

Our research focuses on the enhancement of the remote spectators' experience while watching broadcasted sport events on TV. Within this context, our target is set on the fans that often use (or have intention to use) applications while watching a broadcasted sports event and that, for whatever reasons, do not attend the venue where the event is taking place. By exploring the use of technology to create new forms of social "liveness" (Auslander 2008), we hope to bridge the emotional gap between the sports stadium atmosphere and the remote users' environment, by creating innovative and engaging experiences through mobile devices for worldwide fans.

We started our work by researching on the sports fan motivation, in order to define what fans seek in a sports event. Our findings led us to conclude that sports fans are motivated to attend and watch sports due to social factors where friends, family members, and other fans share the same physical space. In other words, fans are motivated by social experiences. Thus, we outlined our investigation in two domains that are interconnected through this work: activities and communities.

The activities developed in our research consist in the actions that we proposed to users to enhance their experience. In other words, mobile prototypes can invite users to interact by exploiting different elements that play a part in the experience of watching a live broadcast sport event: the venue where the event is taking place, the television broadcast that remote spectators are watching, and the social aspects related to the sports event. Based on these elements, we exploited three different aspects during the design and development of our prototypes:

- **Venue**: promote remote users engagement in the in-venue fans' activities, for example, by participating in the applauses or chants during sports events. Moreover, by hearing or watching through a camera installed among the crowd at specific moments, users can feel what is like to be on the stands watching the sport event with thousands of other supporters.

- **Television**: by adding visual elements to the TV screen, it is possible to enhance the viewing experience. For example, when there is a goal, a TV application can present an image overlaid on the TV content showing the fans' emotions during that period, or the in-venue fans' audio can go higher so remote spectators can "feel" the venue atmosphere.
- **Gamification and Socialisation**: entertainment and engagement can be supported by providing users with game mechanisms in non-game contexts, as well as fostering social experiences around a topic. For instance, users can guess when a goal is happening or answer trivia questions to get points, while chatting with their friends about their performance and the sport event's actions. Strengthening remote fans' connection with sports events and between themselves contributes to reinforce social experiences.

It is also our intention to create social experiences both targeted to fans who share the same physical space with each other and fans who do not have that possibility. We approached these situations by instantiating two types of communities:

- **Local Community**: it is very common for remote fans to gather on a sport's bar, a coffee shop, or at a friend's house to watch a match. In this situation, fans are watching the broadcasted match within a local community, and its members are the individuals watching the match on that space. Therefore, there is room to deploy special prototypes that enhance the users' experience within that physical space.
- **Online Community**: many people may watch matches alone. In this case, it is even more important to make them feel connected with the other fans and provide them with an enhanced experience by creating the feeling that they are not alone watching the match. By using networked computing devices, it is possible to connect them to other fans around the world, allowing them to participate in activities and to share their thoughts about the match, with friends, family members, and even unknown fans.

Next, we present four mobile second screen prototypes that seek to enhance the remote spectators' experience during live sports broadcasts.

2.1 WeApplaud

The first prototype that we designed resulted from a brainstorming session where we asked ourselves an interesting question: "Wouldn't it be great to connect the in-venue and remote communities together?". Although there are second screen

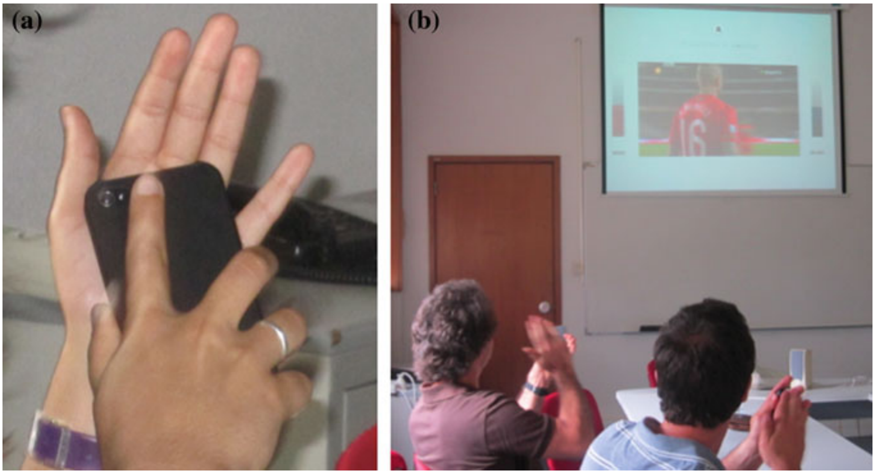

Fig. 1 One participant performing the clapping action (**a**), while playing a WeApplaud game session (**b**)

applications that exploit this concept (like the official X Factor[1] and Rising Star[2] applications), we challenged ourselves to deliver immersive and innovative experiences to viewers. There is a wide range of actions that in-venue fans perform while watching a sports event, such as shout, chant, performing *la ola* (Mexican wave), and of course applaud. Applaud is such a basic action that everyone likes to perform to express themselves, that we decided to develop a game around this concept called WeApplaud. WeApplaud is a multiplayer mobile game that takes users, sharing the same physical location (in other words, in a local community), to participate in the applause happening in the stadium during a simulated soccer match broadcast. By doing that, we expect users to become more engaged in the broadcasted event, increasing their fun and immersion levels, allowing them to feel and act as close as if they were at the event venue.

The interaction is intuitive and non-intrusive, allowing users to clap like they do in real life, and when they are prone to do it, which is usually after a cheerful moment. This way, users simply need to hold the mobile device on one hand, and then move it as if they would hit the palm of the other hand (Fig. 1a, b). This can be done by using either the front or backside of the device. Since a clap is only a clap if a sound is generated by striking two hands together, we decided to use a combination of data from the smartphone's accelerometer and microphone (Centieiro et al. 2012). Therefore, when the mobile device detects a sound peak, it immediately checks if there was also a movement in a particular direction. If so, it is counted as a clap. By using the accelerometer and the microphone data, it was

[1]X Factor clap feature, http://www.itvmedia.co.uk/rimmel.

[2]Rising Star application, http://bit.ly/1CBqKbJ.

possible to decrease the detection of false claps, something that would not happen if only one of these smartphone's features was used.

In WeApplaud, players are challenged to applaud during key moments of a soccer match. To further enhance users' experience, two different challenges were included in our prototype, involving two kinds of applauses: free and synchronised applauses. During free applauses, players just need to keep clapping, like they would do in a normal applause action, to be rewarded with points. During synchronised applauses, like in rhythmic games, players need to be synchronised with the tempo to score points. Examples of synchronised applauses are the slow claps (which happens quite often on the triple jump, or before a free kick in soccer) and the claps that mark the rhythm of some soccer chants. These challenges were triggered by the application at key moments of a match when fans at the corresponding event venue would start performing the same action. The underlying idea was that both of these actions contribute to synchronise the remote fans with the fans at the stadium, creating the feeling of a unique community connected through the event that they are watching.

Before a WeApplaud game session starts, each user must choose to play for one of the two teams of supporters (e.g. the "Reds" and the "Blues") that will compete head-to-head. To create a real-time competition between the two teams of supporters, both are challenged to applaud during the same key moments. While watching the video content (simulating a soccer match live broadcast), both teams of supporters are presented with several challenges. Each time a team member performs a correct clap, the team is awarded 50 points and a consecutive streak count is started. In the free applause challenge, every clap is a correct clap, while on the synchronised applause challenge, a clap is only valid if it is synchronised with the tempo. Since it is very difficult to applaud at precise moments (we took into account the millisecond), we have defined a threshold that allows users to get correct claps within a short interval (300 ms). The consecutive streak count is associated with a score multiplier, and it is intended to reward the team that is synchronised with the tempo during a period of time. We defined four score multipliers: two, three, four, and five. Each of these multipliers is achieved by doing two, four, six, and eight consecutive correct claps, respectively. If a team member claps when he should not, that team's score multiplier is restarted. To visualise the team's performance, we have added two bars to the display: one for the red team and other for the blue team (Fig. 2a). Each time users win points for their team the score bar increases accordingly. The team that fills the score bar quicker wins the challenge. To win the game, a team needs to have more points than the other team, at the end of the simulated broadcast.

To make users aware of a current challenge (alert users when they need to applaud), we use three kinds of mechanisms: a visual message on the top of the main display (Fig. 2a), a hand inside a circle that keeps spinning on the mobile device display while the challenge is on (Fig. 2b), and we set the mobile device to vibrate, so it can get user's attention in a simple and seamless manner. We have also

Fig. 2 Game screen on the **a** main display and **b** mobile device

synchronised the vibration with the rhythm that is necessary to follow. Therefore, in the beginning of a synchronised applause challenge, every time there is a vibration, users know that they need to applaud on that instant. It creates an action–reaction mechanism that helps users to recognise the rhythm and to keep following it after the vibration stops.

To test the WeApplaud concept, guide the system's design, and evaluate users reactions, a first version of WeApplaud was implemented, and preliminary users tests were conducted. These tests were conducted with 16 voluntary participants (mean age of 30.1, 12 males and 4 females) to whom we asked to fill in a questionnaire at the end of a best-of-three WeApplaud games.

Users mentioned that they had a great time playing WeApplaud, a clear signal that the promoted competition encouraged them to have a more active role during the match and increased their fun. In fact, users rated the experience as fun (81 %), immersive (50 %), and pleasant and simple (44 %). It was very frequent for participants to laugh, smile, get exalted, and exchange comments about who was going to win. This corroborates our goal of increasing users' fun while watching a sport event broadcast. While the word immersive was not as popular as the word fun, it was the second most selected, which we believe is an encouraging sign that the system contributes to reinforce users' engagement. Furthermore, participants rated both statements "competition promoted by WeApplaud contributes to increase the level of entertainment during the broadcasted match" and "WeApplaud contributes to make me feel more involved in the stadium atmosphere" positively (Mean = 4.375, SD = 0.81, and Mean = 3.75, SD = 0.57) on a five-point Likert scale. This demonstrates that it is possible to create new ways of entertainment related to broadcasted events, which make users more engaged with these events without diverting their attention to side activities.

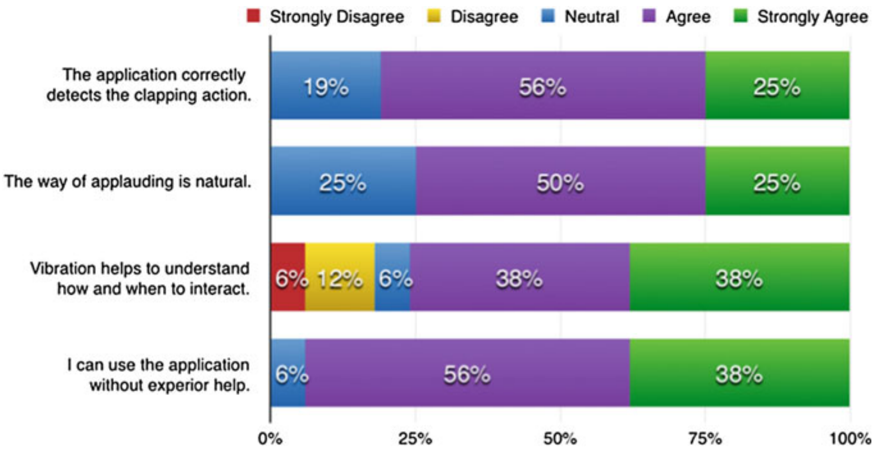

Fig. 3 Summary of WeApplaud usability results

Regarding the interaction method, the analysis of the results of the questionnaire revealed positive feedback, as shown in Fig. 3. Most participants had the feeling that claps were correctly detected by the application and they naturally held their mobile phones while clapping. We observed that sometimes users felt initially hesitant on how to applaud, but after noticing that the score bar was filling in while they were clapping, they started to feel more confident and had no problems in using their mobile phones while clapping. As a side note, in a real-life environment with thousands of people applauding, we could need two score bars: one to give feedback for a single individual, and another to show the overall fans' performance. It was also interesting to notice the different participants' clapping styles (different ways to hold the mobile device while clapping), with no interference on the clapping detection. On the other hand, the results showed that the use of vibration was not enough feedback for users to understand when they should start and end clapping during synchronised applauses.

As we can see, our first prototype gave us a lot of confidence to continue our research. Users had a great time playing WeApplaud, a clear signal that the promoted competition encouraged them to have a more active role during the match and increased their fun. Furthermore, this first version of the prototype helped to validate our concept and we hope that it will be just a matter of time for future research to expand upon it. Imagine what would be if WeApplaud could be deployed on public places (e.g. bars or cafes), where small communities of people usually meet to watch sports events. Or even better: picture the use of a stadium screen to present WeApplaud's feedback, so players and fans at the venue can feel the encouragement coming from people watching the match worldwide. This is our vision for remote spectators to interact like they would do in the venue. This is our vision for connecting the in-venue and remote communities together.

2.2 WeBet

The feedback that we had from WeApplaud motivated us to develop a prototype through which users could rely on tactile and audio feedback to interact during critical moments of a soccer match with reduced attention shift from the TV broadcast. This prototype was WeBet.

WeBet is a mobile game that prompts users to bet if a goal is about to happen during a simulated soccer match broadcast, without requiring users' visual attention on the mobile phone. During a broadcasted sport event, it allows players to see information about the match, and to guess, at anytime, if a goal is about to happen. We designed and developed WeBet aiming to (1) reinforce the connection between users and their sports teams, enhancing their experience when watching a broadcasted match (WeBet allows users to score along with their team when they preview, and bet for, a goal); and (2) provide an immersive social experience, during which users can watch a live match, get real-time information, win badges, and compete with their friends, as well as with fans around the world, battling for exclusive prizes (as in applications like Viva Ronaldo,[3] Heineken Star Player,[4] Preplay Baseball,[5] Preplay Football[6]).

We devised WeBet's development in three stages. In the first stage, we conducted user tests to evaluate if WeBet's concept conveyed an exciting user experience. In the second stage (Centieiro et al. 2013), we performed a user study to analyse what were the usage patterns and users' preferences regarding eyes-free interaction mechanisms that complement the users' experience while remotely watching a live event broadcast (Centieiro et al. 2014a). In the third stage, we collected real users' feedback using the WeBet's concept in a real-world setting (Centieiro et al. 2014b). So, we cooperated with Viva Ronaldo—which besides other features offers a second screen game for remote fans to guess what will happen during a Cristiano Ronaldo's match—to introduce a new feature based on the WeBet's concept, which would allow Viva Ronaldo users to guess a goal of Ronaldo's team during a live match.

We were very careful when designing the eyes-free interaction technique, since it should allow users to interact (place their bets) without looking at the mobile device and thus not missing a feint, a pass, or even a goal. Otherwise, WeBet would frustrate users, instead of creating better experiences. Next, we present the interaction walkthrough, describing how users bet that a goal is about happen during a live match:

1. Users may hold their devices throughout the match to browse the application or just grab it at certain moments. While holding the device, users can perform a

[3]Viva Ronaldo, http://www.vivaronaldo.com.

[4]Heineken Star Player, http://www.creativereview.co.uk/cr-blog/2011/april/heineken-starplayer.

[5]Preplay Baseball, http://get.mlb.preplaysports.com.

[6]Preplay Football, http://get.football.preplaysports.com.

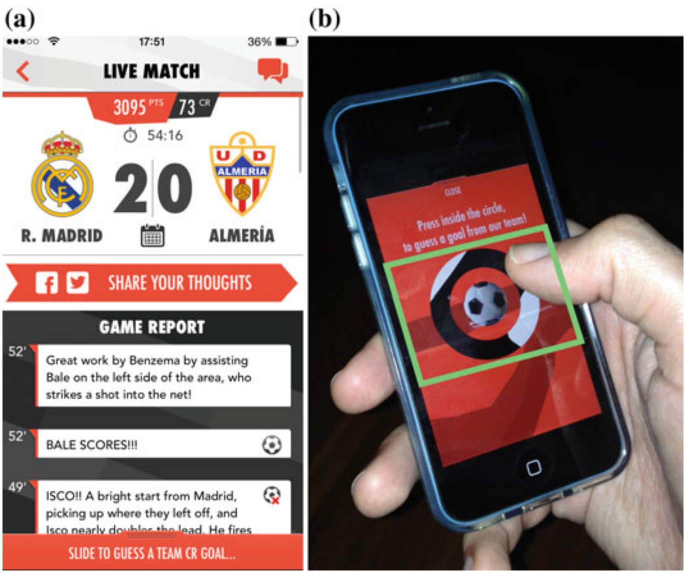

Fig. 4 The eyes-free interaction mechanism on Viva Ronaldo (**a**). Special bet interface with the clickable area to place a bet (**b**). Users can easily touch it using their thumb, while holding the phone with one hand and without looking at the screen

bottom-up gesture from outside to inside the screen. This allows users to start pulling the special bet interface up as their fingers enter the bottom of the screen, with no need to look at the device (Fig. 4a). A quick upward swipe gesture makes the special bet interface go full screen immediately (Fig. 4b).

2. As soon as the special interface is at full screen, an upward sound is played (lasting 500 ms) and the mobile device starts vibrating repeatedly every 400 ms. This informs users that they can now bet that a goal is about to happen, by touching on the middle area of the mobile phone screen (as shown on Fig. 4b), with no need to look at it.
3. To close the special interface (without betting), and return to the application screen (Fig. 4a), users just need to do a downward swipe gesture anywhere on the screen, and a downward swipe sound is played accordingly (lasting 400 ms). At this point, the mobile device stops vibrating and no bet is made.
4. When a bet is placed, the mobile device stops vibrating, the selection sound is played, a 20-s countdown appears, and a heartbeat sound is played to help creating a tension moment. Once in this state, the special interface completely covers the whole screen (navigation bar on the top of the screen included) and users cannot close it while the countdown is running down.
5. In order to further increase the users' emotional levels during a dangerous play, there is a bonus stage. This means that if users already bet that a goal is about to happen (and the 20-s countdown is running down), they can touch anywhere on

the screen to get a percentage bonus (usually 25 %). This action requires users to spend a CR (the Viva Ronaldo in-game currency).

6. Finally, an outcome screen appears stating whether the user won points or not, depending on whether there was a goal during the 20-s countdown. Moreover, a cheerful or disappointment sound is played accordingly to the outcome and the mobile device vibrates once to get the users' attention.

After implementing the eyes-free interaction mechanism on Viva Ronaldo, we started studying what challenges we would encounter when users would try to guess a goal in the next seconds in a real-world setting. Since different TV service providers can have different broadcast delays during a live match, we set different outcomes for bets close to goals. Figure 5 depicts the different bets' outcomes according to the moment they are made in relation to the timestamp of the goal (the real time of the goal), along the match timeline. TS_G stands for the timestamp of the goal. If there is a bet within the 20 s that precede it, the bet is correct (green area), otherwise if it is done 2 s after the goal, just a few points are given (blue area), so that users can be pleased for apparently getting the goal right (while in reality they did not, due to the broadcast delays). If a bet is made on the following 3 s, a message appears stating that the user almost got the goal right (yellow area). Users do not win any points, but understand the reason and do not feel frustrated. Finally, if users make a bet on any other situation, a message states that there was no goal during that interval (red area).

Finally, while the 20-s countdown is running out, users can see the number of points that they might win if the goal happens on the current moment (points are increased each 100 ms). The idea is to get users excited by watching the points increasing as the countdown runs out. This is seen as an extra feature since it takes users' attention away from the match, so using it is at users' discretion. However, as communication and TV broadcast delays can play a role on the user's perception of the match, users might think that they will get a bet right 7 s before the goal, but in reality it may be just 4 or 5 s before it. Thus, we present to the users only 40 % of the points that they might win. Once the outcome of the bet is presented, users will

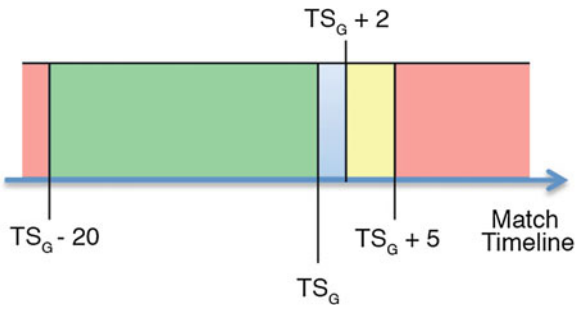

Fig. 5 Match timeline showing the different outcomes according to the moment of the bet in relation to the timestamp of the goal

receive the number of points they expected, or even higher, which will be positive for the user experience.

To gather the users' feedback regarding the use of this feature and the corresponding interaction method in a real-world setting, a user evaluation study was conducted. Fifty-one Viva Ronaldo users with the top match scores during the month prior to the study answered a questionnaire. These users were aged 14–44 (mean age of 22.23, 22 males, 29 females). Participants resided in different countries, such as USA, Colombia, Iraq, and France. During the month prior to testing, there were 10 matches, where Cristiano's team scored 22 goals, and there were close to 10,000 bets.

Figure 6 summarises the results that we obtained. We were initially expecting better ratings for the statement "I like to use this feature". As some users reported at the end of the questionnaire, while they did enjoy using this feature and guessing that a goal is about to happen, they sometimes had disrupted experiences due to the TV broadcasts delays, hence the mix results. However, the results became very positive when we asked if the feature was easy to use and to learn how to use, as Fig. 6 depicts. Based on these results, and on the fact that we did not give any instructions on how to guess a goal in the next seconds, we are keen to conclude that a feature based on this interaction mechanism is simple and intuitive to use.

The participants stated that both vibration and sound helped them to interact without looking at the phone. As a conclusion, we think that similar interaction methods that rely on the use of a touch-based device while looking at the TV screen during key moments should take vibration and sound into account. In particular, well-identified sounds should be used in order to help users to differentiate sounds coming from the mobile device from the ones coming from the broadcasted event. The statement "I can execute the betting action without looking at the phone" got

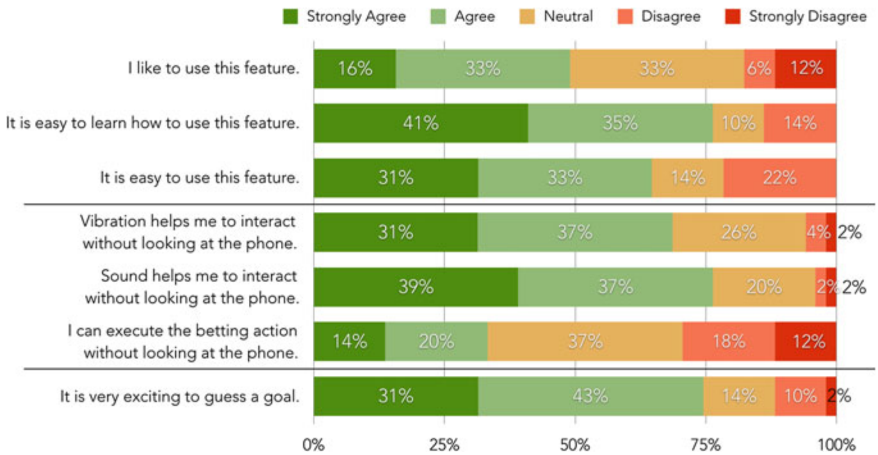

Fig. 6 Summary of the results of WeBet's concept applied on Viva Ronaldo

diverse rates with 37 % of users being neutral about it, and a similar percentage of users having negative and positive feelings about it. These results can be explained either because some users like to have a quick visual confirmation of their actions, despite the complementary audio and vibration feedback, or they simply never thought of using the interaction mechanism without looking at the mobile phone. Hence, the results are neutral. Whatever the reason may be, we will further investigate this issue. We plan to add a small demonstration the first time users participate in a live match, where we show that it is possible to execute the betting action without looking at the phone, by relying on the tactile feedback of the Home button.

Finally, the majority of the users stated that the matches became more exciting when using this feature (43 % agreed and 31 % strongly agreed). We feel that this is a clear sign that this kind of activity increases users engagement and entertainment during a live sports event.

Regarding the overall experience, and as we already mentioned, there were some surprising results. Participants rated this experience as fun (52.9 %), followed by frustrating (43.1 %), stressful (37.3 %), simple (29.4 %), pleasant (27.5 %), and enthusiastic (25.5 %). When we analysed some of the questionnaires in detail, we noticed that there were users who simultaneously selected words like "fun" and "stressful" or "frustrating". After reading their comments and suggestions, we discovered that although users enjoyed to guess a goal in the next seconds, they sometimes got frustrated or stressed because the match on TV was delayed relative to the real match and consequently to the match on the Viva Ronaldo application. That delay makes users think that their bets were correct when they see the goal happening on TV. But then they get no points, because the goal had already happened before they made their goal bets, and also before they saw it on TV. This is a problem that happens in any competition while watching a live broadcasted sports event and using a second screen application. The problem lies in having a competition, where users try to climb on rankings. If this was not the case, users could adjust a match delay (or setting it through audio fingerprinting) on their applications and the server would validate each goal within the users' different delays. Even if they cheated (e.g. by setting a match delay higher than the actual delay of their TV broadcasts), it would not matter because there would be no scores involved.

To conclude, this study allowed us to collect invaluable information regarding the challenges involved in deploying real-time second screen interactions during live broadcasted events. The problem that we faced with the TV delays motivated us to start developing a new prototype that allows users to have great user experiences, even if their TV broadcasts are some seconds behind the second screen application. This prototype—which is still under development—is called WeSync and is detailed in Sect. 2.4.

2.3 WeFeel

During the last stage of WeBet's research study, we noted that many Viva Ronaldo users liked to exchange opinions about the matches (during the broadcasts) through direct messages in the application. This behaviour sparked our interest to create a system that would allow remote spectators of broadcasted sports events, to share their opinions and emotions with their friends, not through a mobile device, but rather through the television screen. Therefore, we created WeFeel.

The idea behind WeFeel is simple: since people naturally share their opinions and emotions with their personal circle while attending live events, remote spectators should be empowered to do the same. Moreover, they should be able to do so in a fun and minimally disruptive way. Thereby, in order to keep the interactions as little intrusive as possible, and since we have two screens to exploit, instead of displaying data (emotions and comments) on the mobile devices, WeFeel displays them on the TV screen (Fig. 7). This helps to reduce intrusiveness and creates a different experience, since users are not forced to shift their visual attention from the TV to the mobile screen in order to see their friends' status. Indeed, as the results of the user tests have shown, participants were surprised and enthusiastic about being able to talk with their friends in real time through the TV screen. To further complement the experience, a chart appears periodically on the television screen, summarising the fans' expressed emotions during event-specific key moments, such as goals or referee decisions (currently, the detection of such key moments follows a Wizard of Oz procedure).

Fig. 7 User choosing an emotion, while two different emotions appear on the TV screen

We implemented WeFeel's emotion assessment method based on Cardoso et al.'s (2013) CAAT. The CAAT was built upon Robert Plutchik's Circumplex Model of Emotions (Plutchik 1980), which, in turn, was built analogously to a colour wheel. In spite of the tool's easiness of use—it simply asks users to select one or two emotions that best describe how they feel—it features 24 emotion words, which can add to the CAAT's visual complexity. This, of course, is not desirable in a system that aims to be simple and straightforward to use, even if at cost of some loss of detail in the assessments. Truly, WeFeel required a simpler, yet still firmly rooted, assessment method. We devised a way to answer this requirement in Lee's (Lee 2013) work, in which six dimensions of emotions frequently associated with professional sport team brands were identified: connectedness, elation, surprise, anger, unhappiness, and worry. Due to the analogy between these six emotion words and six of the eight Plutchik's basic emotions, we adapted the CAAT to use the new emotion words in a way that users could visualise and quickly select them (Centieiro et al. 2014c, provides further insights on this matter).

Next, we set the six emotions' buttons in a radial layout (menu). As an additional visual cue, next to each of the emotions' button we added an emoticon to help users to figure out the emotions and provide them with a preview of the content their friends would see. Users could select any emotion by simply clicking on it, and then they could enter a comment if they wish to. The total space required to present the radial menu, with all the emotions simultaneously visible, takes up the mobile device full screen. However, we added an option to expand and minimise the radial menu, so users can hide or access it whenever they want. This way, the minimised radial menu can be placed anywhere on the left and right borders of the mobile device's screen. When users want to access the menu, they just need to click on it and the menu will expand and show all the available emotions. While in the expanded state, clicking anywhere on the screen (besides the buttons) will minimise the menu. Figure 8a, b shows the final interface with the minimised and expanded radial menu, respectively.

The TV interface was also carefully designed to ensure both a pleasant user experience and a minimal interference with the broadcast. We devised two areas: on the right side of the screen, we display the individual emotions and comments shared by friends and, on the left side, we present, periodically, the emotions experienced by all users watching the match. We chose those areas to avoid obstructing the broadcast with additional interface elements. On the right side of the screen, each emotion shared by a friend is presented on a pop-up with the friend's name and photograph, the comment (if any), the selected emotion word and the corresponding emoticon, and a background featuring the same colour as the selected emotion. On the left side of the screen, we occasionally present a chart depicting the remote users' global emotions during key moments of the match (e.g. after a goal or a red card). Once there was a replay of a key moment of the match, the system analyses the emotions shared in the previous 10 s and shows this data on a chart for 10 s. The idea was to give enough time for users to share their emotions after an important moment. With this feature, we sought to complement the remote users' experience by showing them that there were many other fans watching the

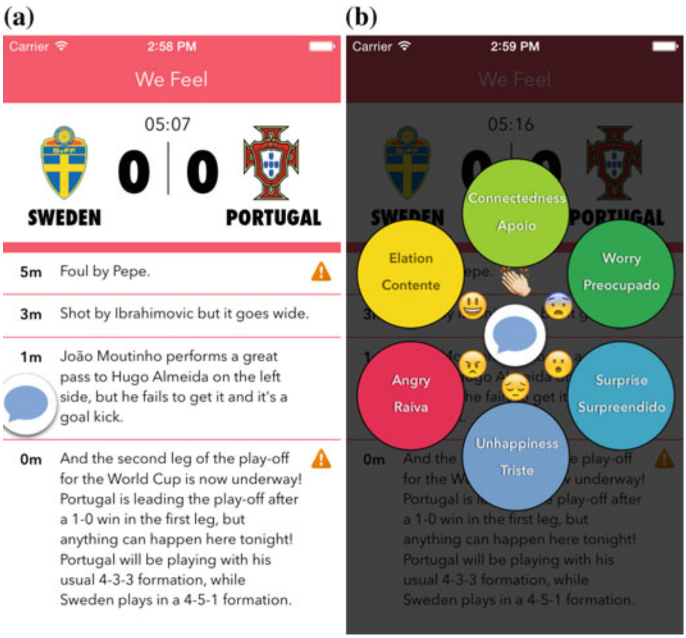

Fig. 8 The minimised radial menu on the *left centre* of the screen (**a**) and the expanded radial menu presenting all the emotions also in Portuguese for user testing purposes (**b**)

match with them and sharing emotions. This helps to create a social experience, even if a user is not sharing their emotions with their friends. In the future, we can even expand this feature by using the ambient light featured on some television sets to represent the top emotions presented in the charts. Figure 9 presents both a chart and two emotions shared by friends.

A significant number of user tests were conducted, in order to evaluate the system, the overall concept and the user's reactions, in order to ascertain if participants would use WeFeel on a real-life environment. The tests were conducted with fifty-three voluntary participants, with ages ranging from 13 to 44 (mean age of 19.56, 34 males, 19 females). We set up WeFeel in a room with two TVs, placed back to back, allowing it to be simultaneously used by two participants, each with an iPhone handed out by the research team. In each test session, users interacted with WeFeel during a 15-min video of a simulated soccer match. At the end of the video, users were asked to answer a questionnaire.

The results that we obtained from the questionnaire were highly positive, as Fig. 10 depicts. Participants stated that the interaction method was appropriate (59 % agreed and 36 % strongly agreed with this statements) and liked to use the radial menu and the way it could be expanded and minimised. However, some users did not perceive that they could share an emotion without writing a comment. This happened because the commentary box did not reflect that a user could simply click on "Send" without having to write anything on it to send the emotion with no

Fig. 9 Emotions being shared by friends on the *right side* of the screen, while a chart appears, on the *left side* of the screen, depicting the overall users' emotions

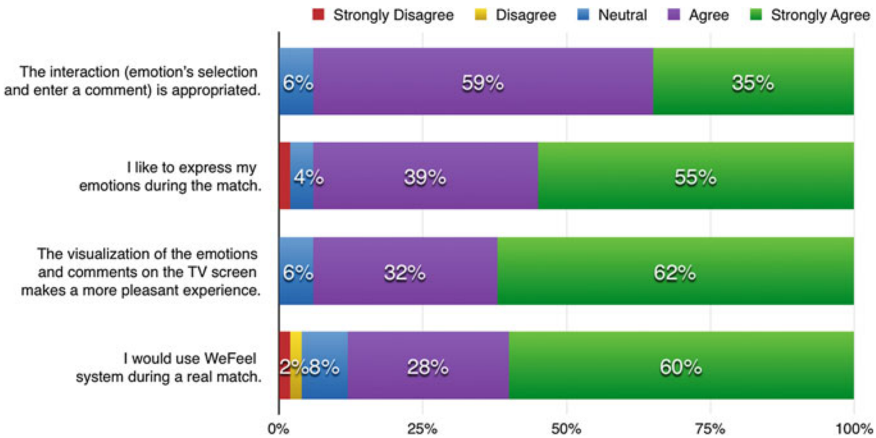

Fig. 10 Summary of WeFeel usability and entertainment results

comment. Therefore, we will change this aspect in order to allow users to quickly share an emotion, without entering a comment. The majority of the participants liked to share their emotions during the match, giving us a lot of confidence in future developments. The visualisation of the emotions and comments made by friends on the television screen was received with great enthusiasm, with 94.4 % of the participants stating that this feature makes the experience more pleasant (62.3 % of the participants strongly agreed and 32.1 % agreed with this statement). Participants got really surprised to see the emotions and comments appearing on the television. We believe that this happened because: (1) this conversation concept is different from the chats users are used to; (2) there is not yet a lot of commercial applications that provide this kind of experience and interaction between mobile phones and TVs; and (3) users liked to read their friends' status on the TV screen, while they are watching the match. Finally, users stated that they would use a similar system during a live broadcast of a real match (60.4 % strongly agreed and 28.3 % agreed with this statement).

Moreover, most participants did appreciate the experience conveyed by WeFeel, rating it as fun, pleasant, and simple (71.7 % each), followed by attractive (64.2 %), innovative (58.5 %), and exciting (45.3 %). Some participants were really excited about WeFeel and took the time to write a lot of suggestions, in particularly concerning different chat modalities. Users wanted to be able to select which friends and groups they wanted to chat with, like they do in popular chat-based services, such as WhatsApp, Facebook Messenger, and iMessage.

This study represents an important mark in our research work. We really felt that participants liked this concept and would love to have it in their homes. In fact, the top comment made by users seconds after experiencing WeFeel was "where can I download it?". This clearly shows a great interest and enthusiasm about the perspective of using WeFeel on a real-life environment. We are now aiming to conduct a study with new features and chat modalities, as users suggested. These features let users choose different friends to share emotions and opinions, and even chat through Facebook Messenger—which means that a person can use WeFeel to chat with friends who even do not have the application—while emotions are shared through the WeFeel's server and seen on TV by whom has the WeFeel's application. We also added an important and useful feature, which allows users to manage where they wish to chat: if on the phone or on the television screen, which can be convenient when someone is sharing the same physical space with others, who should not be aware of the conversation.

2.4 *WeSync*

As mentioned in Sect. 2.2, the results that we obtained from deploying the WeBet's concept on a real-life setting showed that the TV broadcast delays affect the users' experience and must be considered when developing second screen interactions during live events. On Viva Ronaldo, the system considers the real timestamp of the goals (the time when the goal really happened at the stadium) in order to prevent cheating (users predicting a goal that has already happened). However, this approach has its disadvantages, as users who have a TV service provider with a high broadcast delay cannot guess a goal efficiently. With this in mind, we started implementing an interaction mechanism that we hope will mitigate the aforementioned issue.

This interaction mechanism will be used in a new prototype called WeSync, to analyse if users are able to synchronise a second screen application with a TV broadcast, while preventing cheating.

We plan to develop WeSync in two stages: first, it is necessary to implement the interaction mechanism and evaluate if users easily understand how to use it. It is not necessary for them to comprehend how the mechanism really works in the background, but rather to understand how to synchronise the TV broadcast and the application. Second, to prevent cheating during a second screen competition like Viva Ronaldo, we need to develop an algorithm that detects when users set a higher delay than the one they actually have. This can be done by identifying users who are quick to answer right too many questions. Users who try to set a delay higher than the real delay of their TV broadcasts will have an advantage when answering quizzes about the broadcasted events or making live predictions (e.g. guessing a goal in WeBet), since they will see what will happen on the TV, before they will have to interact with the application. This is not desirable, and we hope that by analysing usage patterns, we can automatically infer if someone is cheating about their delay or not.

At this time, one may be wondering why are we implementing an interaction mechanism, and not simply use automatic content recognition (ACR), such as audio fingerprinting, to quickly analyse the sound coming from the TV to synchronise with the application? Well, the answer is simple. First, implementing an ACR system for a given event takes a lot of time and work, and this might be inconceivable to some developers that only want to be focused on the experience being conveyed by the second screen application. Yet, even if developers are able to implement an ACR system, it may happen that it will not work on all the countries where the feed is being relayed, since the audio from the original feed is different from each country's feed due to commentators' audio. Furthermore, developers cannot also rely on using external ACR APIs for any given show—let alone be a live event—on any given country. In fact, Entourage, a popular used API, while very robust, only works on 6 countries and 173 TV channels,[7] which of course is not ideal. All these facts motivated us to implement a simple, yet powerful interaction mechanism that developers could easily add to their second screen applications.

In order to have a better perception on how the interaction mechanism works, a quick interaction walkthrough is presented below, considering a live sports event scenario where questions appear synchronised with the match action in the second screen device (e.g. when a penalty kick happens during a match, a screen appears on the mobile application asking what users think will happen: goal, out, or save):

(1) After users finish a given interaction process, like answering a question and getting the corresponding result, a screen appears asking users how was their experience (Fig. 11a).

[7]Entourage, http://bit.ly/1pNdLCc.

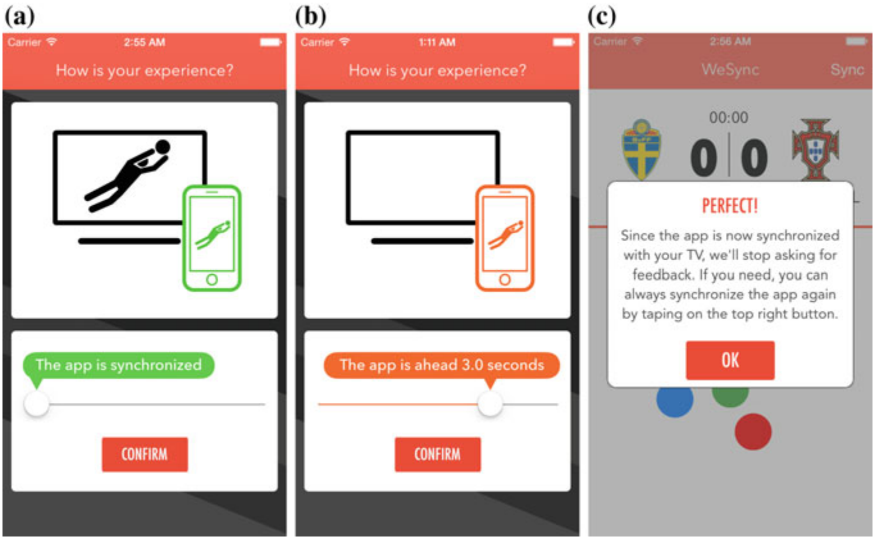

Fig. 11 Initial screen of the interaction mechanism (**a**). User setting a delay (**b**). After the application is synchronised (**c**)

(2) Users may specify that the application is synchronised by simply clicking on the "Confirm" button, or they can adjust the slider in order to select how the application behaves in comparison with the TV broadcast.

(3) If users start adjusting the slider, a text appears stating how many seconds are the users setting the delay, and an animation starts to indicate how that given delay corresponds to the users' experience. So, for instance, if users select that the application is 3 s ahead, an animation starts on the upper side of the mobile device (Fig. 11b) showing a scene occurring on the mobile device image and 3 s after it, the same scene is on the TV image. Users with a high delay can move the slider all the way to the right (maximum is 4.0 s), and once there, if they keep their finger on the slider, the slider scale will increase to allow for a new maximum value (4.0 s are added to the maximum value every 0.5 s a finger is on the slider). Once users are pleased with their choice, they can touch on the "Confirm" button.

(4) If a delay was set, the next time the user is prompted to answer a question, application will delay the request by the number of seconds chosen by the users, so it can be closer to the TV broadcast timeline. After the user answers the question, a screen will appear once again asking for users' feedback. At this time, users can move the slide to the left, decreasing the delay that was previously set (they can also keep their finger on the slider to increase the minimum value, where the minimum is the delay value previously selected). Users can also move it further into the right, increasing even more the delay. This process will repeat until users select that the application is synchronised with the TV broadcast, hence having an optimal experience.

(5) Once the users state that the application is synchronised, the application stops asking them about their experience. Then, a pop-up appears stating that from now on they can adjust their experience when they wish, by clicking on the top-right button that has just appeared on the main screen of the application (this will present the Fig. 11c screen).

We designed the interaction mechanism by taking several facts into account. First of all, we only allow users to delay the application, because there is no way for users to calibrate the television. Users are watching a live feed—which is at least a few seconds delayed, compared to the live action on the venue—and have no control over it. The mobile application is their reference model that they can adjust. Bearing this in mind, we assume that the events triggered on the second screen application are always synchronised with the time that they occurred at the venue where the event is taking place. This is not just for a matter of simplicity, but it is a guideline that developers should have in mind: second screen interactions will not work if the applications are not synchronised with the real time of the live action, or at least, the fastest TV broadcast possible. If this is not the case (e.g. the human operator who triggers the events on the application is watching a TV broadcast a few seconds delayed), users at the venue or with a lower TV broadcast delay will get the events on the second screen application after they have occurred on the TV broadcast, without the possibility of synchronising them with the TV broadcast. Finally, we did not include any information regarding the live sports event, such as the match time (which could easily be used to compare the TV broadcast match time with the application match time to synchronise both feeds), as we wanted to evaluate a universal interaction mechanism that could be deployed on any sport or TV show. Thus, by not having the certainty that a well-defined cue is present on the TV broadcast to help the users, we designed the interaction mechanism without relying on extra information besides the users' feedback of their experience. Of course that developers are free to add extra information to their second screen applications, in order to further help users to synchronise their experience, but they are not required to do so.

As mentioned, in the near future, we will conduct user tests to evaluate how users interact with WeSync. Once satisfied with the results, we will focus on preventing users from exploiting the system (i.e. setting a delay higher than the real delay of their TV broadcasts).

3 Enhancing the Remote Spectators' Experiences Beyond Soccer

In the previous section, we presented four different prototype concepts (at different stages of development) that we developed to enhance spectators' social experiences during live soccer matches broadcasts. We chose soccer, because it is widely accepted as one of the world's most popular sports (FIFA 2015), it moves an incredible number

Table 1 How the different prototypes concepts may be applied to different sports

Sport	Usage of prototype concepts			
	WeApplaud	WeBet	WeFeel	WeSync
	Applaud…	Guess if a … will happen in the next seconds	Present the emotions' chart…	Ask how is the users' experience…
American football	When a great play occurs, points are scored, or to clap along chants	Touchdown	After a great play or when a team scores	After a play's outcome
Basketball	When a big play occurs or on free throws	Dunk	After a great play or at the final stages of a game	After a team scores
Motor racing Cycling	When an athlete performs a specific action (e.g. overtake)	Breakaway or an attack (cycling)	On predefined checkpoints or after a specific action occurs (i.e. overtake)	On predefined checkpoints
Badminton Tennis Volleyball	When a great play occurs, a point is scored, or to cheer a team or athlete	Point	After a point	After a play's outcome
Baseball Cricket		Not applicable	After a great play or when a team scores	After a bat's outcome
Aquatics (swimming events)	After a dive or to motivate swimmers on the final stretch		After a dive, or on predefined checkpoints	After an athlete's performance
Athletics (track and field)	After an outcome or to cheer for specific athletes (e.g. slow clap before triple jump)		On predefined checkpoints, after a specific action occurs, or after a performance	On predefined checkpoints (e.g. during a marathon) or after an athlete's performance
Gymnastics	When a great movement is performed or after a performance		After a great movement or performance	After an athlete's performance

of fans all over the world and generates strong emotions. But, of course, what we introduced more importantly than the prototypes themselves were the different concepts: to applaud during a live event, to bet during crucial moments, to share and visualise users' emotions during a TV broadcast, and to synchronise second screen applications with live TV broadcasts. In this section, we analyse how the different prototype concepts can be applied in different sports, live TV shows, and even electronic sports (eSports).

In Table 1, we present a list with the most popular sports in the world and we give a few examples of how the previous prototypes can be applied to these sports.

Table 2 How the different prototype concepts may be applied to different live TV show genres

Live TV show genre	Usage of prototype concepts			
	WeApplaud	WeBet	WeFeel	WeSync
	Applaud…	Guess if a … will happen in the next seconds	Present the emotions' chart…	Ask how is the users' experience…
Contest	During or after a performance	Not applicable	During or after a performance	When the show goes to commercial or after a specific performance
News show	After an answer from the interviewee	Not applicable	After a news coverage ends or during an answer from the interviewee	After a news coverage ends, after an answer from the interviewee, or when the show goes to commercial
Reality show	After a specific event (e.g. participant is eliminated)	Not applicable	After a specific event (e.g. a kiss between participants)	When the show goes to commercial or after a specific segment
Talk show	After a specific event (e.g. joke by presenter) or answer from an interviewee	Not applicable	During or after an answer from an interviewee	

This list comprises the most popular sports that featured on the 2012 Summer Olympic Games records on Twitter (2012) (we excluded soccer), plus American Football, Basketball, Baseball, Cycling, Motor Racing, and Cricket. We added these sports due to their popularity on countries such as USA, Japan, France, Belgium, India, and Australia.

Regarding live TV shows, some of the most popular live TV genres (Film Victoria 2010) are: Game Shows or Contests (such as Dancing with the Stars or American Idol), News Shows (classic newscasts and interviews), Reality Shows (like Big Brother or The Biggest Loser), and Talk Shows (such as The View or The Talk). Table 2 lists how the four prototype concepts can be applied to each of these live TV genres.

eSports is an entertainment area that should not be ignored. On recent years, the eSports scene had a huge growth in popularity (OnGamers 2014), in part thanks to the focus that game designers put on creating competitive games, but also thanks to Twitch, a live streaming video platform focused on video games. The most popular eSports titles (Wikipedia 2014) are based on the following genres: Fighting (game series like Street Fighter and Super Smash Bros.); First Person Shooter (FPS, with the series Counter-strike and Call of Duty being hugely popular); Multiplayer Online Battle Arena (MOBA, a recent genre popularised by games like DOTA and League of Legends); Real-time Strategy [RTS, a classic genre where series like

Table 3 List detailing how the different prototype concepts can be applied to different video game genres

<table>
<tr><th rowspan="3">Video game genre</th><th colspan="4">Usage of prototype concepts</th></tr>
<tr><th>WeApplaud</th><th>WeBet</th><th>WeFeel</th><th>WeSync</th></tr>
<tr><th>Applaud…</th><th>Guess if a … will happen in the next seconds</th><th>Present the emotions' chart…</th><th>Ask how is the users' experience…</th></tr>
<tr><td>Fighting</td><td>When a great play occurs or after a knockout</td><td>Player's knockout</td><td>At the end of a round</td><td>At the end of a round</td></tr>
<tr><td>FPS</td><td rowspan="2">When an important play occurs or after a player's kill</td><td rowspan="2">Player's kill</td><td>At the end of a round, after a player's kill or after a great play</td><td rowspan="3">After a play's outcome</td></tr>
<tr><td>MOBA</td><td>After a hero's kill or after a great play</td></tr>
<tr><td>RTS</td><td>When a great play occurs</td><td>Player's defeat</td><td>After a great play</td></tr>
<tr><td>Sports</td><td>When a great play occurs or when the score changes</td><td>Score</td><td>After a great play or when a team scores</td><td>After a play's outcome</td></tr>
<tr><td>TCG</td><td>When a great play occurs</td><td>Player's defeat</td><td>After a special card is drawn or after a great play</td><td>At the end of a turn</td></tr>
</table>

Starcraft and Warcraft became famous for filling up stadiums in South Korea (LA Times 2007)], and Sports (with the FIFA series featuring on World Cyber Games since 2001). Also, recently the Trading Card Game genre has seen a growth in popularity due to the Hearthstone: Heroes of Warcraft game. Table 3 lists how the four prototype concepts can be applied to these video games genres.

It is safe to conclude that prototype concepts, such as WeApplaud, WeFeel, and WeSync, can be applied in similar ways to different sports, live TV shows, and eSports. However, a concept like the one explored in WeBet (predict, during unexpected moments, that an event will happen in the next seconds) seems not to work on some sports and TV shows. Although it also makes sense to predict events on the sports and TV shows where WeBet was not applicable, predictions should happen beforehand on predefined moments (i.e. a screen appears, synchronised with the TV broadcast inviting, the user to interact), and not during a very short moment of an exciting performance, as in the WeBet concept. For instance, it makes more sense to ask users what will happen in the next baseball play (hit, out, or walk), than to guess a hit in the next seconds.

4 Challenges and Guidelines

It is fair to say that adapting the four prototype concepts to different sports, live TV shows, and eSports may result in a whole new range of applications. The knowledge that we gathered during the prototypes' studies allowed us to go one step further and describe some challenges and early guidelines for the design of second screen applications for interaction during live broadcasts.

Several elements play a significant role in shaping the user experience when interacting with a second screen application during a live broadcasted event. These elements are: the venue, the TV broadcast, the mobile application, and the socialisation aspects. To allow remote spectators to have an experience closer to the ones at the venue, we can bring elements from the venue to the remote spectators, such as audio or video. This requires the use of special hardware on the venue to gather data and stream it through a real-time feed to the application. Regarding the TV broadcast, this can be behind or ahead the second screen application, and in this case we suggest the use of ACR technology or a manual method like the one developed in WeSync to have both feeds (TV and mobile device) synchronised. Other aspect to take into account is that some remote spectators may not feel like using the application during the whole TV broadcast (and therefore if they leave the application they can miss an important moment to interact). A solution to this issue may be to send push notifications during important events, so users can tap on these alerts to quickly go back to the application. It is also important to prevent the application from entering an idle state; otherwise, users need to keep touching on screen to prevent the mobile device from becoming idle. Finally, as we saw at the beginning of Sect. 2, users can be watching a TV broadcast alone or with others. We think it is important to deploy different experiences to these kinds of audiences: some experiences that make users feel that they are watching the event with others (like WeFeel), and others that encourage users to compete or cooperate on the same physical space (like WeApplaud).

Interaction mechanisms also play a key role in providing an enhanced user experience when using a second screen application. A user can be prompted to interact during predefined moments (as mentioned at the end of Sect. 4) or undefined moments (i.e. users can perform an action at anytime, by their own initiative). For the first scenario, it is necessary to design a well-balanced experience containing different challenges (e.g. polls, trivia questions) properly spaced apart in time, in order to provide users with a dynamic and exciting experience but not an annoying one. For the second scenario, it is recommended to design interaction mechanisms that allow users to interact with the second screen applications during unexpected moments of the TV broadcast, without requiring their visual attention on the mobile phone. Eyes-free interaction techniques, relying on audio or haptic feedback, can be explored, as proposed by WeBet, to make users aware of the application's state without the need to have visual confirmation.

By having two screens to explore, it is necessary to design a well-organised interface both on the mobile device and on the television. If users wish to predict that an event is going to happen in the next seconds—think about the WeBet concept—they need to have immediate access to the interaction mechanism that allows them to bet no matter which application screen is currently on display. On the contrary, if this mechanism is only accessible from a specific application screen or menu, the users will be forced to navigate to that screen before being able to bet (and probably losing the opportunity) or to stay on that section for the entire broadcast, which is also not desirable, especially if the other application screens are equally rich in content (e.g. providing real-time information about the broadcasts). Lastly, if an application provides UI elements on the TV screen (e.g. WeFeel messages and info charts), it is important to select well-defined areas to position the UI elements that do not occlude the main scene displayed on the TV. Moreover, it is necessary to fade the UI elements after a few seconds, in order not to have a cluttered interface and, when possible, to choose less relevant moments of the TV broadcast to overlay this UI elements on the TV display.

5 Related Work

Whether fans go to sports events in stadiums, or watch them on television, individuals usually have a combination of motivations, not just a single one. In their research, Wann et al. (2001) and Wann (1995) introduced the Sport Fan Motivation Scale (SFMS). The SFMS is an instrument designed to illustrate the degrees of fan intensity and help sports decision makers determine how to increase fans' involvement. SFMS comprises eight motivational factors: eustress, self-esteem, escape, entertainment, economic, aesthetics, group affiliation, and family. Two of our prototypes, WeApplaud and WeBet, focus on entertainment, group affiliation (the desire to be with other people, sharing the same passion), and eustress (positive stress that is created from taking part in a challenge) to enhance the remote spectators' experiences.

Other examples of applications that aim at improving the viewer's experience do it by providing additional show-related information, access to social networks, and content synchronised with interactive experiences, such as polls or quizzes. Cesar et al. (2009) proposed taxonomy for the different uses of the second screen in the TV environment. They classify use cases into three main categories: content control, content enrichment, and content sharing. In content control, users are given the opportunity to decide which content is appropriate to display either on TV or on the second screen device. MEO GO[8] is a mobile application developed within the MEO triple-play subscription home telecommunications platform. This application allows users to watch a TV channel either on the mobile device or on the television screen, as well as control the TV by switching channels and volume, and even accessing special features, such as the MEO video club.

[8]MEO GO, http://bit.ly/1vckvFB.

Content enrichment refers to the content manipulation that users can perform on either the TV or the second screen device. Several studies were conducted within this context, with second screen applications tackling different areas such as newscasts, TV series, and sports. Take for instance the FanFeeds prototype (Basapur et al. 2012), which provides in-sync additional content-related media on the second screen device. Another related example is the system developed by Blanco et al. (2013), where the authors use information retrieval techniques to display in real time an online news article that matches the piece of news discussed in the newscast currently airing on TV. Similar examples can also be applied to TV series, either by presenting character background (Murray et al. 2012) or story information (Nadakumar and Murray 2014) at the right time. On both cases, viewers who miss a previous episode can visualise key information synchronised with the TV broadcast, in order to ease the comprehension of the narrative. When applying these concepts to sports, it may be useful to visualise simultaneous channels of sports events and associated statistics (Anstead et al. 2014) or simply have fun while predicting events with other friends (Centieiro et al. 2014a, b, c).

Finally, content sharing empowers the users to share their opinions and comments with others. This is a topic of major interest within the second screen concept, which resulted in different research studies. For instance, Geerts et al. (2009) discuss the effect of TV show genres on social TV activities like chatting or clip sharing. In a survey conducted by Nielsen (2013) on the first quarter of 2013, it was showed that nearly half of smartphone (46 %) and tablet owners (43 %) use their devices as second screens while watching TV everyday. Another example is the users' activity on Twitter during the Super Bowl 2014 edition: there were 24.9 million related tweets (most of them done after exciting plays or touchdowns), which edged out the 2013 edition by 800.000 (Twitter 2014). Finally, the study conducted by Buchinger et al. (2009) concluded that news, soap operas, quiz shows, and sports were the genres during which participants talk the most while watching, making them highly suitable for social media use. Furthermore, Schirra et al. (2014) presented a study where the authors concluded that viewers were mainly motivated to tweet during television series due to their desire of connecting with a community also watching the same show. WeFeel takes this into account by allowing remote spectators to share opinions and emotions in a novel way, through the television screen.

With the growth of the second screen concept, there have been some mobile applications that seek to provide game experiences during sports events. Viva Ronaldo[9] is one of those applications. Viva Ronaldo allows fans to follow all of Cristiano Ronaldo's live matches, support and predict his in-game actions, play trivia challenges, and answer polls, all while collecting points and rewards. Another example is the Tour de France companion application[10] that delivers secondary information about the race on the mobile device, synchronised with the live timeline

[9]Viva Ronaldo Mobile Application, http://bit.ly/1vLH2wu.

[10]Tour de France Mobile Application, http://bit.ly/1c86zo0.

of what is happening on television. It also allows the audience members to communicate with each other about what is happening, either through chat or polls.

However, while second screen applications are designed to enhance spectators' experience, the use of an extra screen results in a competition for users' attention. If attention is not appropriately directed between screens, the second screen could diminish rather than enhance engagement with the broadcasted content. Conversely, the television could distract from time-sensitive, interactive content on the second screen. This issue is studied by Holmes et al. (2012), who suggest that adding a synchronised second screen application to the television viewing experience has important impacts on the distribution of visual attention as indicated by point of gaze.

Another issue that needs to be taken into account is the effect of the TV delay when watching broadcasted live events. Mekuria et al. (2012) conducted a study regarding the synchronisation between different TV service providers and presented empirical evidence that relative delays encountered in digital TV degrade the football watching experience, especially when there are fans closer to each other (e.g. neighbours) watching non-synchronised TV feeds. In our research, we have a similar problem, since we have to deal with the synchronisation between what is being watched on TV and the content that is displayed on the second device. Both of these feeds have different sources (television broadcast and the server handling the second screen application), and they need to be synchronised to provide a non-disruptive experience. Moreover, television providers have different broadcasting delays, making it more difficult to achieve a solution to this issue. It is possible to deal with this issue by using ACR or by manually setting up a delay. In the first case, companies like Wywy[11] offer a proprietary solution to calibrate TV shows with a second screen app in real time. ACR aggregates a bunch of technologies and the two main methods used are audio watermarking and audio fingerprinting. The latter relies on the content being unique, which is not always the case. Audio watermarking is more definitive, but it requires introducing a change to the TV broadcast audio (a watermark sound), which may annoy some remote spectators. However, since we cannot use such solution on our work—nor it is our research goal to develop similar solutions—we intend to solve this problem by letting users manually set a delay as described on WeSync, on Sect. 2.4.

6 Conclusions and Future Work

This chapter describes how second screen interactions can help to enhance the remote spectators' experience during live broadcast events. It presents a set of four prototypes that prompt users to interact in innovative and exciting ways during a soccer match. These prototypes invite users to participate in the applauses

[11]Wywy, http://www.wywy.tv.

happening in the stadium, guess if a goal will happen in the next seconds, share opinions and emotions with friends in a innovative way, and effortlessly synchronise a TV broadcast with a second screen application.

We also detail how the prototype concepts could be applied on the most popular sports, live TV shows genres, and video games genres featuring on eSports. We concluded that the four prototype concepts could be applied, in a similar way, to several sports (due to the analogous way the different sports' action unfold), while in a few cases the WeBet concept is not applicable. This nuance is more evident on live TV shows genres, where we cannot find any scenario where the WeBet concept can be applicable. However, the results shift when we approach the different video games genres on eSports with all the prototype concepts being applicable without any major difficulty. We think that this is explained by the resemblance of the competition conveyed by video games with the one of sports: two or more performers are competing to achieve a win, with fans reacting to the game's action by cheering and supporting their favourite performers.

The user studies we conducted so far were overwhelming positive not only because they helped to validate our concepts, but also because we obtained important insights into the challenges and issues that users faced while participating in the different experiences. With this in mind, we assembled an initial set of guidelines for the development of second screen interactions during live broadcast events. We think that these guidelines can be useful either for developers, user interaction designers, or researchers that seek to create second screen experiences.

As for future work, we plan to conduct additional evaluation studies to deploy WeFeel new features and chat modalities, to study how users interact with WeSync, and analyse how the WeSync's algorithm behaves to prevent users from exploiting the system. We hope that the results from these studies will give us more insights into how to enhance the remote spectators' experience through second screen applications.

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