5th STS Italia Conference
A Matter of Design: Making Society through Science and Technology
Milan, 12–14 June 2014

D-STEM : a Design led approach to STEM innovation

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Advances in the Science, Technology, Engineering and Maths (STEM) disciplines offer opportunities for designers to propose and make products with advanced, enhanced and engineered properties and functionalities. In turn, these advanced characteristics are becoming increasingly necessary as resources become ever more strained through 21st century demands, such as ageing populations, connected communities, depleting raw materials, waste management and energy supply. We need to make things that are smarter, make our lives easier, better and simpler. The products of tomorrow need to do more with less. The issue is how to maximize the potential for exploiting opportunities offered by STEM developments and how best to enable designers to strengthen their position within the innovation ecosystem. As a society, we need designers able to navigate emerging developments from the STEM community to a level that enables understanding and knowledge of the new material properties, the skill set to facilitate absorption into the design 'toolbox' and the agility to identify, manage and contextualise innovation opportunities emerging from STEM developments. This paper proposes the blueprint for a new design led approach to STEM innovation that begins to redefine studio culture for the 21st Century.

***Keywords**: Design Process; STEM; Design Education; Smart Materials; Emerging Technologies*

Introduction

We imagine our man-made environment of the future as a fluid, intuitive, human centred ecosystem that will sense and react to conditions both inside and outside the space in order to provide experiences and services that will elevate quality of human life while coexisting seamlessly with the natural environment. The indicators that suggest this as a future eventuality we find to be within the explosion of material technologies that are entering the realms of commercial processes. A new class of stimuli

responsive materials able to alter their properties in the presence of triggers such as pressure, light, temperature, moisture, electrical current, magnetic force or microbes enable designers to create products that are bio-responsive, can sense, harvest energy, alter appearance, generate light, etc. The possibilities presented by these new materials shatter the boundaries of our current understanding of the 'object' as *inanimate* and usher us into a new era of '*intelligent/animated'* products, surfaces and systems. The increasing activities around the world that explore ways of using these materials in, on and around the body is transforming science *fiction* into science *fact*; the field of wearable electronics, for example, resided mainly in sci-fi narrative and exclusive technology driven labs that strapped clunky electrical components to the body 20 years ago, today, is becoming a commercial reality.

The authors have extensive knowledge in textiles and fashion at the boundaries of Design and STEM from the perspectives of both higher education and industry funded research. This experience combined with industry driven discourse has lead to the identification of a gap in designers' capabilities and training that prevents the seamless transfer of information between the STEM and design communities both in academic and industry sectors. This paper sets out to articulate the gaps in design training and begin to identify possible solutions.

Discussion

Design practice has evolved from the craft-based model of the pre-industrial age to the professionalised disciplines of the 20th century. Alexander (1964) argues that the change from the unself-conscious pre-industrial approach to the self-conscious professionalisation of design is an inevitable response to a society that is subjected to a sudden and rapid change that is culturally irreversible.

Lawson (1980) suggests that the changes in materials and technologies during Britain's Industrial Revolution between 1760 and 1840 became too rapid for the craftsman's evolutionary process to cope and that this gave rise to design practice as we know it today.

As Designers entering a post-digital, new materials age we need to question our practice as the rapid rate of change driven by advances from within the STEM communities challenge our understanding and knowledge of the artificial or man-made world.

Designers in the UK have strong creative skills, but are often ill equipped to engage with the technical challenges and opportunities presented by general advances in material science. The vast majority of artefacts unveiled annually at both interim and final degree shows at leading design graduate and post-graduate institutions, in the UK, reveal creative, yet relatively unexplored articulations of the potential of new materials that are limited to provocation or points of discussion and fall short of exploring potential for product innovation. This is evident in the areas of textiles and fashion.

Textiles and textile-type materials make up a huge portion of our man-made environments, from aeroplanes to implants; textile technology is omnipresent in our current world and, inevitably, our future environment. The significant STEM advances in soft materials coupled with the pervasive nature of textiles could be a reason why this knowledge and skills gap is so evident within the discipline as the rapid rate of change in STEM is not reflected within the discipline's design practice. Textiles, as a discipline, still has craft-based knowledge at its heart. In order to maintain its currency in the 21st century this must be balanced with advanced materials and fabrication methods. However, in the UK there has been a gradual (last fifteen years) decline in the technical training at undergraduate and postgraduate level that echoes the demise of the UK's textile industry. A key factor is the high cost to the institution of running and retaining practical workshops populated with skilled technicians and availability of raw materials to experiment with coupled with inadequate public funding. This inevitably has had an impact on the knowledge and skill-set of young professional designers concerned with design and materials innovations.

Art, Design and STEM collaboration

There is no doubt regarding the adjacency, relevancy and interdependency of design and technology with regard to innovation. Bringing design and technology together is not a new idea. Buechley et al (2007) propose the introduction of E-Textiles (electronic/ conductive textiles) into the American school curriculum at k-12 stage to widen participation in learning electronics and programming, and promote innovation. The UK's Technology Strategy Board's 'Investing in innovation in the creative industries' programme (TSB, 2012) and the Materials Knowledge Transfer Network's Materials and Design Exchange, 'MaDE', initiative (recently closed) (KTN, 2012) are two of many examples that strengthen the interconnections between these domains.

There have also been many examples of Science / Art initiatives involving collaborations and the creation of work that responds and comments on our emerging world. The1951 exhibition inspired many creative responses and influenced design aesthetic for some years. More recently is Rhode Island School of Design's 'STEM to STEAM' initiative that places Art within the STEM communities (Robelen, 2011).

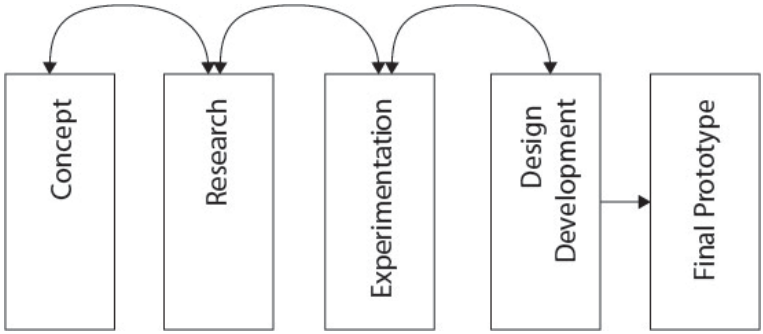

Figure 1 Image of general creative design and development process in fashion and textiles as taught at higher education institutions, the image represents an indicative system and is by no means exhaustive (source V. Kapsali)

Many 'ideas' and scenarios of how our future lives will be affected by socio-economic changes and advances in science and technology have been explored in a conceptual way. These examples are powerful 'Agent Provocateurs' and stimulate debate, inspire and offer the opportunity to explore emerging science and technology advances in a theoretical way. However, they stop with the idea, the intangible and the conceptual. There is an emerging space filled, primarily, with designers who are hungry to deal with the evolution of these design fictions into design facts.

In an attempt to bridge this gap, independent groups of design-tech hybrids have begun to populate the space between design and STEM. Fuelled by the recent explosion of Open Source, these individuals have adopted an alchemic, almost 'guerrilla' approach to relatively exclusive types of technology such as synthetic biology, computing hard and soft-ware and advanced materials. Today, numerous 'hacking' communities around the globe inhabited by designer-scientists-engineers, experiment with anything from DNA to programming to create artefacts such as bioluminescent plants or grown garments. The emergence of these communities is testimony that curiosity is a driver common to the art/

design and STEM communities but lacks the rigor and discipline of an academic framework.

D-STEM, an acronym for Design: Science, Technology, Engineering, Maths, is the nomenclature we have given to our holistic, interdisciplinary approach to addressing 21st century needs through materials interrogation. We see this as different to commenting on the advances in STEM and goes beyond the knowledge transfer of Design and STEM interdisciplinary collaboration. This is an adaptation of the conventional design process and aims to merge the creative, opportunity seeking aspects of design with the systematic, experimental, knowledge seeking aspects of STEM areas. A D-STEM designer can understand enough STEM to not only exploit a novel or emerging material but is also able to absorb it into their toolbox and has the agility to manage and contextualise innovation emerging from STEM communities and vice versa.

Figure 2 Examples of garment (left) with printed detail and jacket with structural details made exclusively from cellulose material produced by bacteria in the Biocouture studio (Source S. Lee).

D-STEM is not to be confused with what Cross (1975) refers to as a desire to 'scientise' design, nor is it about the science of design. It is closest to what Cross calls scientific design, and refers to modern, industrialised design – as distinct from pre-industrial, craft-orientated design, and is based on scientific knowledge but utilising a mix of both intuitive and non-intuitive design methods. He suggests that this is merely a reflection of the reality of modern design practice. It is perhaps too early to decide if D-STEM is a new design paradigm or merely a shift in response to the advancement towards intelligent material systems.

If we are going to realise this D-STEM vision, it is critical that we have a design community who can navigate these emerging spaces of material technology and direct the developments that will enable a product landscape with genuine impact in the quality of peoples' lives. Given the speed of material innovation, designers of the future need to be Design-STEM hybrids, capable of understanding, exploiting and influencing STEM developments. We propose that a shift in design education is needed to develop designers that can address the challenges of 21st century society.

Figure 3: 'Loom to hanger' project developed by V.Kapsali and J. Stephenson at Middlesex University in 2008. The shrinking effects of wool in hot water were studied in combination with effects of weave and yarn structure. A 2D layered textile was engineered (left) that when exposed to hot water, transformed into a fully fashioned vest with design details without the need for further processing i.e. cutting and sewing (source V.Kapsali)

Figure 1 illustrates the conventional design development process specific to fashion and textile design. This process is presented as linear for purposes of simplicity and is indicative and by no means exhaustive of creative stages as taught at higher education institutions in the UK, it does not include industry cycles such as buying and manufacture nor is it exhaustive of the complexities of the creative process. Designers, during their training, develop their own styles and patterns of work.

Designers are trained to develop a conceptual framework to underpin a design project usually influenced by trends, art and/or abstract notions. Design students are trained in creating a narrative to describe their concepts and fuel the design process. This stage involves research into the topics relevant to the concept, it could be historical, observational etc. The work at this stage is usually visual and includes images/ references to colour, mood and texture. Students carry out work in sketchbooks that document this part of the process and create mood-boards that convey the concept visually.

During the research stage, design students also begin to gather information on materials and techniques relevant to their concept. Activities will involve sourcing specific materials, components that will be used during the practical work and/or techniques that will inform the practice.

The experimentation stage involves initial practical activity that seeks to test out the combination of materials and methods the designer has selected. This comprises a trial and error period during which the individual will acquire knowledge and hone skills specific to the handling of the chosen materials in the context of the creative concept, in other words towards the development of a 'toolbox'. Materials and techniques are often discarded and new must be sought out; research activity is key to the support of this stage in the process.

The design development stage is the most creative practice based activity in the process and is inextricably linked to experimentation. The knowledge and skills developed through the previous stage forming the 'toolbox' are applied to articulate the concept as textile or garment manifestations. Many ideas are explored and the outcomes of the experimental stages are examined through 'filters' such as scale and proportion. Once complete, design students are trained to evaluate the outcomes of this stage and plan the final prototypes. Once these decisions have been made, students proceed to the production of a final collection of artefacts.

Generally speaking, the design student and/or practitioner's materials knowledge bank is limited to what they already know, have experienced or have access to. The same applies to fabrication methods. If these aspects are limited in terms of raw materials, characterisation and fabrication methods the designer is disadvantaged when faced with the challenges of 21st century materials advancements.

D-STEM Principles

D-STEM uses existing design practice as a point of departure to articulate the merger of established design principles with recent STEM innovations in areas such as biotechnology, electronics, material science and engineering. Initial observations suggest that as an approach it has, at its core, one or more of the following:

- Design using advanced fabrication
- Designing advanced material systems
- Designing with advanced materials
- Designing products with advanced functionalities

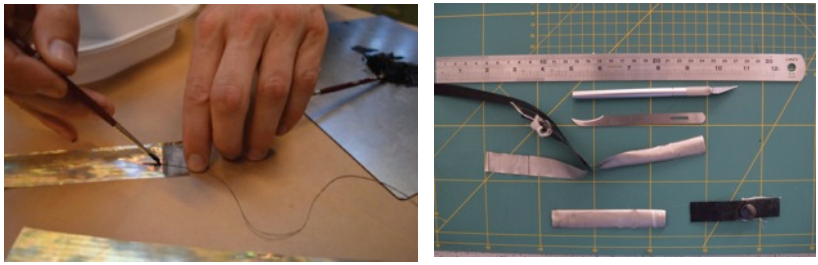

Figure 4: Dielectric electroactive polymer (DEAP) thoracic sensors project developed by A.Toomey, N.O'Connor and P. Stevenson-Keating in 2012. The industry standard sensors were taken apart and fabricated in-house to enable bespoke specification and integration into the sensing vest.

Design with advanced Fabrication

Pioneers of this approach are practitioners such as Suzanne Lee, director of BioCouture; a consultancy that explores the application of grown materials in the fashion industry. Lee, originally trained as a fashion designer, wanted to explore ways of growing materials for garments as an alternative, more sustainable approach to the conventional materials and processes. Lee sought to address global challenge regarding waste materials during the manufacture specific to the apparel industry through pushing the boundaries of the territories conventionally occupied by this area of practice by combining creative thinking with the fabrication concepts from biotechnology. Lee achieved this by introducing specific knowledge and skills from biology into the concept and research stages of the design processes. In doing so she broke out of the conventional research topics in fashion design and began to investigate ancient methods used to produce kombucha and collaborated with a biologist in order to get a deeper

understanding of the processes involved and produce her own material. Following an intense experimental stage, Lee developed a unique 'tool box' that enabled her to produce grown cellulose and through further design led experimentation developed the ability to manipulate to enable the creation of experimental garments (fig 2) comprised of distinct design features.

Figure 5: Dielectric electroactive polymer (DEAP) thoracic sensors project developed by A.Toomey, N.O'Connor and P. Stevenson-Keating in 2012. The thoracic muscles and anchor points were mapped onto the vest toile and used as the blueprint for the integration of the bespoke sensors.

Design advanced material systems

Advanced knit technology has enabled viable 3D knitted, seamless garments, however this had not been achieved using woven systems. Kapsali (2013) wanted to explore the possibility of a deeper understanding of the material properties and performance of merino wool gained by adopting the analytical processed from material science to create an advanced material system that truncated the traditional manufacturing processes and techniques in order to move towards notions of self assembly.

The factors effecting structural changes caused by exposure to hot water of the textile were studied during the research and experimental stages of the design process; these were fibre, yarn and weave type. Knowledge and skills emerging from this process informed the design of a textile that when cut off the loom resembled a 2D flat, rectangular piece of cloth, yet when exposed to hot water, the material was transformed into a fully fashioned vest with design details without the need for further processing i.e. cutting and sewing. This simple project we call "Loom to Hanger" demonstrates that a shift in thinking about materials can deliver structures with that self

assemble when exposed to certain conditions shifting from 2D design to 4D spatial and temporal engineered structures (Kapsali et al 2013).

Designing with advanced materials

Toomey initiated a design-led study exploring the potential use of dielectric electroactive polymer (DEAP) sensors for human centred applications in interactive products and assistive healthcare. Inspired by the similarities of both the sensor and human skin and muscle, Toomey applied concept, research and experimental design methodologies to identify applications for the DEAP sensor, the concept of a-real time breathing, monitoring vest was selected for development.

During experimentation, Toomey concluded that in its current format, the DEAP sensor presented limitations for this specific application, in house modification of the sensor was required. This involved the combination of principles from stretchable electronics with design making methodologies to handcraft bespoke sensors that map critically relevant areas of the thorax. Initial findings suggest that DEAP sensors are a promising technology for direct body mapping and that it is possible to identify different activities based on the patterns of data created, i.e. laughing, eating, breathing.

Designing products with advanced functionalities

Fashion textile designer, Kapsali embarked on a doctoral project in Biomimetic Engineering at Bath University's Mechanical Engineering department in 2005. The purpose of the work was to engineer a textile system that applies the mechanical principles responsible for the moisture induced opening and closing of pinecones and other hygroscopic seed dispersal mechanisms, that would demonstrate counterintuitive behaviour in the presence of moisture in that it would become more permeable in damp conditions and less in dry. Conventional hygroscopic materials such as cotton, wool and rayon behave in the opposite way and are linked to physiological discomfort caused by build-up of moisture in the microclimate.

Kapsali's concept involved researching the hierarchical principles of hygroscopic shape change in wood type fibres and combined this knowledge to her experience in textiles to develop a 'toolbox' of new fibre and yarn technologies that when introduced into a textile context generated counterintuitive properties that enable the management of airflow through the textile system. This work was consequently patented, absorbed by the private sector and branded *INOTEK* ™. INOTEK ™ is the first biomimetic shape change technology to reach pre-commercial stage.

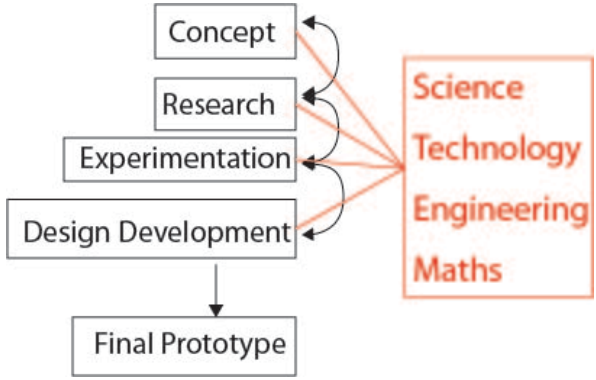

Figure 6: D:STEM approach, the image suggests how and when STEM and Design methodologies merge, based on examples of existing design practice, to create the D:STEM process (Source Kapsali and Toomey)

Conclusions

All four examples of D-STEM innovation, mentioned previously, challenge the existing hierarchy where the designer is introduced at the end of the innovation chain, once the technology is cemented. Figure 6 suggests a framework for D:STEM that shows how STEM and Design can merge however the realisation of this approach requires a significant shift in current practise as demonstrated in the examples discussed previously. Interestingly it is in the early stages of the design process where there is most impact, this suggest that when Design is placed as a core stakeholder from the inception of an idea, there is a significant shift in the resulting innovation.

Conventional design inhabits studio spaces and largely draws upon conventional design knowledge and skill. The D-STEM approach requires a new hybrid environment, a studio-lab that integrates design, science and technology from the outset with both the Design and the STEM domains working in unison on interrogating human centred needs, such as assistive healthcare, energized architecture and performance products, to design and develop products and services for Future Ways of Living.

The D-STEM approach also requires new knowledge and skills from practioners, this brings into question the equipment, tools and training currently available and largely based on the typical 20th century studio, with

perhaps, the exception of 3D printers. We suggest that more advanced fabrication tools and methods alongside adequate characterisation equipment are necessary for the D-STEM studio-lab of the 21st century.

In addition to this the design and material science communities need to build on models designed to strengthen connections between the two communities such as the UK's Technology Strategy Board's 'Investing in innovation in the creative industries' programme and the Materials KTN's MaDE, to create advance platforms for meaningful connections. Knowledge transfer between communities is necessary at early stage of material science innovations rather at pre-commercial stages, which is current practice.

There are many examples of successful interdisciplinary ventures where these challenges have been overcome but they are predominately contained within specific interdisciplinary partnerships and groups who, having once overcome the challenge of shared communications, continue working within those architectures of expertise. In order to grow and develop the essential trans-disciplinary approaches of the twenty-first-century if follows that trans-disciplinary communication must be more fluid.

With the examples that we have started, including grown materials, wearable DEAPs and biomimetic textiles, it is beginning to emerge that this holistic approach makes sense and has potential to go beyond established technology transfer, share and exchange initiatives as a route for innovation.

We propose that elements of this approach, if examined and challenged thoroughly, could potentially be of use to others as a methodology for integrating Design and Technology for innovation. We believe a D-STEM approach would fill the current gap between the rapid STEM developments and the slower design advances evident today. We need to identify from industry what qualities, knowledge and skills they need from graduates designers to establish how they can contribute more holistically within the innovation ecosystem by bridging the gap between design and technology in a more authoritative manner, to show strategic leadership and direction with an ability to cross discipline cultures.

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