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Twist-hands and shuttle-kissing

Understanding Industrial Craft Skills via Embodied and Distributed Cognition

ABSTRACT

This paper seeks to understand the skills of operating automated manufacturing machines of the C19th as craft practices, employing externally powered and automated tools around which new cultures of practice emerged. We draw upon situated/embodied/enactive/extended/distributed (SEED) approaches to cognition to explicate the sensibilities of these practices, as well as the history of science and technology, Anthropology, STS and related fields. Our case study is a body of work focused on embodied/ embedded knowledge in the textile industry – specifically in the making of machine lace. We conclude with a proposal for multi-modal museum exhibits that provide an understanding of know-how, kinesthetic/proprioceptive skills and procedures. The authors are both long term practitioners of crafts, both traditional and industrial (see biogs). This experience informs the research at every step.

Keywords:

Cognition; Industrial Craft; Embodiment, Know-how; Material Engagement

INTRODUCTION

We have two goals in this paper. First: we propose that the skills of machine tool use that developed in the shops and factories of the industrial revolution constitute an historically novel mode of skilled practice whose sensibilities are consistent with pre-industrial artisanal practices but which developed to embrace the speed, precision and automation of the technologies and the qualities of new industrial materials, from cast iron to fine thread. Second: we introduce a case study of industrial crafts in mechanised textile production, presenting elements of a lace factory ethnography. We conclude by proposing a physical/ virtual hybrid mode of presenting industrial craft skill in museums.

Our first goal is to propose that in workers' cooperation with automated machines, both gross physical and cognitive functions came to be shared in new ways and to new extents. Not only does the machine access mechanical power to which the worker adds their power to control and calibrate, but cognitive or 'computational' functions were 'offloaded'. A new cognitive symbiosis or prosthetic relationship emerged. We leverage the contemporary embodied, enactive, extended and distributed

(SEED) approaches to cognition as these paradigms provide us theoretically well-founded ways to reject the (artificial) division of bodywork and mindwork.¹ It seems especially relevant, in this realm of skilled physical actions in the context of semi-autonomous and potentially dangerous machines, to consider cognition-in-action (know-how, Ryle 1949²) as an enacted, temporally immersed process, in unceasing interaction among a constellation of agents, human and machine.

We aim here to begin to explore and characterize the cognitive dimensions of these practices, which are computational³, but rather than being abstract and disembodied, are fundamentally embodied, concrete and embedded in actions. In this we deploy contemporary SEED approaches to cognition, because these approaches afford a range of ways to understand intelligence in practice – the exercise of judgement and reasoning in doing, in process, amongst a constellation of tools, machines, materials, documents, techniques and ‘tricks of the trade’. These approaches provide leverage on such practices in a way that conventional mentalist, internalist, computationalist approaches to cognition cannot, since these treat cognition as reasoning on symbols, occurring exclusively in some abstract mental language in the brain. In contrast, the perspective that SEED provides allows us to track intelligence in practice, cognition in action, as it circulates between workers and their equipment. Through this process, we hope to come to a new understanding of C19th industrial trades as crafts, and to discuss them in the same terms we discuss traditional crafts. This is the project of the international Industrial Crafts Research Network the authors are building.⁴

There are a number of methodological challenges to this work, the resolution of which is aided by following the implications of our SEED framework. We wish to stay close to the material relationality that is involved in all crafts. It features in industrial crafts in particular ways because of the extent and complexity of the cognition that can be ‘off-loaded’ from humans to machines, embedded in them, and the simultaneous parallel existence of particular intelligences that are embodied in workers. In our efforts to understand these skills we take a hybrid methodological approach, structuring the work through case studies of specific areas of skilled industrial practice. This article reports on a completed case study of a lace factory that combined ethnography, the practice of 3D computer modelling and animation, and oral history/ memory work, described in Fisher and Botticello, 2016. Observation and deep engagement with human and non-human ‘others’ must be prominent in our approach; this is the stuff of ethnography. At the same time, both the authors have extensive and deep experience of industrial craft processes, which means that in the tradition of ‘heuristic Inquiry’, it is valid to use introspection – Polanyi’s ‘indwelling’ – to “understand [...] unique patterns of experiences in a scientifically organised and disciplined way” (Moustakas 1990: 16), those being the experiences of skilled industrial craft workers, including the authors.

The second aspect of this paper’s content points towards further work that is design/technological and pedagogical. Drawing on an ethnographic study of industrial crafts skills and processes, we propose design ideas for developing museum exhibits that provide an understanding for museum goers regarding the know-how related to industrial crafts, and the kinesthetic/proprioceptive skills inherent in these crafts/trades, through embodied and immersive interactive exhibits. This proposition engages embodied cognition in the sense that it is embodied knowledge, ‘skill’, would be communicated through the embodied engagement of the audience. Museums are full of objects made through the exercise of embodied skill – often of the highest order, however items (artifacts) on display in museums that relate to, or are the product of, craft processes cannot on their own give any direct access to the skills that brought them about. The history and cultural significance of these objects is usually well understood, documented and researched, and can be presented effectively to a museum audience. But the same cannot be said for the embodied processes that realized them. (‘Working museums’ are of course exemplary exceptions.)

This ephemeral or intangible aspect, we argue, is key to understanding both machines and their products. Even when a museum’s mission is to preserve the machines that were responsible for mechanisation, it usually cannot engage visitors with the skills involved in their operation, meaning these remain either hidden, or the preserve of specialist demonstrators. As a museum visitor, performing (or attempting to perform) some of these actions is clearly far more informative of the know-how involved than simply watching a demonstration, because the kinesthetic/proprioceptive

modalities of cognition are engaged. We have considered these problems in relation to museums of industry, particularly textiles, but it is relevant to all museums that want to display and interpret items of material culture – all of these are the product of skilled craft practices. There is an aspect of preservation in this, as the craft knowledge and material understanding necessary to produce such objects may be lost or exist only in a few hands/minds/tools. Both these themes – one theoretical, one practical - lead us to the literature on cognition and tool use as we delineate the relationship of skilled practice to the industrial crafts we consider.

INDUSTRIAL CRAFTS

We begin with the recognition that these technologies did not diminish the extent to which their operators were craftspeople. It is true that the process of mechanization pushed craft practices to a meta level - rather than performing complex bodily routines to directly achieve production, they oversaw machinery that performed a standardized and speeded up version of these routines. However, weaving is weaving and knitting is knitting, they involve similar actions over similar materials, whether performed by hand or machine and mechanised production depended on embodied skill. Raphael Samuel's compendious discussion of skill in C19 mechanisation notes that "In the Lancashire mills the 'self-acting mule' depended on the nimble fingers of the piecers, while power-loom weavers kept their machines at work by 'shuttle-kissing', threading the weft with their lips" (1977:46). But these machines not only did physical work, facilitated by their operators' bodies, they performed actions of 'judgement' and computation as well – working within highly specific tolerances, counting sequences and performing patterns.

A useful way to understand these technologies is to see them as a midpoint – historically, technically and cognitively - between artisanal hand tools and contemporary computing. Their operation involved a mode of work that was entirely bodily, materially- engaged and sensorimotorically attuned – pulling levers, adjusting tensions, lubricating bearings, listening for sounds, feeling for vibrations, in a contingent but rhythmic dance to the beat of, and at the pace of, the machines. In their operation, some technical tasks (we might call them "computations") were offloaded from the human operator into the machinery. These machines were analogue computers in a precise sense, but they output textiles or screw threads instead of numbers. While they act at a meta-level, their operators' bodily engagement with the machine's process makes them distinct from both their craft forebears and their virtual descendants. The tasks we are studying involve skilled operators who are immersed in and integrated with an environment of semi-automated machines drawing on external power sources. Their work is a choreographed dance to a tune played by an orchestra of machines.

Theoretical resources

The behaviour of the operator of such machines is at once physical, intellectual, sensorially highly attuned and rapidly responsive. The combination of these qualities, with learned experience, constitutes her skill. Any attempt to separate the 'mental' aspect of this work from the 'physical' aspect would be absurd. Because of this, we find embodied, situated and distributed cognition approaches to be singularly applicable to this study. Within these approaches it is assumed that intelligence or cognition is not (exclusively) a process of mental operations, but involves the entire body, in sensorimotor integration with environments - prosthetic integration with tools, in distributed synchronization and cooperation with nonhuman agents.

As well as drawing on embodied cognitive science perspectives, this research serves to augment them with tangible examples. For instance, in his notion of 'epistemic action', which has become a fundamental concept in embodied cognition, David Kirsh distinguished between pragmatic action (work), and actions that aid cognition (1994). Tellingly, the standard examples are 'informational': Tetris and Scrabble, both cases where the materiality of the manipulated tokens is of no consequence. We sense that in the 'real world' of mechanised labour, these distinctions are less distinct and perhaps do not hold. We pursue a reconsideration of the notion of epistemic/ pragmatic actions, accepting their theoretical validity but proposing they are not always separable, either occurring simultaneously, or in linked sequence. Our experience and the textile case studies we examine include actions that are

simultaneously pragmatic and epistemic, and pragmatic actions that lead to epistemic actions or epistemic discovery. The latter is often then case when repairing a machine or simply ‘tinkering’.

Indeed, from the perspective we take here, this is what tinkering is, both pragmatic and epistemic. Its clear relationship with the material object being tinkered with makes it exemplary of the principles of the ‘Cognition in the Wild’ that Hutchins delineated, which positions individual cognition among a constellation of instruments, documents, and the procedures of multiple persons (1995). This idea of cognition being distributed amongst humans, instruments, documents and structured work environments lends itself smoothly as a discursive context in which to discuss industrial workplaces such as the lace factory. When the Card Puncher⁵ transfers a pattern from the long-hand notation of the ‘figure sheet’ into a chain of jacquard cards, they are effectively loading a program into the memory of the machine [Figures 1&2]. This is a process of transcription. That program then runs the machine to produce the encoded pattern, enacting a precise rhythmic process. The tasks of the technician are cognitive - monitoring, adjusting and calibrating the machine, both on the fly, and when it is still.



FIGURE 1. A sequence of images showing L-R: ‘draft’ of lace design (schematic diagram of threads); more and less formal ‘figure sheets’ recording the arrangements of machine components needed to produce the pattern. 2013. Photo credit, Julie Botticello. Copyright Nottingham Trent University.

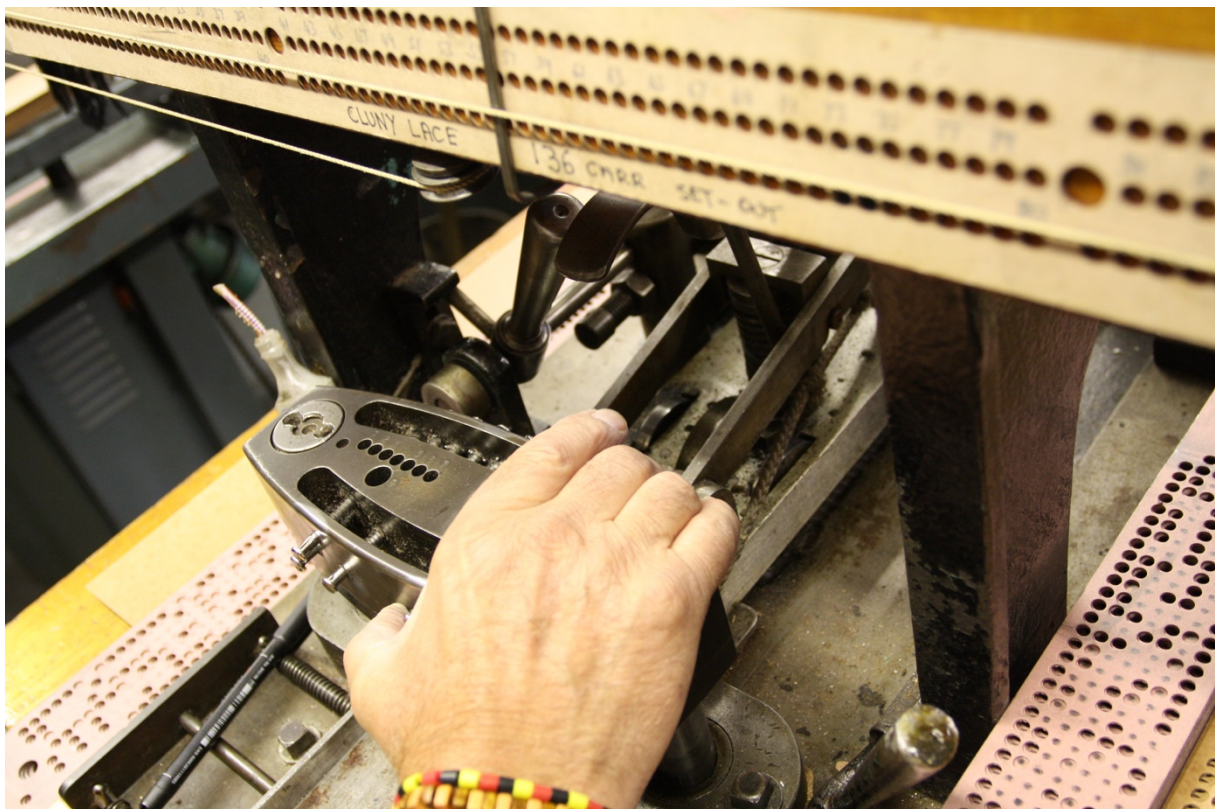


FIGURE 2. The card puncher, Ian Emm, using the card punching machine to transfer the numbers on a figure sheet, to punched cards for the Jacquard mechanism. 2013. Photo credit, Julie Botticello. Copyright Nottingham Trent University.

This process involves fine sensory attunement. What to the novice is a mechanical din is articulated to the technician as the sounds of the instruments of an orchestra is to the conductor. The Twisthand quickly becomes aware of any variation in the sound of the machine. Implicit here is the question of ‘variation with respect to what’, and the answer is ‘with respect to (expectations of) the sound of smooth running, learned through hours or years of attentive listening’. The contemporary neuro-cognitive debate around ‘predictive coding’ that might usefully be applied in this analysis of ‘expectations’. The Twisthand, in noticing a ‘bad noise’ is recognising an error in relation to an expectation. This is precisely the topic of the emerging neuro-cognitive research area called ‘predictive coding’, also known as the ‘Bayesian Brain’ hypothesis. It also relates to Hutchins more recent work in ‘cognitive ecologies’ - in this case background acoustic cues (2010).

It can also be related to principles of enactive cognition – specifically the idea that cognition occurs in what Maturana and Varela (1980) called structural coupling with the environment through sensorimotor loops. In essence, enactive cognition disputes a main tenet of the computationalist internalist paradigm (implemented in the conventional von Neumann machine) that sensing, logical processing and output occur separately and serially. Contrarily, enactivists contend that cognition is always ‘embodied and embedded’, to use Haugeland’s phrasing (1995) in iterative feedback loops. According to enactivists, we (often) act in order to perceive.

Remarkably, this bodily attunement generalizes over differing scales and varying materials and in interactions with different types of tool and machine. This is aided, in no small part, by the design development and scaling of tools – which themselves, even the lowly ones, must now be regarded as having a cognitive component or as involving an offloading of ‘computation’. There is a reason why, in a set of wrenches/spanners, the tools that fit larger nuts are longer, and it has nothing to do with the user, whose size does not change. They are directly proportional to applied torque. And, in the hands of an experienced user, the flexing of the wrench itself can be distinguished from the flexing of the bolt. The degree to which a seemingly rigid chrome-vanadium bar reliably flexes and can be perceived to flex – is indicative of the high degree of refinement of the tool, and the ‘feel’ of the tool marks (for the adept) a significant difference between a good tool and a bad one. This is as true for paintbrushes and axes as it is for wrenches and, if the category ‘tool’ is stretched, to lace machines.

Case-Study: Lace making in the East Midlands.

The paper’s central case study, and the domain in which we are developing our response to the second challenge above, is in the textile industry of the East Midlands of the UK. This is now much contracted, but during the C19 was characterized by technology that had mechanised hand craft processes – knitting, lace-making - some of which remains in use to the present. This process of the mechanisation of textile processes started a long time ago. The first knitting machine, the so-called ‘hand frame’ appeared in 1589, in the reign of Queen Elizabeth the 1st (Felkin 1867).⁶ By the early nineteenth century John Heathcoat had developed out of the hand frame a machine for making twisted net, which was the basis for John Levers’ technique for making patterned lace, first by transferring the pattern instructions to a toothed wheel and later by using a Jacquard mechanism with the pattern encoded on punched cards. It is relevant to the subject of this paper that both Heathcoat and Levers were inventive ‘framesmiths’ – they were trained in mending and setting up textile machines. The state of development of machine tool technology in this period, means that they deployed a range of skills supported by machinery but reliant on hand and eye.

The context for our discussion, and the examples which we point to, are two research collaborations, one was with the last company that remains in the East Midlands using the Leavers process, Cluny Lace 7. The other is a developing relationship with a working museum of framework knitting at Ruddington, near Nottingham. The former work used ethnography (Fisher and Botticello 2016) and 3D modelling to uncover some aspects of the human/machine interactions that are

necessary to producing lace with a 150-year old technology [Figures 3&4]. It resulted in a short film, 'Twisthands at the Deadstop', which explains the Leavers technology using animation 8. The latter is currently in development and seeks to apply these insights to framework knitting in collaboration with the Ruddington museum. The economic importance to the Leavers lace technology of the operators' embodied skills and knowledge is indicated by the fact that as the technology spread across the world in the C19 and early C20, notably to Northern France and the USA, workers from Nottingham and the East Midlands went with it. These skilled bodies were necessary to the successful growth of the industry. As the industry in the UK has contracted almost to the point of disappearance, its technology has been sold to other countries – notably China and East Asia. Just as twisthands accompanied the exported technology in the C19, they did so in the late C20 and early C21.



FIGURE 3. A 'Twisthand', Ian Palfreman, organizing threads in a Leavers lace machine at Cluny Lace, Ilkeston, 2013. Photo credit, Julie Botticello. Copyright Nottingham Trent University.

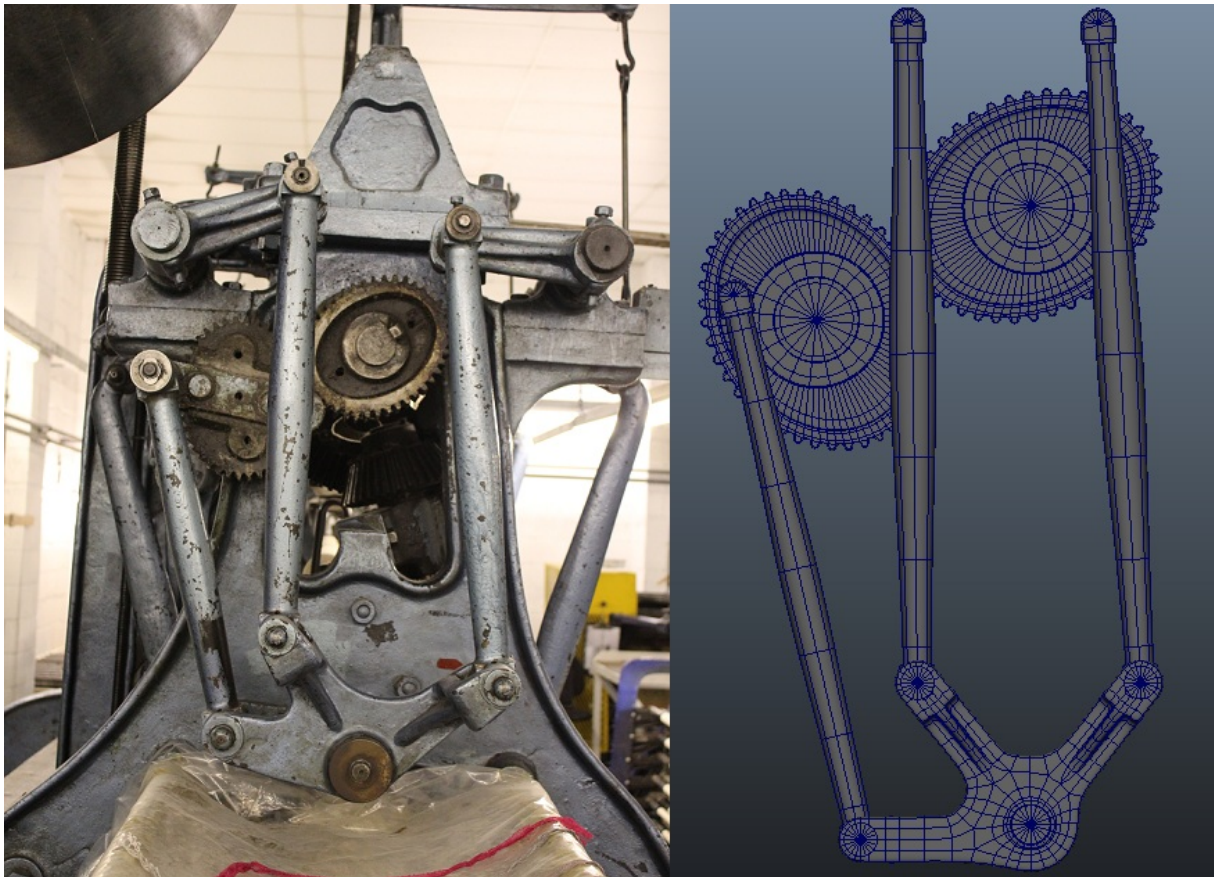


FIGURE 4. Photograph and corresponding 3D model of the drive system in a Leavers lace machine, showing ellipsoid gears that even out the motion; Cluny Lace, Ilkeston, 2013; Photo/ 3D model credit, James Thompson; Copyright Nottingham Trent University.

As ‘Twisthands at the Deadstop’ shows, a range of apparently mundane, but actually highly skilled actions are required to keep Leavers lace production going. Many of these actions feature in the processes needed to keep the machine supplied with thread that are the special preserve of particular workers – the twisthands, the menders, the bobbin winder. Thousands of brass bobbins must be re-filled with thread by the specialist winder. They must be heated and pressed to make them thin enough to pass between the vertical ‘beam’ threads in the machine. Each bobbin must be installed in a steel carriage, with its thread passed through the tiny hole in the steel ready to be taken up into the web. This last ‘mundane action’ is constantly required, and all the workers are expected to learn it, whatever their specialism. Its ubiquity means they bring it to such a high level of skill they can do it without looking and at great speed. These skills are part of a reckoning with the complexity of the mechanized computation in the lace machine, which simultaneously involves intimacy with the material and the immaterial dimensions of the process. The mechanism, the threads and the documentation associated with the process, which is both formal and informal, embody a set of instructions embodied in these materials. This embodiment encompasses notation, improvised tools, figurings-out and even marks on the machine, that ensure that the right threads get tied in the right places.

Ewa Klekot’s (2020) study of work in a Polish ceramics factory (like Erin O’Connor’s (2007) experiential research on the skill of glassblowing) emphasises the embodied skills that are involved in such dynamic hand work. She sees these actions as replete with high level human/ material dialogue, as we do with the lace factory workers. The element that the lace making case-study adds to this literature is the degree to which the twisthands both off-load the calculative aspects of their trade into

their material partners and work with them in a dynamic dialogue. Most examples of this off-loading are formally codified and use formats that would be recognisable and legible among the Leavers community of practice – most obviously the jacquard cards which legible by the machine itself. Others are more informal, some are personal. It was conventional for textile workers to off-load the details of patterns and actions in personal notebooks to help them keep track of their work (Wood, 2013). The temporal aspects of cognition-in-action that these informal notations comprise extend the work beyond being ‘in the moment’ and can even stretch the process back in time, allowing twisthands to make use of notes that their predecessors have left. So it would be mistaken to assume that the highly abstract and genuinely computational aspect of the Leavers process evident in the ethnography at Cluny Lace characterizes all of this aspect of the workers’ engagement with the process.

A significant proportion of that engagement involves the fine, direct, attunement of the workers’ bodies and the material they work with that is familiar from pre-modern craft processes. For instance, twisthands own, and jealously guard apparently inconsequential, sometimes home-made, but vital hand tools, intimately connected to both their bodily actions and the particulars of the process. As one put it: “...you can leave money out on your workspace, but not tools, money will remain, but tools will go missing...” Such tools point to a degree of bodily attunement to the process that was strikingly demonstrated by a technique that was part of the process of re-loading the machine with filled bobbins in their carriages, outlined above. In a procedure called ‘shining’ the twisthand holds a group of carriages up to the light, gripping them at the bottom so they fanned out above his hand. Shining the bobbins in this way allowed him to check that the filling, heating and pressing processes had not left any of the bobbins too fat to pass between the vertical threads without snagging them (Figure 5).

This action used light and bodily comportment to supplement the sense of sight, in the knowledge of the importance of the thickness of the bobbins to the smooth running of the process. It gives the twisthand information; It is an epistemic action, on which subsequent pragmatic actions depend - bobbins that look too thick are sent back into the filling/pressing/threading process (cf Kirsh and Maglio 1994). There is a direct connection here to the work of David Kirsh between conceiving of skilled actions in this way – simultaneously epistemic and pragmatic – and the proposal we introduce in the conclusion of this paper for using the insights from analysing industrial craft practice, as above, to find ways to supplement museum exhibits with material/ virtual hybrids. As Kirsh puts it writing about virtual museum exhibits “If I am right, and a core interactive strategy is to project then actualize then project more, then the trajectory of thought will be sensitive to the actions we can perform” (2010).



FIGURE 5. Twisthand, Ian Palfreyman ‘shining’ a set of bobbins at Cluny Lace, Ilkeston, 2013. Photo credit, Julie Botticello. Copyright Nottingham Trent University.

Future work – Machines and the museum

As we noted at the start of this article, museums that cover the period of mechanization in the West, whether production techniques are their focus or not, face a challenge in addressing the ‘know how’ implied by their exhibits, alongside the ‘know that’ in which they excel (Ryle 1949). Building on our theoretically informed analysis of Leavers lace making, we propose to extend our work into deeper and broader field research and oral history collection, neurophysiological research, and technological prototyping for embodied interactive exhibits, initially collaborating with Ruddington Framework Knitters’ Museum, Nottingham.

The intention here is to help the museum remain a ‘working museum’ in a context where the framework knitting industry has disappeared, stopping the supply of people proficient at working the machine. This will deploy an analysis of the knitting process in the design of a ‘simulator’ for the frame, informed by the SEED approaches outlined above. The simulator would combine a screen-based interface with physical interaction to replicate the whole-body engagement that working the frame involves. There is a pedagogic driver for this, beyond the possibility of helping to train framework knitters. The simulator would help address what Penny has referred to as the ‘sensorimotor debility of the born-digital generation’. With the demise of making hobbies at home and skill-oriented teaching in schools, children and young adults cannot be expected to have extensive familiarity with nuts and bolts and wrenches or needles and threads. We intend to address this debility by applying SEED insights to the design of a new class of exhibit that attends to industrial craft processes, procedures and sensibilities while exploiting contemporary interactive technologies

that impart 'knowledge' to audiences through directly enactive sensorimotoric experiences that emulate aspects of the machines, and permit re-enactment of technical procedures.

To achieve this, there is clearly potential to use interactive technologies, given the increasing availability of sophisticated sensors and VR/AR. However, to avoid missteps in the use of such technologies in this setting, it is vital to be aware of the ontological context in which and for which those technologies have been developed and deployed. In that context the prevailing paradigm is of storage, transmission and display (and production) of (dematerialised) information, from code itself, to textual documents, to multimedia documents. Likewise, in museums computer-based technology is almost entirely oriented to the purveying of information, usually textual, or in image, audio or video form with interactivity usually limited to 'clicking', 'swiping' or 'scrolling'. These are highly constrained and codified bodily actions, designed to be 'intuitive' because they conform to a known set of conventions that have as little to do with skilled action in the world as could be.

Our intention in working in the museum context is to explore ways to use a combination of physical interaction and 'de-materialised' information, to make it possible for visitors to connect their own action with resultant effects in a sensorimotor loop, learning how action and effect are linked, how 'skill' is expressed in the judgement and calibration of action through bodily experience. This is possible using technology that offers sensorimotor experience in a simulation of operating machine tools - far more than pushing a button to see an animation, it implies an entire suite of force-feedback interfaces to augmented (AR) or immersive (VR) environments allowing visitors to operate, in the proprioceptive, kinesthetic and sensorimotor realm, augmented by acoustic and visual components.

The ontological challenge of this work is that, when all is said and done, such environments remain, inescapably, representational in some degree. They are simulations, and a simulator is always, by definition, a simplification of the target context, raising the possibility that a museum visitor would learn about the simulator, rather than the industrial craft. The question of whether the knowledge does 'transfer' to the real world dogs all kinds of simulatory technologies applied to flying and driving for instance (see Penny 2004). This is an especially complex and awkward question when the 'real world' in question exists only in the past.

Conclusion

In this paper we propose that industrial skills or trades be considered as crafts, but crafts of a special kind, seeing skilled workers as enmeshed in a dynamic machine environment. This paper draws on the authors' direct craft experience as makers and users of tools – this study is in this sense deeply 'practice-based'.

We draw from the rich body of recent theory on embodied and distributed (etc) cognition to inform our understanding of the enactive ecology of tool use, from artefacts held in the hand with which humans directly work on material, to contemporary computational tools. We have argued for the special relevance of SEED approaches to understanding the embodied cognitive knowledge that constitute skilled practices, not simply in the industrial realm but in crafts practices as a whole.

The two industrial craft case studies in textile technology, one retrospective and one prospective, are particularly appropriate as vehicles for this enquiry, as they exemplify modes of cognition that are simultaneously 'computational' *and* reliant on enactive embodiment, immersed in a cognitive ecology of human and non-human elements. They therefore justify the application of SEED approaches as a more relevant theoretical environment than conventional dualistic approaches.

We have indicated an isomorphic problematic in designing 'exhibits' that communicate these kinds of know-how, and recognise that the conventional focus on 'knowledge-that' in museology confounds efforts to address questions of skill in museums. We recommend that SEED approaches should provide a theoretical foundation for a design strategy. We intend to apply the insights analysis gained in the case studies to museum exhibit design by combining novel embodied interfaces with interactive systems to engage audiences in the proprioceptive and embodied dimensions of heritage skills.

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¹ SEED is the authors acronym for a range of more-than-intentionalist approaches to cognition that Penny has also referred to as 'postcognitivist'. SEED covers roughly the same territory as '4E' but names Situated and Distributed specifically. We would also include Malafouris' designation Material Engagement but we couldn't think of a catchy acronym.

² Gilbert Ryle established the distinction between know-how and know-that in his 1949 work *The Concept of Mind*.

³ Readers may balk at the use of the term computational, because we are used to thinking about computation in terms of abstract, disembodied information. However, we insist that these machines perform at least calculatory functions. These machines computed, but their output was a thread cut in metal or a pattern in lace and the history of automated machines is entirely entwined in this period with Charles Babbage's difference engine informed by both theoretical and technical developments in manufacturing.

⁴ Industrial Crafts Network, <http://simonpenny.net/industrial-crafts.html>

⁵ The labour process in a lace factory is divided between workers with different skill sets, more and less specialised. The Card Puncher is perhaps the most specialised, there being only one individual in the UK who still does this work. The lace machine is supplied with new threads by a Winder, who is specialised in the skill of filling brass bobbins with thread. They are then prepared for the machine by workers with more generalised skills, before going to the Twisthand to be installed. The Twisthand oversees the operation of the machine, as it twists the threads to make the lace.

⁶ Framework knitting's historical significance is demonstrated by the fact that from this development of mechanized lace-making from adapted knitting frames came a regional lace industry that by 1901 saw 20,000 people, mostly women, employed by 250 lace manufacturers, with annual global exports of £1,000,000 - equivalent to £100,000,000.

⁷ Thanks are due to the Mason family, owners of Cluny Lace for the access they granted us to the factory in Ilkeston that has made all of this work possible.

⁸ The Leavers process, is understood to be so spelt to facilitate its pronunciation by French speakers – the technology was soon established in northern France. Twisthands at the Deadstop can be found here: <https://www.youtube.com/watch?v=2mYtIPKmrwo>