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ORIGINAL ARTICLE

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Interactive and experiential design in smart textile products and applications

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Abstract The technical textiles industry in the USA and the EU is growing. As we advance into the knowledge age, objects and material technology will disappear into our material environment, turning unintelligent objects into active and intelligent participants in our lives. As much of our environment is made up from textile materials, they will be the targets of smart engineering. The future of smart textiles will rely on the convergence of electrochemistry and textiles in order to process electronic polymers into fibres and fabrics. The integration of smart functionality into clothing and other textile products will radically change the culture surrounding these products, fundamentally altering people's relationships with them and the way they use them. Smart functionality will also have an impact on the way products are designed and the materials developed.

Keywords Hybrid industries · Ubiquitous intelligence · Interaction design · Experience and emotion

1 Introduction

This paper suggests that shifts in the textiles, electronics and information and communication technology (ICT) sectors will give rise to the area of intelligent textiles and clothing. The technical textiles industry in the USA and the EU is growing. The western clothing market has segmented into two distinct areas: low cost, high volume, and high-end specification goods, for example, sports performance and designer-led fashion. The textiles industries of the USA and the EU are focussing on technical textiles for high-specification products partly in response to the approaching end of the *Multi-Fibre Arrangement*[1]. In recent years, market growth in clothing has been fuelled by the emergence of new fibres, new fabrics and innovative processing technologies. This trend is set to continue where technical innovations in textiles will become more important than the fashion content itself. The market has also been boosted by changes in consumer lifestyles. Much of these new developments have come from the technical textiles industry. *High-tech* fabrics must continue to cross the boundary into everyday fashion apparel as well as into home interior furnishings to meet the challenge of future lifestyle needs and consumer requirements. Products that *win* will be those that enhance the quality of life in some way, and have added value in terms of functionality and performance. As we advance into the *knowledge age*, objects and material technology are forecast to pervade our material environment. The market for technology products generally is growing. Consumer requirements of products are changing, gravitating towards higher order needs that stimulate the intellect, such as experience and sensory and emotional fulfilment, and are set to become the new commercial imperatives in the developed world.

The integration of smart functionality into clothing and other textile products will fundamentally change cultures of clothing and interior products. It will also radically alter people's relationships with them, and, hence, on the way, these products are designed and the materials developed. This paper highlights key developments in computing, such as ubiquitous computing and human–computer interaction, and suggests that the design of textile products will converge towards

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[1] Since 1974, world trade in textiles and garments has been governed by the Multi-Fibre Arrangement. This provided the basis on which industrialised countries have been able to restrict imports from developing countries. It will expire at the end of 2004.

computing and the field of human–computer interaction design. The areas in which textile materials development might occur, how different industry sectors will need to collaborate, and possibly converge, for these developments to happen and the implications for the development process are also highlighted.

2 Knowledge age: dematerialisation of information and communication technology and the rise of ubiquitous intelligence

We are advancing into a knowledge-based economy, where ideas and information mean capital and information access and communication systems are the drivers. Science is increasingly impacting on and permeating all aspects of our lives through products and services, as the market for technology products expand. According to Philips Electronics, Netherlands, ''our environment of the future will consist of invisible interactive systems that will be embedded in our living spaces and clothing, creating an ambient intelligence that could form a natural part of our life'' [1]. The silver and black plastic products that currently house electronics and computers are set to vanish as technology dissolves into our material environment, i.e. interiors, buildings, furniture and clothing. As technology becomes *dematerialised* and embedded within these hitherto dumb products, they will become active and intelligent. They will be the future mediators of technology. Our contact with these everyday objects will become a central focus in our lives, facilitating new methods of accessing entertainment, knowledge and communication. New methods of information access engaged with how people access computer intelligence embedded within everyday objects and devices, whose user interface is intuitive, have been in development over the last 20 years in the areas of ubiquitous computing, wearable computing and human–computer interaction. A good example of the ubiquitous computing vision is Smart Paper by Gyricon, which combines the best of modern computing technology with the best of established technology, the book. The vision of the paperless office never materialised; in fact, we use more paper now than ever. This is because no one wants to read text off a computer display; the printed word on paper simply looks better. By coating paper with electronic ink, the contents of a book or a newspaper can change on command or continuously, by downloading it wirelessly. Out of ubiquitous and wearable computing has arisen the field of *human–computer interaction design*. ''As products and services are increasingly being created using information technology, interaction design is likely to become the key design skill of this century'' [2].

3 New commercial imperatives

Running in parallel with, and complimentary to, the rise of ubiquitous computing and information access are changing consumer requirements. The societies of the developed world are gravitating towards a culture that will be focussed firmly on human senses; it is becoming epitomised by a requirement for more intensive *experiences* and higher order meanings as we diverge from a purely material culture. According to Maslow's *Hierarchy of Needs* there are two levels of need on the scale, basic and meta, along which people constantly strive to move. Now that basic needs have been met in the developed world, people are striving to satisfy meta or higher order needs. Meta needs include cognitive, aesthetic, self-actualisation and self-transcendence. Hence, the transition from making and marketing a product to developing non-tangible concepts that satisfy the demand of higher order needs, such as ideas, sensory and emotional fulfilment, cultural experiences and entertainment which stimulate the intellect, is underway and gaining momentum. ''The experience economy is a new stage of economic offering'' [3]. Pine [3] suggests that consumers must be drawn into the *offering*, much like a viewer watching a theatre performance, but the viewer must also be an actor and participate in the experience.

Elements that stimulate our senses (sight, touch, sound, taste and smell) form our experiences of our environment. Products have always engendered some kind of sensorial quality. Intelligent materials will provide a new array of sensorial qualities, which will impact both on how we experience our surroundings and how we interact with them. An intelligent world will be one in which our interactions with products become ever more intuitive, using materials and systems that are responsive to our methods of communication, such as touching and the use of body language. Intelligent materials will improve our control over our material environment and facilitate our creative interaction with it as we seek to be *co-creators*, tailoring experiences to correspond to our various moods. Gershenfield [4] states that, ''in the laboratory and in product development pipelines, information is moving out of traditional computers and into the world around us, a change that is much more significant than the arrival of multimedia or the Internet because it touches on so much more of human experience.'' As a result, we are seeing the rise in the industrial design community of what is termed, *experiential design*; a method engaged with the value of the *experience* that the user derives from using a product. Designers have to investigate how people use, engage and feel about things and places to build a body of knowledge with which to frame experiences.

4 A new language for textiles: combining the real and the virtual

Given the vision of dematerialising ICT, and the fact that much of our living environment is made up from textiles, which are familiar and ''friendly'', soft and tactile, the ICT industries are now expressing keen

interest in textiles. One of the concerns that consumers often have of new technology products is their tendency to become more sophisticated, thereby, making them difficult to use and adapt to. Therefore, *high-tech* must not make our products more complicated by having more components; rather, they should become seamlessly integrated into everyday objects, without altering their character, and enhance their function. This section looks at how the design of textiles and clothing can converge with ICT and play a key role in this emerging genre of intelligent products and environments.

Embedded intelligence will completely alter people's relationship with our everyday products and environments. No one yet knows how people will react to, or engage with, technology on their bodies or integrated into their homes. Intelligence has no tangible form. Seamlessly embedded intelligence will change the way designers design and develop products, as it will no longer be just about the physical form of the product, but about intangible features, such as the notion of experience and emotional fulfilment that affect all the senses. The designers' task will become one of giving *form* to *virtual* content. In the realm of human–computer interaction, content is seen as service, experience, communication and information access. Intelligence will give the designer greater scope for creativity, a new tool with which to explore and apply computer intelligence in new ways. Will the designer become more of a facilitator and enable users or wearers to be inventive by means of the technology?

There are a number of fundamental issues that need to be understood before technology can be applied to the body or integrated into people's homes in a way that is truly meaningful. Addressing these involves a multidisciplinary effort, which examines conventions and cultures of product use and experience. ''As the human–computer interface becomes more pervasive and intimate, it will need to explicitly draw upon cognitive science as a basis for understanding what people are capable of doing. User experience and situation should be integrated into the computer system design process'' [5]. To examine the established roles and places that objects have in our everyday lives, and the psychology of interaction and cognition of products, should involve the human sciences and the designer of clothing and products from the outset of the design of systems and materials.

Referring again to *Smart Paper*: ''We're just learning how to use a lot of new technology to match performance of the mature technology in books, transcending its inherent limits without sacrificing its best features. The bits and atoms belong together. The story of the book is not coming to an end; it's really just beginning'' [4]. By building on what we know about existing products, we can begin to extend and augment the utility of clothing and other textile products, such as furnishings and building materials.

The author's research in this paper explores the interface of intelligent technology, as well as extending the application of computer intelligence through the application of existing technologies, such as wireless communications, textile antennas, chromic display materials, textile switches, textile circuits and microcomponent welding technology, in new ways, whilst building on existing cultures of clothing and products. Disseminating concepts and ideas in the public domain has the potential to excite market demand and, therefore, materials development. It is well known that textiles have their own *language* that is tactile, sensorial as well as visual, which textile and fashion designers have traditionally exploited to engineer or express a *look*, a concept or idea, by carefully composing and manipulating the many facets of its special vocabulary. The textile language will be expanded exponentially as a result of the integration of electronic technologies to build smart textile systems. This research aims to discover what new codes of interaction and experience will arise when textiles are transformed from a passive into an active, intelligent state. The notion of clothing as a *tool box*will be conceptualised. These tool boxes will enable the user to experience a sense of being creative, communicate more expressive and emotional messages, and engage in social interaction and gaming. The visual look and haptic qualities of smart clothing and interior environments can be customised by the user through non-verbal channels of communication that are intuitive, such as gesturing and touching. The research seeks to rationalise the function of ICT content together with conventional interaction with, and cultures of, everyday clothing and map one onto the other to ascertain what new interactions and experiences will arise.

The interaction design process is an iterative one, where known conventions of people's product use and experience are used to map a conceptual framework for *content*—form and experience. The method used here makes reference to methodology explored by the University of Art and Design, Helsinki, Finland [6]. The framework is based on observations and research on: how people use, interact with and experience conventional clothing and interior environments; social psychology of people's clothing use and behaviour; sensory perception of textiles; how people communicate their emotions through non-verbal channels, such as body language; how people communicate through wireless communications systems, such as mobile phones and the Internet; how expressive communication is portrayed in contemporary culture in terms of language, moods and colours. User group tests are based around a seminar in order to test conceptual assumptions. The results are fed back into the framework, which is then used to build prototype designs. These are also tested on user groups, and are again fed back into the framework.

The following design scenarios suggest a way in which textiles and clothing can converge with ICT. The scenarios make reference to a newly emerging area of expressive interaction, interpersonal and haptic[2] com-

[2] Sense of touch.

munication, and gaming. For example, the *Super Cilia Skin* is an interactive membrane developed at the MIT Media Lab. The skin functions as a computer output device, capable of visual and tactile expression, allowing gesture to be seen or an image to be felt via an array of actuators mounted onto an elastic membrane. "Most computational tools rely on visual output devices. While such devices are invaluable, influential studies in neurophysiology have shown that physical experience creates especially strong neural pathways in the brain. When people participate in tactile/kinesthetic activity, the two hemispheres of the brain are simultaneously engaged... assuring that new information will be retained in long-term memory" [7]. Another example of interpersonal communication by use of haptic technology is *ComTouch*, again developed at the MIT Media Lab. *ComTouch* is a handheld device that translates finger pressure into vibration, thereby, augmenting voice channels of communication. "A device that conveys touch might allow for more expressive interactions" [8].

4.1 Tools for remote interpersonal communication

The aims of this scenario are to develop: a clothing concept that facilitates the sending of expressive messages to friends or partners by conveying a sense and experience of touch or presence through clothing; clothing that is a mobile aid that facilitates the expression of other aspects of human communication, supporting the user's need for subtle communication and complementing existing communication channels.

This scenario is built on conventions and cultures of clothing and textiles in being expressive media, and on the close bond we have with our clothing, which connects people through touch and gesture. One of the main attributes of textiles is their huge range of tactile qualities (cool/warm, hard/soft) as well as acoustic properties, having certain effects on the way people feel and respond to them. Sensory science, or psychophysics, is an emerging area of experimental psychology that was first applied to product areas such as food. It is now being applied to textiles to measure people's subjective experiences of textiles when touched. Touch is an important part of human interaction and communication; for example, warmth and affection are often conveyed through touch. Also, people communicate through gesture or body movement, which constitute a type of *language*, a "language of emotions" [9]. Clothing is an emotional medium; it envelops us, is our second skin and is, in some way, an extension of our body. "Dress is the way in which individuals learn to live in their bodies and feel at home in them. Dress is... an intimate experience of the body" [10]. The conceptual framework is illustrated in Table 1.

Sending the message The signal sent is based on the relationship of the sender with the recipient. The message can be purely non-verbal, an expression of how the sender is feeling or a feeling that he or she wants to convey, or illustrative, reinforcing verbal messages over the telephone. The sender's interactions (or switching actions) with his or her clothing are based on conventions of touch and gesture associated with expressive communication and/or touch or gesture that serves to concretise verbal communication. For example, emotional expressions that demonstrate affection could be conveyed through touch and body gestures, such as an embrace or stroking an arm/sleeve. The garment consists of pressure-sensing and gesture-sensing textiles connected to a textile antenna by a textile circuit, to which a communications chip is welded. When the pressure-sensing textile is pressed or stroked, or when the gesture sensor senses a gesture or movement, a signal containing a code is sent to the communications chip. Each type of pressure or gesture is assigned a code.

Receiving the message The change effected in the recipient's clothing is based on translating the expressive meaning of the touch or gesture into colour or tactile configurations, realised in a chromic display material. The pressure or gesture code is picked by up the receiver's antenna, causing the communications chip to send a signal to the display on which a colour appears. The emotion expressed by the sender is translated into a colour, which is based on known colour psychology and cultural values of colour. Colours are purported to have emotional, physical and behavioural values; for example, in many western cultures, the emotional value of red is love, vitality, courage, passion and danger. Colours have positive and negative effects on us, caused by their energy entering our bodies. By being able to effect a colour change in the receiver's clothing, the sender can either let the recipient know how he or she is feeling, or influence his or her mood. The receiver's garment is composed of a textile antenna and communications chip, which are connected to either display materials or actuator textiles by textile circuits. Touch and gesture can be conveyed

Table 1 Tools for remote interpersonal communication

Emotional expression or mood	Sending message/switching action	Receiving message/change effected (in recipient's clothing)	
		Display	Actuator
Warmth	Gentle squeezing of arm	Yellow	Squeezing sensation
Love	Stroking of arm	Red	Soft tactile
Affection	Embrace/arms wrapped around the wearer	Yellow	Hugging sensation

more literally using actuator textiles; for example, an embrace sent could be conveyed through the contraction of the textile fibres, causing the garment to *hug* the body. Touch can also be tactilely sensed; for example, where different haptic qualities of textiles can be conveyed. Configurations of haptic qualities are based on research conducted on the sensory properties of various types of textiles. The concept could also be extended to include interior environments, where a sense of presence can be conveyed via furniture and furnishings.

4.2 Tools for social interaction and social gaming

"Social interactions are the focus of our existence. We are social animals, and for any technology to be useful, it must eventually support socialization" [11]. The aim of this scenario is to develop clothing concepts that facilitate social interaction by provoking and eliciting emotional responses. People can interfere and interact with the clothing of others in the vicinity by changing the visual appearance (colour, pattern), tactile quality or shape of the clothing.

This scenario is built on conventions of clothing as an expressive medium and on the social nature of humans. Clothing facilitates social interaction, as it is a means of making the body social. It can create a sense of belonging or enable anonymity through a process of managing personal appearance to form a total composite image. Clothing can be used as a channel of communication, where "one person would *say* something to another person with the intention of effecting some change in that other person. ...the effect on the receiver is important in that it is the effect on the receiver that constitutes social interaction" [12]. The effect can be an emotional response, or change of behaviour or state of mind. People express and communicate their emotions through their behaviour and body language. "...bodily, non verbal communication operates within a social context, but also that the messages conveyed by bodily expression are about the society itself" [13]. The conceptual framework for this scenario is based on people's clothing behaviour as well on explorations into the social behaviour of people. This scenario is also built on the emerging area of personal electronic data exchange, and gaming becoming more of a social activity. The *vCard* is an electronic business card, which is a new means of sending business cards to people via electronic devices. Electronic games developers, such as Sony, are looking into making gaming less of a singular activity and more social. The conceptual framework is illustrated in Table 2.

As in the previous scenario, interactions between people are based on gestures and actions as communicators of emotion, which serve to trigger changes in either the sender's or the recipient's clothing.

4.3 Tools for creativity and gaming

The aims of this scenario are to develop clothing and interior environment textile concepts that facilitate a sense of being creative by allowing the user to be a *co-creator*. The user or wearer customises the visual appearance (colour, pattern), tactile quality or shape of the textile, thus, giving the wearer a sense of self-expression.

This scenario is built on conventions and cultures of clothing. Clothing facilitates individualistic expression, allowing individuals to differentiate themselves and to declare their uniqueness. "...it seems that more and more people are becoming addicted to the feelings they get when they wear something new. Those feelings may be of increased or reinforced uniqueness or of pleasure in presenting a different appearance to the world. Individuals may also derive aesthetic pleasure from either 'creating personal display' or from appreciating that of others" [12]. Clothing can also serve to reflect, hide or generate mood. Sometimes, by expressing a mood, the wearer can influence other people's moods. This scenario is also built on *celebrity culture* or *limelight syndrome*, prevalent in western cultures and the gaming field. Sony and Microsoft are looking at ways of making gaming more interactive and fun; for example, researchers at Sony are investigating the use of gestures as game commands to replace the joystick. The conceptual framework is illustrated in Table 3.

Clothing can be customised whereby aesthetics, colour, pattern, shape and size of clothing can be altered according to size, taste and mood. The wearer can be expressive by changing aesthetics and effects; for example, changing light, colour and patterns, shapes and textures. Gaming or role-playing can be enhanced through mediated environments, where the space is also smart or active, delivering content. In a mediated environment, the user can live out fantasies and engage in

Table 2 Tools for social interaction and social gaming

Emotional expression or mood	Sending message/switching action	Receiving message/change effected	
		Display	Actuator
Being playful/attracting attention	Squeezing or tapping arm, shoulder	In recipient's clothing: orange	In recipient's clothing: squeezing sensation
Sending personal message	Positive body language	In recipient's clothing: yellow	In recipient's clothing: pressing sensation
Social/cultural groups gaming	Gaming actions	In recipient's clothing: *hit* spots	In recipient's clothing: *hit* sensation

Table 3 Tools for creativity and gaming

Emotional expression or mood	Switching action	Change effected	
		Display	Actuator
Customising aesthetics: personal display	Virtual paint box: drawing hand down sleeve effects *brushed* colour changes	User's clothing: any colour	User's clothing: change in size, shape, tactile quality
Role play/fantasy: celebrity, icon, film character	Role play actions	Mediated environment: provides context	User's clothing: force feedback
Game/sport: performance enhancing and/or monitoring	Gaming/sport actions	Mediated environment: provides game context User's clothing:*hit* spots	User's clothing: force feedback

games, sport, performance or role-playing/acting in their own homes; for example, where body actions are read and sent to a wall display. By monitoring performance, the clothing can augment sports activities; for example, by embedding sensors in running shoes or in the flooring, facilitating feedback on technique and performance. Clothing can also enhance performance by providing extra strength, which may have particular benefits for those with injuries or disabilities.

5 Technology enablers

The scenarios are explored using currently available technology to build smart textile systems, such as wireless communications, textile antennas, chromic display materials, textile switches, textile pressure and gesture sensors, textile circuits and micro-component welding technology. Testing of textiles is being carried out in collaboration with Cliff Randell, Bristol University and Matthew Chalmers, University of Glasgow, as part of the EPSRC-funded Equator project. See Fig. 1 for the location of active materials.

However, there are many electroactive polymers currently being developed by the electrochemistry industry, a convergence of electronics and chemistry. The electrochemistry sector is developing electroactive polymers for what are being termed as *plastic electronics*. The future prospects that these polymers can enable, if transferred to the textiles industry, will be soft intelligent

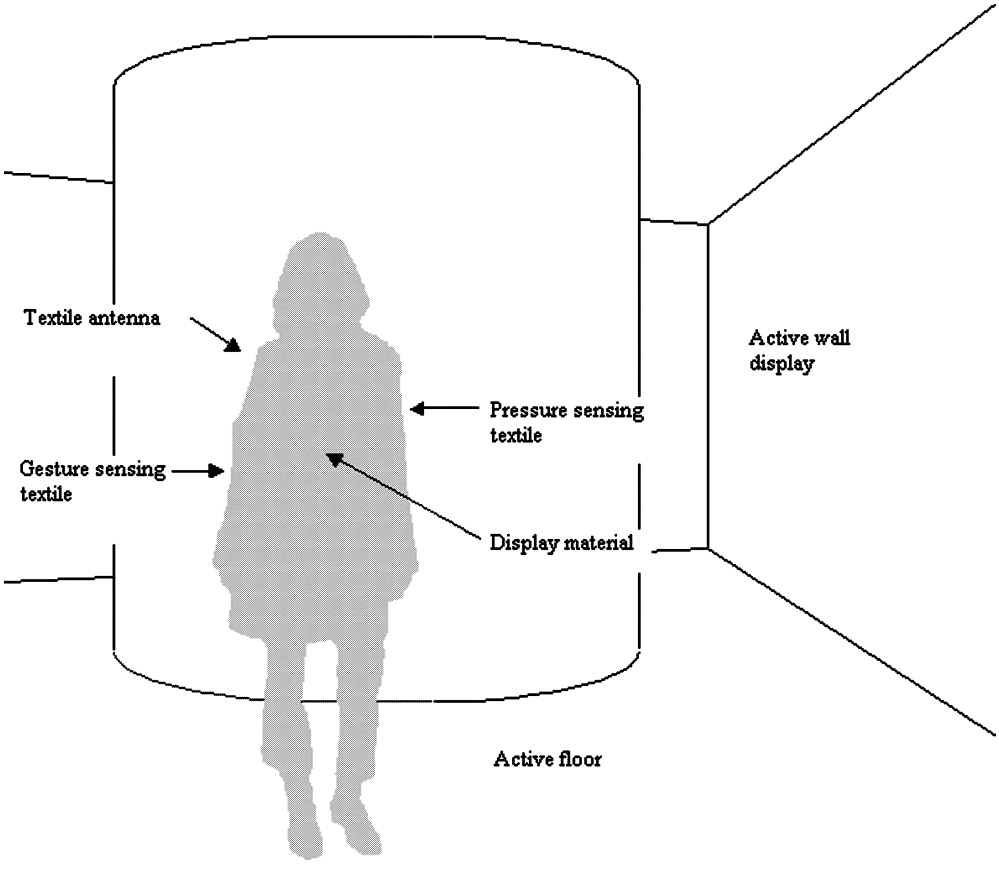

Fig. 1 Location of active materials in clothing and in an environment

textile products that will permit a broad spectrum of functions and capabilities. Light-emitting textile displays could be engineered through applying electrochormic or light-emitting diodes to inherently conductive fibres. If fibres could be fabricated from actuator polymers, textiles that change shape, surface texture could be realised. Plastic electronic circuits could be fabricated out of polymer transistors, as well as sensors and memories for smart devices. The future of truly smart textiles lies in the potential of *technology convergence*, where these electroactive polymers or molecular electronics are processed into, or fabricated onto, fibres and fabrics. The realisation of intelligent functions into textiles using the aforementioned electroactive polymers will rely on nanotechnology. Nanotechnology will be the next industrial revolution following the knowledge age. Nanotechnology is the creation of functional materials, devices and systems through control of matter on the nanometre (nm) scale. Research is going on into modifying fibre surfaces, grafting materials onto fibres to create multi-functional, responsive and adaptive fibres, in order to tailor a hybrid nanolayer of polymer film that will afford a number of functions and properties; for example, colour change. The electronics sector is developing nanowires that are grown from vapours of atomic ingredients, and act as diodes or other electronic component.

If the predictions are correct, a life where intelligence is embedded into everything is going to make the development processes of products and materials much more complex than has been the case, as it will encroach on different sectors and involve many complex issues.

''Dozens of smart fabrics and interactive-textiles- enabling technologies are under development today, yet, few of the OEMs or end-users of SFIT-enabled (smart fabrics and interactive textiles) solutions know about these technologies'' [14]. In other words, formal channels of communication do not currently exist between the users and the developers, nor do between discrete sectors that will be involved in the development of materials. Electronic textile development is underway within defence research agencies in the USA, but it may be some time before they are spun out into the commercial domain.

To address this lack of dialogue, there is a need for mechanisms that bring the different industries closer. For example, the author coordinates the network, *Smart Textiles for Intelligent Products*, funded by the Engineering and Physical Sciences Research Council, UK. This network is a *think tank* for future intelligent or smart consumer products and applications in the context of societal futures and future markets. It seeks to create new formal channels of communication by bringing together all sectors that will be involved in the design, development and production chain into a new *hybrid* community. These include: application-based industries (sports, clothing, medical, automotive, gaming, architectural and interior environments), defence agencies, cognitive science, social science, computing, electronics, electrochemistry, textile and fibre engineering, the design community (fashion, textile, industrial, interior designers and architects), economists, business and markets specialists and lifestyle trend forecasters. The various industries have discrete cultures, whose time scales for development and production vary hugely, as well as languages. Through its workshops, the smart textiles network aims to break down these barriers. Technology special interest workshops bring together users with different fields of expertise required to develop smart textile platforms; for example, textile actuators and sensors, and displays. This workshop brings together the potential users and designers with the materials developers. Workshops that look at the *bigger picture* explore projections of the future of society, lifestyle, work, travel, economics and markets, which members can use collectively to brainstorm about possible product scenarios for the future. It is hoped that these scenarios will set a trajectory for the development of smart textiles.

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