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Serendipity as a Catalyst. Knowledge Generation in Interdisciplinary Research

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Abstract: Our paper discusses the design-led processes in a project starting as multidisciplinary, focusing on three serendipitous cases that influenced the outcomes and the textile-design-research path taken in the overall project. The work presented here revolved around semiconductive cotton, suitable for textile design, and examines it from the design team perspective. This paper identifies and discusses three cases, as they had considerable weight on the project path. In order to understand these cases, we evaluated them based on a model for a serendipitous experience. The follow-ups to the serendipitous connections gave empowerment to the design research team, increasing their ownership of the research results. Relaxing boundaries between disciplines and varying routines have been highly relevant factors in the new knowledge generation. Ability to perform a consented and significant diversion to the research path was crucial for reacting to the serendipitous discovery and establishing the research space of the interdisciplinary project.

Keywords: Serendipity, interdisciplinary, textile design research, empowerment, change

1. Introduction

Our paper discusses the design-led processes in a multidisciplinary project, with a focus on three serendipitous cases that influenced the outcomes and the textile-design-research path taken in the overall project. The overall project was a four-year collaboration between three schools: Chemical Engineering, Electrical Engineering and Arts, Design and Architecture, all situated within the same university. The prime topic of the project, energy harvesting, was approached from the perspectives of each school, aiming towards developing materials and methods for extracting energy from ubiquitous waste heat, and creating novel concepts for new applications. One of the main focuses of the science-led project involved the development of a full thermoelectric module, and a search for materials with the needed requirements. The research was based on atomic layer deposition (ALD) (Tynell, 2013) (Tynell & Karppinen, 2014), in which thin films, are fabricated one atom layer at a time by exposing the surface of the material to alternate gaseous species, i.e. zinc oxide (ZnO). One of its advantages is the deposition of substrates of different shapes and sizes (Jur, Sweet, Oldham, & Parsons, 2011).

One of the project interests was to utilise flexible substrates for novel end applications, which in practice, meant identifying and selecting textile-materials for the atomic layer deposition, as well as exploring them for use after the deposition. Thus, this work revolved around semiconductive cotton, suitable for textile design, and we examine it from the design team perspective. (Karttunen, Sarnes, Townsend, Mikkonen, & Karppinen, 2017; Mikkonen & Townsend, 2019; R. Townsend, Karttunen, Karppinen, & Mikkonen, 2017; R. Townsend & Mikkonen, 2017; R. Townsend & Ylirisku, 2015).

Research Direction Clusters

As the goal of the project was to develop approaches for energy extraction, each school focused on their respective tasks, while collaborating with others to augment their research. Thus, the project had independent research tracks, where each of the three university schools focused on their core area. These produced their own outcomes and could be examined with respect to project goals. However, applying the notion of Sensemaking (Weick, Sutcliffe, & Obstfeld, 2005), offered a framework for understanding the process and intricacies of the project in view of design, driven by plausibility rather than accuracy. As such, it allowed examination beyond the original research direction; it enabled identifying unexpected phenomena, its meaning both as an individual action and as a series of actions, thus as an entity in view of the project outcome. Based on interpretation rather than analysis, the project was labelled and categorised through a human-generated clustering process (Chan, Dang, & Dow, 2016) by splitting the project to what we now call research direction clusters. We knowingly explored textile-designer tacit-clustering, focusing on what was perceived as necessary from a textile perspective. Clustering was based on the activities, experiences and the outcomes relating to the same conceptual, thematic focus, which were bound by a significant direction change. Additionally, the work which did not produce typical research outcomes, e.g. papers or patent applications, was still considered to be significant for examination due to an insight or a change in the research direction.

We chose this perspective, as it allowed us to focus on multidisciplinary aspects; through the work done towards the outcomes and the intermediate steps, the interactions between disciplines, as well as interpret what the textile designer's impact was in practice. Moreover, it helped us identify the serendipitous and unexpected moments, as well as the influence due to those situations. Overall, we identified six clusters (R. Townsend et al., 2017), and from three of these clusters, this paper examines and discusses three cases, as they had considerable weight on the cluster formation. The simplified clusters are shown in Figure 1, with the three cases indicating a cluster exit and creating a new direction. The three cases are 'Solar flare', 'Inking vs Dyeing' and 'Lost in Translation'. The first case describes the experience of drawing a connection between UV responsiveness and ZnO cotton yarns, which resulted in a change in research practice for the design team. The second case revolves around the spark of the unorthodox 'dyeing' of ZnO yarn, leading to an additional understanding of the almost unrealised UV reactive qualities of the dyed ZnO yarn. Finally, the third case portrays the unforeseen development path towards a methodology visualising electrical signals. The path was a result of the cross-pollination of science and design knowledge, through which one phenomenon could be identified from two different types of yarns, enabling new design potential.

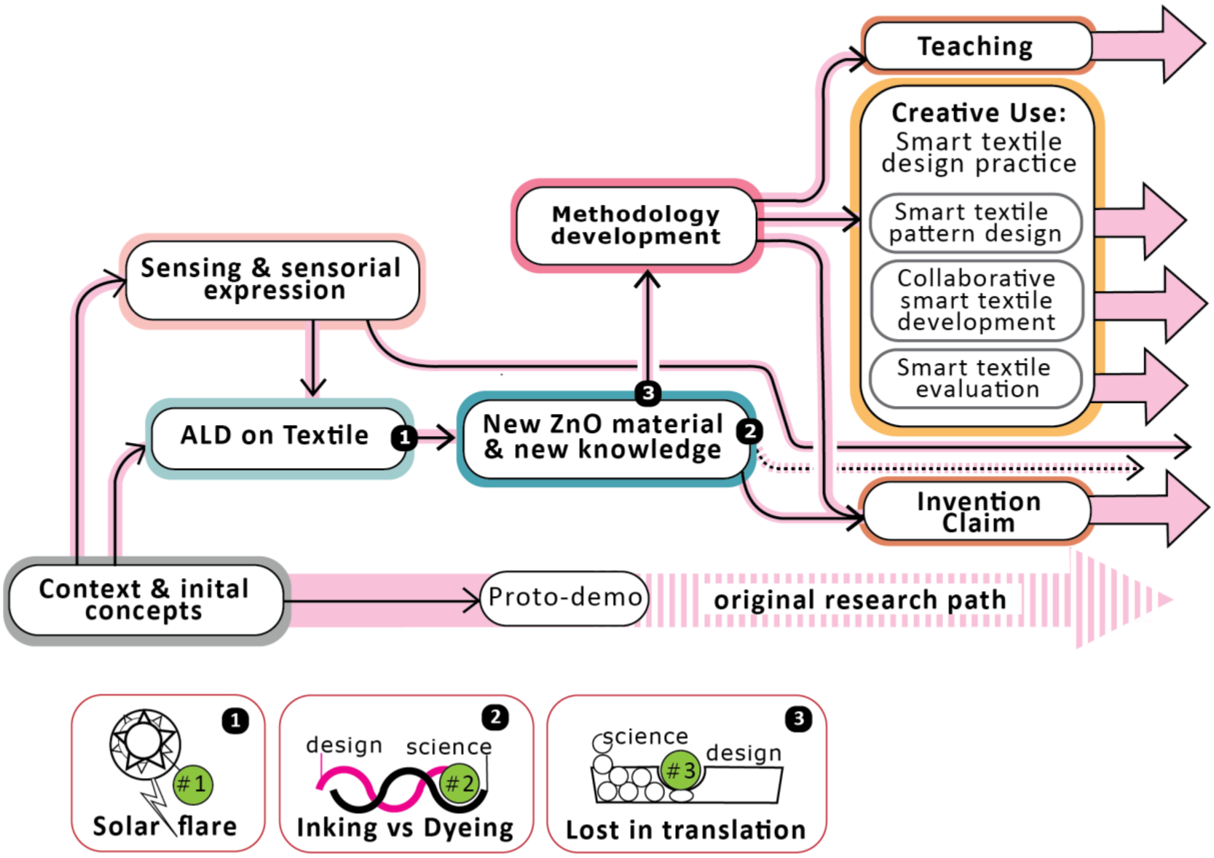

Figure 1. The three serendipitous cases positioned in the research direction clusters and depicted in the development path of the overall project from a design perspective. The diagram illustrates the cases resulting in a cluster exit and branching out to new directions in the project.

2. Background

2.1 What is the designer-researcher role in scientific research?

The role of the textile designer-researcher is becoming more important, and examples of interdisciplinary research topics, such as e.g. interactive olfactory textile surfaces (Tillotson, 1997), digital 3D textiles (Harris, 2000), spray-on fabric by Manuel Torres (Amato, 2011), the development of linseed fibre material (Härkäsalmi & Koskinen, 2010), laser-dyed patterning (Akiwowo, Kane, Tyrer, Weaver, & Filarowski, 2014), and botany and horticultural techniques challenging the design process (Collet & Foissac, 2015), echo our work, suggesting this role being fundamental in serendipitous activities. After all, the role of the textile designer has been essential for justifying the research-direction and therefore findings: Satisfying human senses is an essential factor when designing textiles and textile-based products. Understanding the influence of each design element to meet the sensorial requirements, needs and desires of the end-user are therefore fundamental.

2.2 Understanding Serendipity

Literature suggests that serendipity is a difficult concept to define. Outside literature, it could be seen as having a stroke of luck in order to notice the connections between different subjects to get an idea. However, we try to address the basic concepts of serendipity to identify how those connections could be formalised. Finally, we select a model with which we analyse our three cases.

To understand the role of discovery related to our domain, we look at basic qualities which can be seen affecting creativity. Goldschmidt discusses the role of visual stimuli in design, pointing out two major factors influencing creative processes (Goldschmidt, 2015). The first, neurophysiology of the brain, is typically beyond control and varies individually. Preparedness, which is the second factor, can be influenced by individual expertise and a high level of 'visual literacy'. Being able to take in new, and navigate within, visual influences were seen essential in creative discovery. However, to understand the delicate nature of serendipity, we identify some rudimentary boundary qualities.

First and foremost, we understand that the very essence of serendipity may be found within the free-spirited attitude. According to a controlled experiment, serendipity cannot be forced upon (Bogers, Rasmussen, & Jensen, 2013). Neither it is typically addressed to random luck, even though it "may benefit from a degree of sloppiness, inefficiency, dissent, failure and tenacity" (de Rond, 2014). de Rond describes four varieties of serendipity, identifying two relations and two intentions. Relations describe how the events causing the serendipitous discovery are related; either by pure chance or more causally due to a plan or a design. Intention describes the nature of serendipity itself. It can be either an accident when looking for something else, or an accident when finding precisely what was looked for. de Rond also suggests, that serendipity might not be an event, rather a capability. The suggestion seems to reflect well with Goldschmidt's understanding of creativity (Goldschmidt, 2015). Furthermore, to attempt explaining why some institutions are better at discovery than others, de Rond proposes the concept of 'organizational serendipity'. This organisational aspect resonates well with our multidisciplinary teams.

Focusing on computer science, André et al. (2009) suggest a concept of the 'sagacity', to discuss serendipitous connections (André, Schraefel, Teevan, & Dumais, 2009). While they agree the serendipity is a vast concept and aspects of it vary between contexts, they point out the delighted surprise and accidental nature in the discovery. These aspects could be seen to imply that a positive attitude and openness to discovery are essential to opening the possibility to serendipitous moments. The breakthrough was mentioned to be an unexpected connection, suggesting that there was an element which was not anticipated. Andre et al. (2009) also point out to Foster and Ford (Foster & Ford, 2003), saying that "serendipity was widely experienced amongst inter-disciplinary researchers, where it was categorised by reinforcing an existing problem, taking the researcher in a new direction". Fine & Deegan (Fine & Deegan, 1996) discussed the role of serendipity in qualitative research by using methodological suggestions from fieldwork encounters in sociology and anthropology. The authors examine how temporal, relational and analytical aspects of serendipity is embedded into the research process. They suggest that serendipity is an 'interactive outcome of unique and contingent "mixes" of insight coupled with chance', which needs to be accepted as a central component of research to the collection and interpretation of data. The recognition and acceptance of serendipitous findings and events in qualitative research provide a way to understand how research findings are created and appreciated in practice.

Makri et al. (2014) interviewed several creative professionals to determine how serendipitous moments could be influenced and created a framework to create opportunities for achieving serendipity (Makri, Blandford, Woods, Sharples, & Maxwell, 2014). They found creatives make serendipitous connections through six behaviour strategies, of which two are used to estimate the value of the connection. The connections were made by varying routines, being observant, making mental space and relaxing boundaries. Additionally, drawing on previous experiences and looking for patterns were also used for connections, but also for estimating the impact. To exploit the serendipitous connection, the strategy was to act upon it. This meant, that even when the opportunity did not appear risky, it required an active decision.

2.3 Model for analysing serendipity

In order to understand our cases, we chose a model for serendipitous experience process that we saw having a comprehensive literature background (McCay-Peet & Toms, 2015). It identifies five main elements in the process of serendipity. The first main element, the trigger is an external catalyst for experiencing serendipity, which plays out in three identified forms: a) verbal, stemming from a conversation, b) textual, derived from text-based cues, and c) visual, as a result of nontextual cues, e.g. from observation. Delay is not considered as an element, as it does not need to be always present. As such, it refers to a period in which it takes to recognise and form a link from the trigger to the second main element, connection. Connection implies the recognition of the relationship between the trigger and the individual’s knowledge and experience. It is divided further into two sub-types: a) known problem -connection, related to the relationship between the trigger and a previously identified or current problem, and b) new direction- connection, referring to the relationship between the trigger and a new, undetected opportunity or direction. Third, follow-up is defined as an action, or series of actions carried out to capture and exploit the reflected value of outcome from trigger and connection to create impact. Fourth, the valuable outcome is described as the positive effect (reflection and achievement) perceived in the serendipitous experience, which can impact on three levels: a) personal (e.g. intellectual pleasure, personal satisfaction), b) organisational or community, and c) global (e.g. generation of new knowledge). The fifth and final element, unexpected thread, can be considered as the reflection of the ‘unexpected, accidental or surprising qualifiers’ present in the different elements of the process model, forming a ‘narrative’ to the serendipity experience. Apart from the follow-up, these elements contribute to the perception of serendipity. We see the model proposed by McCay-Peet and Toms to reflect well with our overall related works, and therefore provide a fitting model to our interdisciplinary cases.

3. Cases

The idea towards the flexible zinc oxide (ZnO) substrate using atomic layer deposition (ALD) emerged after a series of design-led research actions (R. Townsend & Ylirisku, 2015). This deviation added to the original research project plan, creating a research setting in which the design research team was ‘an auxiliary agent’ in ZnO development to a textile substrate. In addition to a supportive role to the scientific work of the chemists, the aim was to enhance the scientific research by finding use-cases for the novel materials. The design research team did not have a comprehension of how the new hybrid material under development should behave. Facing the dilemma of having to create exemplars with the material that was not understood, the design research team began conducting independent electrical measurements to gain some understanding of the material which had crossed over the domains of both textile and electronics. In the following section, we describe three serendipitous related cases, each having had a direct influence on the overall project.

3.1 Case 1: Solar Flare

One of these electrical measurements involved investigating the moisture-related behaviour of the ZnO-cotton yarn, shown in Figure 2. During one afternoon, the signal flattened for a moment without any observable influence, leaving the design team puzzled. Upon hypothesising the cause, the influence of the sunset was briefly discussed. This cause was dismissed, as the ‘dip’ in the signal recovered soon. Later in the evening when returning home, the textile designer spotted a news clip of a reported powerful solar flare. It was not until lying in bed later that night that the possible connection between those two phenomena entered her mind. The following day, timings from both the solar-flare (Spaceweatherlive, 2015) and lab-journal were checked. The design team was able to see them coinciding.

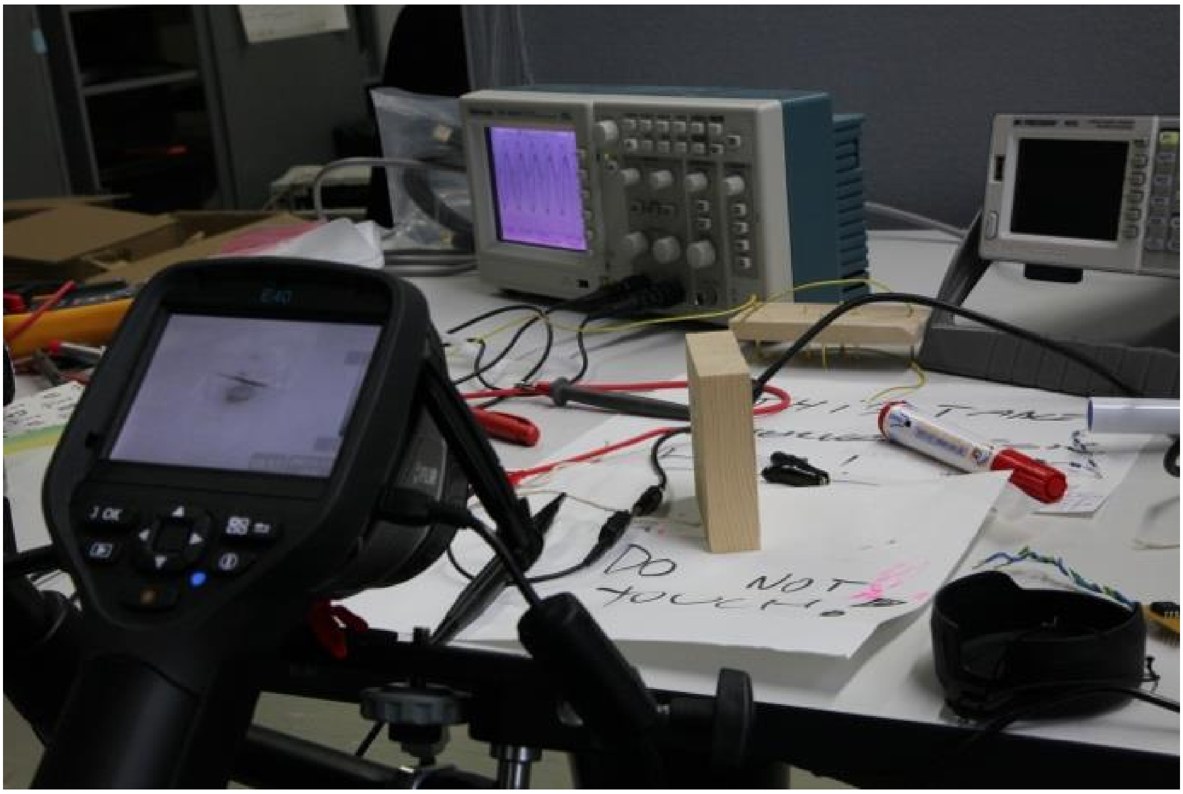

Figure 2. The measurement set-up at the design school. Conducting electrical measurements of ZnO-cotton yarn, while investigating the yarn's moisture-related behaviour.

At that point, they were not sure to what this meant. Despite the verification, the lack of confidence and doubt with the measurement set-up guided the next steps. The design team discussed the possibility of 'disturbances' to other project partners and expressed the need for an isolated, noise-free measurement lab. The intention was to verify the measurement setup at the design school to continue working independently. During a meeting with the other project partners, the design team deliberately avoided mentioning anything about a solar flare to avoid being labelled as nutcases. However, during a joint bus-ride with the chemist professor, the possibility of a solar flare was mentioned off-hand. The professor confirmed that the solar flare could have affected the yarn, as ZnO has been identified as being sensitive to UV radiation.

When conducting the next measurements in an electrically isolated room, the design team already had the knowledge of UV influencing the yarn's behaviour. However, this was shadowed by other phenomena, and since the yarn was unprecedented, there was so much new information to absorb that the connection between new signals and the UV was not realised until later. Following the events of the two other serendipitous cases, this case was followed up by constructing an isolated box with UV-lights. The correlation between the yarn and UV radiation could be established through new knowledge on testing set-up procedures. After obtaining promising results, an invention claim was made involving both the chemistry and design research team.

3.2 Case 2: Inking vs Dyeing

The yarns handed from the chemists for the design team to use differed between each sample (Karttunen et al., 2017). Since the visual appearance of the differing deposited yarns was identical, the yarns were marked with different coloured felt-tipped pens for identification. The markers were left lying on the desk, which led to an unplanned series of events. On a curious moment, the electrical engineer took a felt pen marker and applied colour to one short piece of yarn, by scraping the pigment onto the yarn surface in an attempt to 'dye' the yarn. Followed with electrical measurements, this procedure had not changed the yarn behaviour.

Figure 3. A close-up of the yarn 'dyed' with a felt marker pen (top left, right) and yarn dyed with reactive colour dye (bottom). The felt marker 'dyed' yarn has only surface colour changes, while the reactive colour dye has fully penetrated the yarn.

The idea of applying colour to yarn with a felt pen marker seemed bizarre to the textile designer. However, she acknowledged the importance and commercial potential of applying colour to the yarns. This acknowledgement prompted the textile designer to dye properly, to apply colour to deposited yarns with two different dyeing methods, exhaust - and padding dyeing using Remazol reactive colour pigment. Both the felt pen marker inked cotton, and one of the dyed cotton yarns are shown in Figure 3. The methods were adapted from the industrial process to suit a university dye lab environment. The two different dyeing methods were chosen based on their different dye procedures, to determine how the dyeing process influences the semiconductive properties of the yarns. While the outcome of the dyeing provided vibrant and even colour to the yarns, the electrical measurements of the dyed samples were disappointing. The initial measurements suggested that the semiconductive properties were, in all but one, destroyed. The measurement results were in considerable contrast to those from the felt-marker inking. Although the actual dyeing outcome seemed a failure at the time, the core idea of dyeing the ZnO-yarns was still considered valuable. However, all concrete follow-up procedures were put on hold, to address and take actions regarding the third case.

A bright summer day, more than a year later, woke up the electrical engineer to take out the non-functional dyed yarns. The resistance was measured, and seen changing in powerful sunlight: the yarns were not destroyed as earlier assumed. Instead, through the accumulated knowledge, it was understood that the UV sensitivity of the dyed yarns was not as strong as before dyeing, but enough to cause a response in the strong sunlight. However, regardless of the new data and identifying it as having a potential impact on a new research path in the project, an in-depth follow-up was put on hold yet again. The new knowledge was accepted as a catalyst for an entirely new research project for the future.

3.3 Case 3: Lost in Translation

Two years prior to the third case, the electrical engineer (of the design research team) was on a research visit and asked from another smart textile researcher if he could use some steel-based yarns for developing a circuit. The response he got was: “sure, but they are a bit weird” along with a proposal to try something else instead. This discussion, however, was quickly forgotten while the work at the time moved forward. During the early measurements (of the first case), the design research team briefly saw a distorted, S-like shape in the sinusoidal signal. Inability to reproduce the wave-form at the time left a nagging feeling of missing something. The signal and the setup are shown reproduced in Figure 4. As the electrical measurements of the yarn continued, the textile designer was not able to understand any signal or the numerical values, and at the same as the electrical engineer did not understand the S-signal.

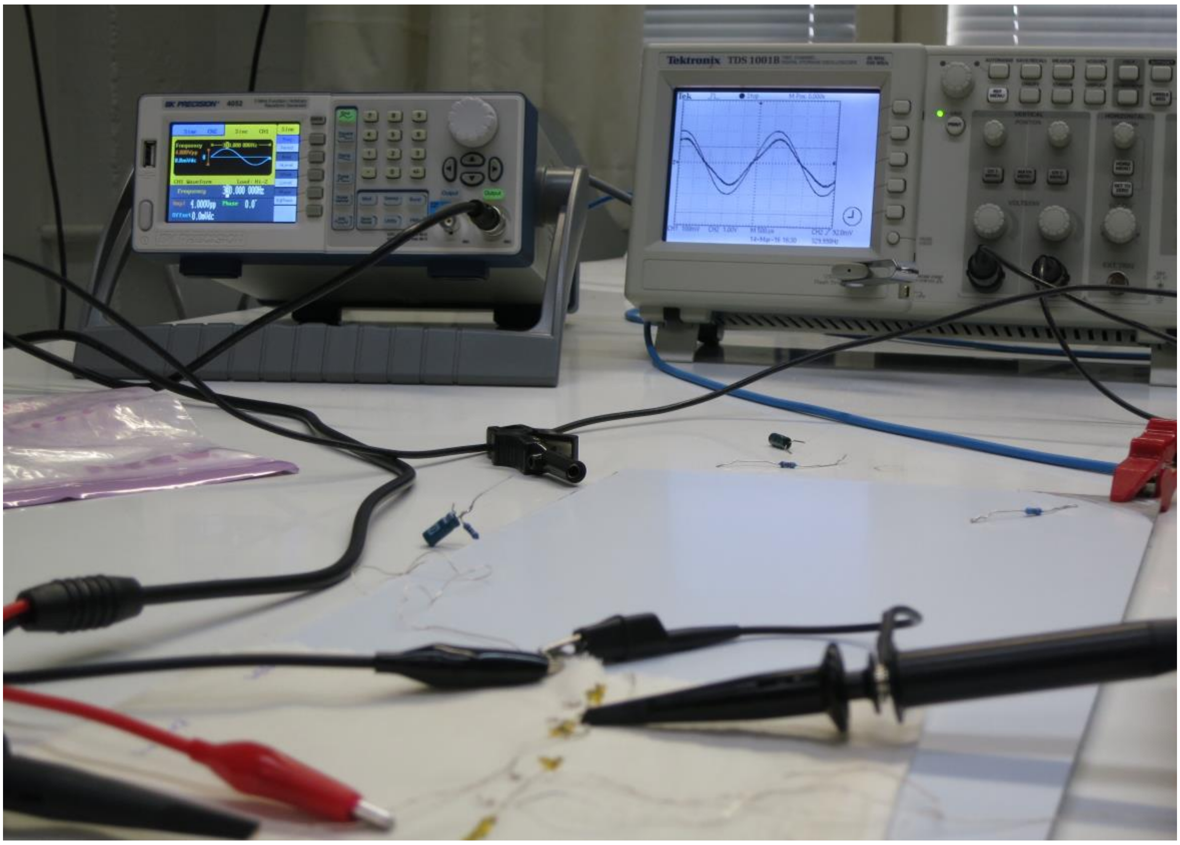

Figure 4. Distorted S-signal in a sinusoidal form (reproduced using ZnO-cotton, after verification measurements)

The next time the S-signal was seen was in the electrically isolated room, in the presence of a project team governing the isolated room. The signal was stable enough to be recorded at different signal frequencies. Although there was a feeling of excitement facing this phenomenon again, the textile designer could not understand how the ZnO-yarn differed from basic conductive yarn. The electrical engineer, on the other hand, was unsure as he had not seen such phenomena “in anything before”. However, the signal was real and verified. This irregularity caused considerable frustration between the two design team members, leading to heated discussion. In other words, this created productive friction (Hagel & Brown, 2005), which resulted in a discussion to look for new forms of representing signals. Consequently, the Lissajous-method was identified as a means for understanding how electricity flow can be visualised in an active circuit.

This decision prompted a significant backtrack, during which a set of textile samples were knitted. This deviation from the original research path can be seen in Figure 1., included in the methodology development - cluster. The knit samples were systematically measured to detect any changes, with the sine-wave and Lissajous presented side-by-side. The textile designer did over 3000 individual electrical measurements. Finally, the measurement results were constructed into a visual map to verify that the methodology works. The results enabled identifying how textile design variables affected the electrical signal (R. Townsend & Mikkonen, 2017). Alongside verifying the so-called Lissajous-methodology, the sample-map was evaluated through resistance measurements. Unexpectedly, the textile designer was confronted with a baffling issue, as some steel yarns were not 'settling'; thus, pointing to a fluctuating resistance. The electrical engineer thought this was due to reasons other than electronic, but after measuring them first-hand, he concluded that the issue was indeed electronic and was not present in all conductive yarns. Adding to this puzzlement, while the textile samples knitted with the same steel yarns were measured using the Lissajous-methodology, the textile designer noticed yet again the S-shaped signal in a few of its measurements.

The textile designer recognised it to be similar to the S-shape in the ZnO-yarn, and the electrical engineer had a flashback to the discussion two years earlier. This realisation prompted furious research into the scientific literature, trying to make sense of the phenomenon. In a study by Yin, D-Haese & Nysten (Yin, D'Haese, & Nysten, 2015), the steel yarns, which were also the same as in this case, were found with semiconductive properties as a result of the surface being specifically oxidised. The design team were able to draw a connection with the yarn's earlier fluctuating resistance measurements, to a discussion held two years earlier, and relate those to the S-shaped figure discovered in the new measurements through Lissajous-figures. Accordingly, this implied to the steel yarns not being electrically non-functional, or 'weird', even though they had changed from their original state. Instead, the yarns were still useable by providing new functionality, even with altered conductive properties, i.e. semiconductive, which were most likely due to changes caused by oxidisation. As such, this moment was crucial to understanding how important having a new look on a signal was, and how several factors turned to a useful result. The methodology has been briefly evaluated in connection with the project (R. Townsend et al., 2017), and then developed to an Arduino-based transdisciplinary system (Mikkonen & Townsend, 2019).

4. Discussion

4.1 Triggers

All three cases had multiple triggers, of which visual triggers were the most predominant. Interestingly, the textual trigger was not from academic literature, and was more of a transient visual observation of a text, eliciting a delayed emotional response. All verbal triggers originated from discussions between different academic disciplines. The sudden, unexpected signal (solar flare) during electrical measurements, however, left a confusion towards its source and reason. This sudden occurrence sparked a mental state of preparedness, and a temporary period of openness, which created the conditions for encountering the other triggers (McCay-Peet & Toms, 2015).

In case 2, the triggers were curiosity-led and pointing to the researcher himself. In contrast, the two other cases were notable of their multidisciplinary nature; Case 1 involving a textile designer, electrical engineer and a chemist, whereas case 3 involved an electrical engineer, textile designer and a designer with textile focus. Unlike the other cases, the latter had a trigger beyond the local academic circle. Timewise, triggers in case 2 and 3 were separated by a couple of years, while in case 1, the first three triggers occurred within 24 hours, and the fourth within a few weeks. All triggers have been summarised in Table 1.

Table 1. Characteristics of 'Trigger' in all three cases.

Case 1: Solar flare	Case 2: Inking vs Dyeing	Case 3: Lost in Translation
Visual trigger: sudden, momentary flattening of the yarn’s electrical signal	Visual trigger: ‘dyeing’ yarn with felt pen marker	Visual trigger: a momentary, distorted shape in the electrical signal
Verbal trigger: dismissed hypothetical reasoning to the cause (sunset)	Visual trigger: bright sunny day	Visual trigger: a second encounter of the distorted shape in the electrical signal
‘Textual’ trigger: a glimpse of a news clip		Visual + textual trigger: the signal representations making no sense
Verbal trigger: Off-hand discussion		Visual trigger: a third encounter of the distorted shape in the electrical signal
		Verbal trigger: a recollection of an offhand discussion from 2 years before

4.2 Connections

All connections are shown in Table 2. The knowledge concerning the sensitivity of ZnO to UV was not novel with every project team, but it solidified a need for research practice change for the design team, in order to generate understanding and new knowledge. This change follows the connection criteria for ‘new direction.’ In case 2, the textile designer would have never coloured yarn with a felt tip marker. The difference between inked and dyed yarns suggested to the design team’s engineer that the structure and yarn composition would be relevant. Not giving up on the “destroyed” yarns enabled observing the resistance change. The third case relied on the design team’s engineer to understand the importance of having a visual tool and being able to suggest Lissajous-patterns. However, being able to see the yarns through these patterns enabled the textile designer to make a connection between the S-shapes of steel and ZnO yarns, and relate it to the team engineer, who then connected it to the ‘weird steel’ discussion.

Interestingly, the roles and the experiences between the electrical engineer and the textile designer were reversed between case 2 and 3. In case 2, the team’s engineer’s understanding of the dyeing process was minimal, and the textile design knowledge on dyeing was dominating, which almost prompted ignoring the “wrongly dyed” samples. Inversely in case 3, whereas the textile designer’s understanding of signals was marginal, the team’s engineer’s knowledge on signals was taking over, which almost silenced the textile designer’s frustration on not understanding signals. Through productive friction (Hagel & Brown, 2005), both members were able to overcome their personal experiences and pride in "doing things correctly" in accustomed fashion. This acceptance enabled a true mixing of disciplinary boundaries, where mutual understanding is more important for research than being methodologically correct in one discipline.

Table 2. Aspects of 'Connection' in all three cases.

Case 1: Solar flare	Case 2: Inking vs Dyeing	Case 3: Lost in Translation
New direction: the potentially interesting, but 'hidden' characteristics of ZnO yarn	(Indirectly) new direction: the relevance of yarn structure and material composition to dyeing	Known problem + new direction: acknowledging the importance in having a visual tool for understanding signals applicable for design intent
New direction: solidifying the need for research practice change (for the design team)	New directions: different degrees of UV sensitivity to ZnO yarn instead of functional vs destroyed	Known problem + new direction: realising two different types of behaviour in steel yarn as one phenomenon, enabling new design potential.

4.3 Follow-up

The follow-ups are summarised in Table 3. All research partners acknowledged the request for isolated measurements, resulting in support by both collaborating departments, with an offer for electrically isolated facilities and personnel. Furthermore, this led to the construction and utilisation of a UV-box by the design team. The results were discussed in open and good spirits between all teams. For the second case, the follow-up measurement was very small but resulted in useable knowledge that can be put to use.

Table 3. The aspects of 'follow-up' in all three cases.

Case 1: Solar flare	Case 2: Inking vs Dyeing	Case 3: Lost in Translation
ZnO yarn measurements in electrically isolated environment	Re-measuring UV effect of the "destroyed" dyed yarns	Lissajous methodology development
Construction of UV-box and UV-electrical measurements of ZnO yarns		Re-evaluation of ZnO-yarns using new methodology
		Case: Smart textile pattern design
		Case: Smart textile evaluation
		Case: Collaborative smart textile development
		The development of an Arduino-based system

As for the third case, it had the most considerable follow-up with several continuous research tasks and outcomes. It was driven by interdisciplinary work with intent for a transdisciplinary tool.

Furthermore, the utilisation of the method itself fed back to the original ZnO-yarn understanding. Of all cases, the third became a systematic and directed effort, while the first two cases retained their open-ended approach.

4.4 Valuable outcome

For the first and third cases, being able to verify measurements, one-time occurrences of patterns and having validation to uncertainty gave the designer team confidence to proceed forward. These experiences could be seen as a personal value, being able to trust oneself and deal with unexpected research data. For the third case, the outcome opened a new dimension towards transdisciplinary smart textile design practice in the form of a useable tool (Mikkonen & Townsend, 2019), extending its outcome value beyond personal importance. Compared to the other cases, case 2 is a curious inversion. While the team engineer understood how to utilise the yarn structure, dyeing and yarn twisting were already known for the textile designer. All valuable outcomes are summarised in Table 4.

Table 4. The aspects of 'valuable outcome' in all three cases.

Case 1: Solar flare	Case 2: Inking vs Dyeing	Case 3: Lost in Translation
Personal value: trust in own measurements methods	Personal value: opening up to the potential & possibilities in combining functional and non-functional material in yarn	Personal value: the ability to discern differences & to notice new phenomena using the Lissajous methodology.
Personal & Community value: knowledge to identify and take action with unexpected research data for valuable impact	Personal, Community & commercial value: promising prospects for a new research project	Personal & Community value: the ability to explore textile-signal –connections in designer friendly fashion; A communication tool between electrical engineering & design: having the ability to describe electrical phenomena and relate them to the signal-cause in textile and interaction; Better utilisation of steel-based yarns
Societal/commercial value: Invention claim		Community value: opening a new dimension (design+electrical) for smart textile design practice, and in general for other creative practitioners, and hobbyists

4.5 Unexpected thread

When looking at the overall paths, both cases 1 and 2 are clear in retrospect and can be understood and traced back with ease. The third case was very chaotic in early results, having extremely tense productive friction (Hagel & Brown, 2005). However, after the utilisation of the Lissajous-patterns was decided on, it became a very streamlined process. It was also interesting to note, that while the first two cases were driven by curiosity, the third was driven by a need for ability. Specifically, the textile designer took the inability to understand signals at face value. All elements creating the serendipitous processes are shown in Figure 5., where all three unexpected threads are summarised to sequences. The diagrams reveal that all three cases follow a different pattern. Clearly, the main elements in the process of serendipity surfaced multiple times and in different order. Our three serendipitous cases demonstrate that the unexpected threads do not always follow a straight line with the main elements following in the same order. Instead, the thread may 'unravel' into multiple strands, and the number of elements change. The unravelling is emphasised in case 3, where the follow-ups outnumber the valuable outcomes. Curiously, this co-insides with the third case having the most significant impact.

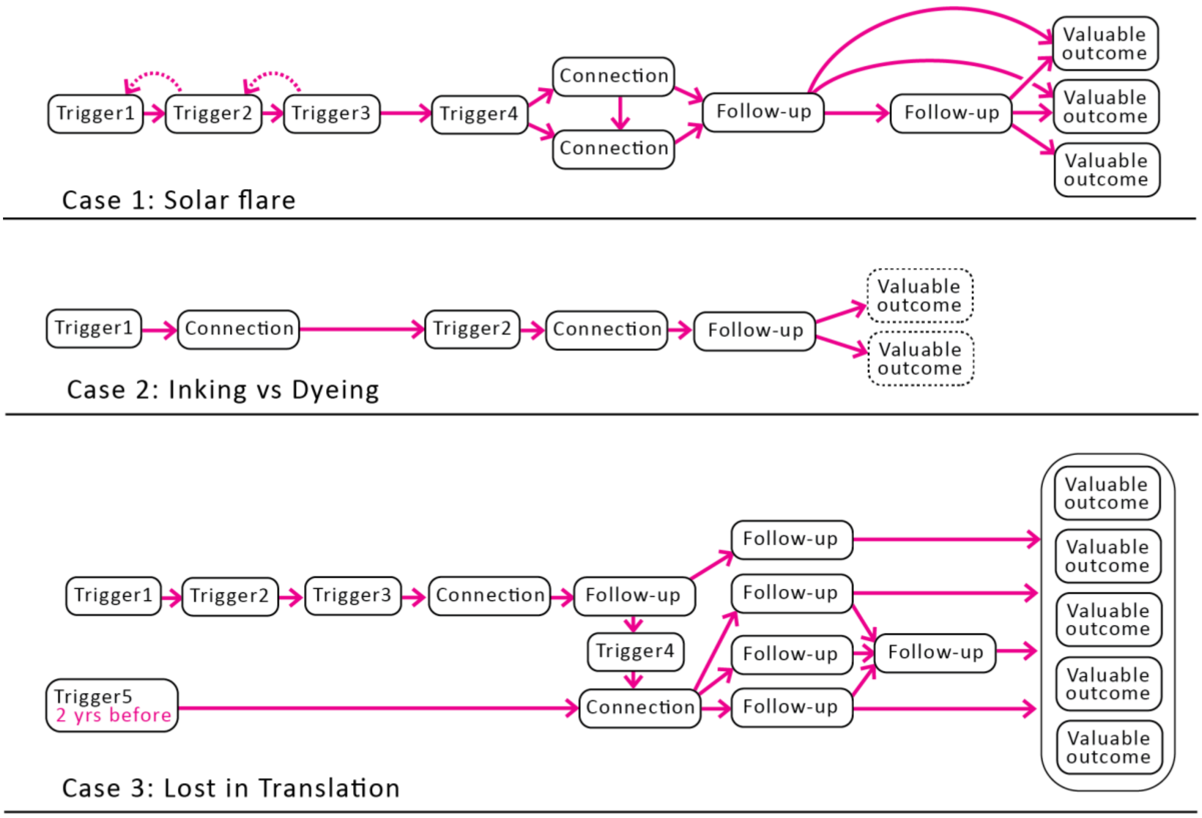

Figure 5. Unexpected Threads of the Three Cases

4.6 Ownership and empowerment

Overall the three cases demonstrated instances of an alternating and reciprocal shift in the individual roles of the design team within the research project. On reflection, this shifting seemed to add new diversity and depth onto the existing professional roles, both on a personal and collective level.

The personal roles of the design team members initially dictated the ownership of the results. In cases 1 and 3, the engineer had ownership due to being able to see the measurements, even though the understanding of their meaning occurred later. Inversely, the textile designer was initially beyond her core expertise and faced tension to what and how textile design could contribute to the process. Towards the end, the textile designer's ability to make the connection between S-shapes indicated an increased capability towards personal ownership, empowerment, and demonstrably, serendipity (de Rond, 2014). However, there was a significant role-reversal for the second case, during which the textile designer was able to exploit her core expertise purposefully.

The construction of the UV-box provided collective ownership and empowerment for the design team, being able to create valuable results that sagaciously lead to an invention claim (de Rond, 2014). Additionally, the solar flare incident had another effect; after receiving the trust in the measurements from the other project partners. It not only gave the design team a boost of confidence to the creative thinking and practical work conducted between disciplinary boundaries of the three schools but also created an open-minded research space within the design team allowing to be more flexible in other explorations.

McBirnie (McBirnie, 2008) argues that *"although one cannot control the process of serendipity, one may be able to control one's perception of the result of the process"*. Our experience thus suggests that it is possible to make a conscious decision towards acknowledging the needs of another discipline and give time, space and trust, in order for the multidisciplinary insights to emerge.

4.7 New Knowledge generation

Given the individual design team members, there was a difference in the approach to sensemaking. The team's engineer understood the early measurements as an act, whereas the textile designer perceived them as a capability, or in her case, an inability that was compensated with a passion for understanding. While this period could be labelled as inefficient, it was high in tenacity, some of the basic characteristics of serendipity (de Rond, 2014).

Due to the several thousands of measurements conducted by the textile designer during the development of the Lissajous- methodology, the combination of multidisciplinary tacit and explicit knowledge accumulated into new interdisciplinary knowledge applicable not only for smart textile design practice but also to design practitioners in general. This new knowledge, in turn, has branched new research directions (visible in Figure 1.), which have the potential to branch out further. Relaxing boundaries between disciplines, varying routines and being observant have been evident in all our cases, which can be found in creative serendipity (Makri et al., 2014). In our opinion, these were highly relevant factors in knowledge generation.

Although we have demonstrated that each serendipitous case generated new knowledge with impact both on a personal and collective level, we see that the chain of serendipitous cases was needed for being able to reach the usefulness of the Lissajous-methodology.

4.8 Research space in multidisciplinary research

As seen in the connections, and especially in the inverse experiential roles within the design team, being able to let go of one's pride in correctness was crucial for having research space. This personal action can be attributed to positive Attitude (André et al., 2009). However, the most significant gains were to be found in the research diversion to create the knits and the signal map. The fact that the team was not forced to come up with results, and that the overall project leader gave the permission to massively divert research outside the project plan, strongly supports the unbound serendipity (Bogers et al., 2013) and openness to discovery (André et al., 2009). The overall process relates to the interdisciplinary team's serendipitousness (Foster & Ford, 2003).

These social aspects lead to the central element in all three cases: the ability to be flexible with the results and to be able to spend time and effort in understanding the other perspective. We identified the "no-hypothesis-argument" (Andel, 1994) when dealing with completely unexpected and uncertain phenomena. We suggest approaching this "upside-down" so that even when working with an active hypothesis and research direction, one should reserve time to support serendipitous work, to allow the findings and abnormalities to be followed diligently through. This strategy may seem counter-productive to a systematic and seemingly deterministic research approach, which values known, well-defined and specified plans. In practice, this could be as simple as reserving a work-package with a plan containing “sacrificial research activities”, which in the face of serendipitous reality can be exchangeable to allocate time for expanding the unknown.

5. Final Words

For future projects, small work-packages with relatively open goals could provide a serendipitous alternative to following set plans strictly. Capability to put the dictated research on hold, or accept that it may not be returned to, in order to make a detour, could provide new discovery in light of serendipitous connection. In retrospect, the process of clustering itself was a serendipitous action, which organised the clusters in a directed way, and not based on pre-determined criteria.

The value of a researcher should not be only evaluated based on the ability to create academic outputs, but also by the ability to look at what is happening to the research process, and why. It can lead to a new direction, which may end up being more impactful than the original research intent. As one of the end-results in our third case, we diverted towards a visual representation that has already proven useful. This representation has been taken to a reproducible system that can be exploited by practitioners. However, being able to do this requires supportive research conditions. Being able to follow an identified issue, especially one related to methodology, might be extremely difficult to do with limited budgets and expectations of research outputs.

In all cases we emphasise researcher reactions, facing unforeseen incidents and unexpected outcomes as potentials rather than failure, and actively cross-pollinating knowledge. When something does not seemingly work or is against perceived possibilities or even challenging disciplinary boundaries and practices, one can step back and take a deep breath. In retrospect, serendipity itself became a vehicle in which the designer was able to gain ownership and empowerment to their research.

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