The evolution of the HMI design

From the current landscape towards industrial machine interface design innovation framework

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Abstract: Human-machine interface (HMI) design is a multilayered discipline that includes the study of human factors, engineering and interaction design. By its own definition HMI brings together heterogenous and emerging design challenges that cross multiple domains. In this chapter, we propose the interface as the material and conceptual place where the novel challenges of HMI should be addressed and solved. Our goal is to open a debate on the centrality of the interface design in industrial machines and to analyze the current trends by case-based analysis. The authors propose a discussion over specific interface design aspects, from interaction model definition to the visual language, that might constitute the levers for the innovation of HMI design landscape. Co-design is finally proposed as a transformative systemic and community-driven design method to facilitate innovators to continuously identify, connect, codefine and share with other peers their innovation and learning journeys to build capacity over time for addressing industrial innovation challenges.

Keywords: HMI; Automation; Interface; Design

1. Introduction

When we look at the interactions between humans and machines, we may address heterogeneous factors ranging from the human experience and the quality of interaction to the system architecture, until machine automation. In this chapter we want to focus on the Human-machine interface (HMI) in the industrial domain, defined as an interface that allows humans to interact with machines and systems (Papcun et al., 2018), including computer monitors, tablet devices and mobile/cell telephones, for manufacturing and production purposes. The interface is the “space of the interaction” (Anceschi, 1993) where the functional and informative nature of the machine controls are thought to support the emergence of a valuable machine operators’ and technologists’ experience.

Since the ‘40s the new landscape of interactive products (Kepes, 1949) has been investigated as a novel kind of industrial products whose innovation is pushed by technology development. In his historical review, Maldonado (2003) states the emergence of an even-new landscape based on the wave of miniaturization and cost lowering of consumer electronics, and its application to industrial production. Today HMI finds evolutionary innovation in the fields of machine learning, material science, manufacturing processes, sensing and actuating systems, that are rapidly transforming the way we interact with technology. The authors want to explore current industrial machine interface design culture with the goal of understanding and interpreting the design solutions implemented by *best of class* interface projects and, on the basis of the results of this analysis, to claim for the need of establishing an HMI innovation framework.

The history of industrial machine interfaces has been featured in the past by HCI/HMI frameworks such as those by Shneiderman (1987), Nielsen (1994), and Wickens et al. (2004) aimed to better guide the design of HMIs and improve HCI by putting human user experiences, needs and capabilities at the heart of the design process. In the ‘60s, Man-Machine system (Cherry, 1963) has been established as a distinct area where the interaction domain is at the very heart of the reflection on modern industrial design; however it is only at the beginning of the ‘80s that a systematic analysis of the interface domain has emerged as leading debate in the design community, with the influence of the Olivetti, XEROX and IBM interface design projects (Barbacetto, 1987; Johnson et al., 1989; Anceschi, 1993). The authors wish to contribute to this tradition looking for current industrial machines interface design best practices and putting light to the overall maturity of the landscape. The main components of interface design are disentangled in the case-based analysis with the goal of tracing the evolution of languages and interaction strategies. Based on this analysis, we will discuss how an innovation framework might be established and evolved.

In fact, as design researchers and professionals we are used to understand the potential of the technology, such as the impact of hardware and software innovations, and we have the responsibility of the design of the aesthetic, functional and experiential aspects of interactive products. We research people's cognition and experience, such as intrinsic motivation, attitudes, attractiveness, implicit intention and assumptions, but we are accountable to elaborate this knowledge into the design of the interaction and, ultimately and concretely, in the design of the interface. That is why the ultimate goal of this research is opening a debate on the centrality of the interface in industrial machine innovation and the need for establishing a novel theoretical, methodological and capacity building framework for product innovation that keeps interfaces at the core of the design practice.

2. An historical perspective on industrial machine interfaces

The recent industrial revolution in manufacturing is known as Industry 4.0. This is meant to be the fourth industrial revolution based on the concept of ubiquitous computing in the manufacturing industry (Vaidya et al., 2018). A smart factory is a representative form of manufacturing in the era of Industry 4.0, which adopted new integrated manufacturing technologies, such as cyber manufacturing systems, augmented reality (AR), virtual reality (VR), and Internet of Things (IoT) (Xu et al., 2014).

We argue that it is possible to entirely understand and interpret the current Industry 4.0 landscape only looking at what has happened in the previous industrial revolution turns (Kumar, Lee, 2022), since every change in work, systems and enabling technology has brought a paradigm shift in human-machine interfaces (HMIs) as well (Adwernat et al., 2020; Lucke et al., 2008; Monostori et al., 2016). As long as technology has innovated industry, the task and information complexity inevitably increased and consequently the need of developing HMIs for effective and efficient task performance arose.

Starting from the second industrial revolution (Industry 2.0) the electrified mass production system began, which enabled the supervision of data from the manufacturing line and controlled the integrated manufacturing process. In this era, the demand of HMIs considerably increased as they were necessary to supervise and control the system (Papcun et al., 2018).

The third (digital data) revolution owed to the introduction of computerized robots and automation in manufacturing sites (Noyes and Bransby, 2001) had produced vast amounts of data requiring computer-based HMIs enabling graphical information to be presented, and extending the possibility of capturing more information from various functions (Henderson and Card, 1986). In consequence of this shift, graphical user interfaces (GUI) have extensively broaden their adoption in HMIs to supervise automated production processes (Noyes and Bransby, 2001). At the same time process instrumentation diagrams displaying the production operations information, with the possibility of accessing every phase of the process started to be easily traceable and manageable from remotely controlled HMIs (Astrom, 1985). Operators could easily control any device on the plant using a programmable logic controller (PLC) and supervisory control and data acquisition (SCADA) systems. The advent of SCADA system in factories for supervision of shopfloor gives the advantage of pictorial presentation of shopfloor information (Ivergard and Hunt, 2008). However, GUI had limitations in presenting SCADA-based graphical information in mobile devices such as tablets, phones, etc (Kumar, Lee, 2022).

Today Industry 4.0 smart factory is a representative form of the novel production site where human operators are challenged with multiplicity and heterogeneity: multiple and diverse systems, a multiplicity of actors and roles, and heterogenous workplaces, including remote work and tele operation. At first, Industry 4.0 HMIs are equipped with IoT technologies and embedded network systems to support teleworking (Xu et al., 2014). Operators can observe the manufacturing process even if they are not present at the site (Lee et al., 2015). Additionally, the production process can be supervised simultaneously by different authorized users (e.g., operators, managers, and engineers) (Duman and Akdemir, 2021). Secondly, various interaction modalities (e.g., voice interactions) can be used and a variety of automated and intelligent agents might be involved in machine operations (Pollini, Iacono, De Donatis, 2021). However, although the manufacturing industry attempts to progress towards the next version with the fourth industrial revolution, little attention has been paid to investigating HMIs in smart factories from the perspective of Human Factors and Human-Computer Interaction (HCI) (Gorecky et al., 2014; Papcun et al., 2018) as well as from the perspective of interaction and interface design.

3. Case-based analysis: approach, dimensions and selected cases

Case-based evaluations focus on the systematic analysis of projects. In this research the cross-case analysis leverages upon the selection of a number of case studies analyzed with the same headings in order to generate findings, lessons and conclusions across multiple design projects. The research approach based on collective case studies is useful to understand and generate an in-depth, multi-faceted understanding of a complex issue (Stake, 1995).

As for the selection of analysis dimension we argued for including aspects comprised in the two main HMIs interface functions:

- display elements can present the machine parameters, the status of the machines, the production automation information and the pictorial schematics,
- control elements are used to provide input to the machines and involve interaction models and alarm management strategies (Zhang, 2010).

In particular the analysis has been carried out according to the following dimensions:

1. Interaction model and interface navigation: it includes all the design elements of the HMIs which could reflect user mental models, standard navigational patterns and task-based interactive strategies. UI components (es.: input controls, menu), UI framework (eg.: layouts) and user interactions (es.: selection, zoom in/out) should be consistent throughout the navigational and operational paths.

2. Production automation process: visual and interactive solutions which help users to better understand the manufacturing process and the production operations' status, predict future situations and support decision making. They include KPIs, charts, informative messages and interactive data visualizations.

3. Schematics and system representation: it focuses on the graphical representation of electrical infrastructure or general production processes in order to provide users with intuitive and clear information about the system. These representations could be used in both monitoring and controlling scenarios.

4. Visual identity: the digital user interface could be based on specific visual style (es.: flat design, material design, skeuomorphism) borrowed from traditional UI web and mobile applications. Otherwise, custom-based visual strategies based on accessibility standards and brand style guide.

5. Alarm management: alarms and events provide users with crucial information about machine or system status and require them specific and tempestive actions. For this reason, alarms visual representation (eg.: color hierarchy, consistent shapes, code or text labels) and interactive strategies (eg.: pop-up messages, contextual acknowledgement) are designed to support users in critical situations.

As the interface design literature widely demonstrated (Usability.Gov, 2020; ISO, 2018; Norman, 2013), display and control functions are inextricably linked in concrete components that both serve the scope to inform, show and visualize process and system data, and, at the same time, offer the opportunities for the user to interact. The case-based analysis leveraged both upon principles of interaction design and user interface design (Bagnara, Crampton-Smith, 2006; Tognazzini, 2014; Moggridge, 2007; Kolko, 2011; Preece et al., 2015; Chignell, 1990).

As already anticipated in the introduction we selected the *best of class* HMIs design cases based on the recently awarded projects related to two of the world's largest design competitions, the iF Design Award (*iF Design Award*, n.d.) and the Red Dot Design Award (*Red Dot Design Award*, n.d.). The selected projects come from the last 3 years of contest editions (from 2020 to 2022) with relation to two main sectors, based on the statistical classification of economic activities (NACE Rev. 2. Statistical Classification of Economic Activities in the European Community, 2008):

1. **Manufacturing**: it includes HMI projects for both monitoring and controlling production processes, related to craft and large scale activities.
2. **Electricity, gas, steam and air conditioning supply**: it includes HMI projects which focus on monitoring and controlling activities related to providing electric power, natural gas, steam, hot water and the network of lines, mains and pipes.

4. Today industrial interface design landscape

In this section, we will describe the main design strategies related to the HMI projects selected for each design dimension, intended to support richer and more meaningful design solutions, according to usability and interaction principles.

4.1 Interaction model and interface navigation

EMAG DNA (*EDNA*, 2020) is a modular ecosystem of interconnected software and machine components in metalworking factories. The HMI addresses different scenarios in a multi touch panel, from the setup of a machine, its operation and the process monitoring. Production data is graphically displayed with a 3D representation of the machine, which also clarifies the tools' status. In Figure 1, the user is guided to create a machine process through a sequence of predefined steps called *EDNA Nodes*, available in a contextual library.

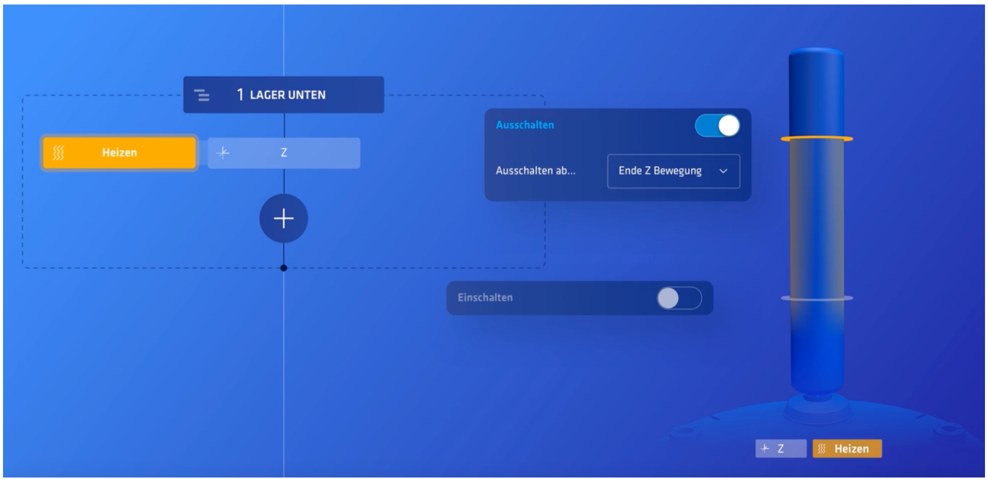


Figure 1. EDNA Nodes, interactive strategy to support users in creating production processes by using a library of single steps. Retrieved from: https://www.red-dot.org/project/edna-the-ecosystem-for-production-processes-and-the-future-of-the-connected-factory-48347

4.2 Production automation process

In LMS LIFE (*LMS LIFE*, 2021), the HMI has been designed to monitor the performance and efficiency of production machines in manufacturing IoT. The design concept focuses on intuitive infographics used to showcase the collected data. The goal is allowing the user to reduce errors and optimize production. The navigational model is based on a drill-down principle that enables users to get a panoramic overview of the plant and enter in the machine details to identify anomalies (Figure 2).

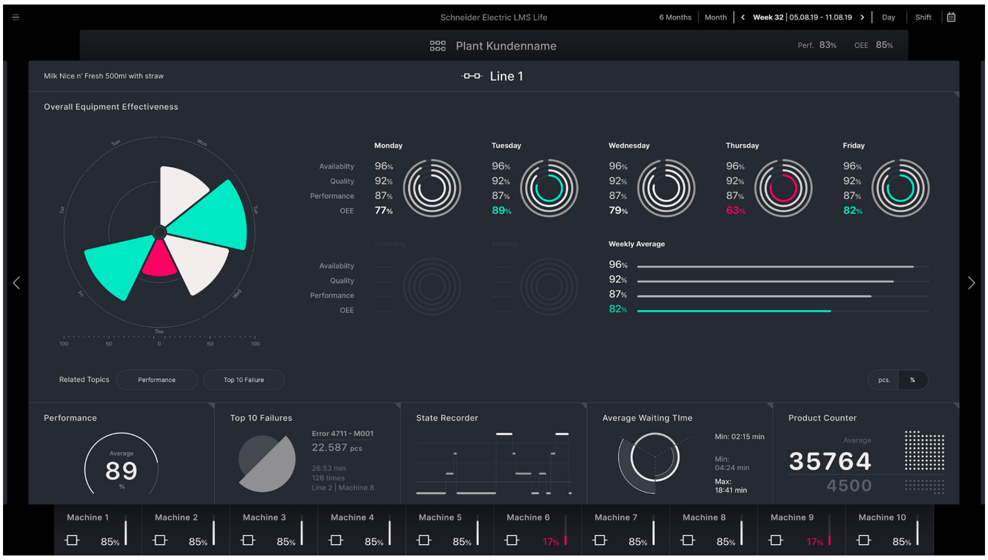
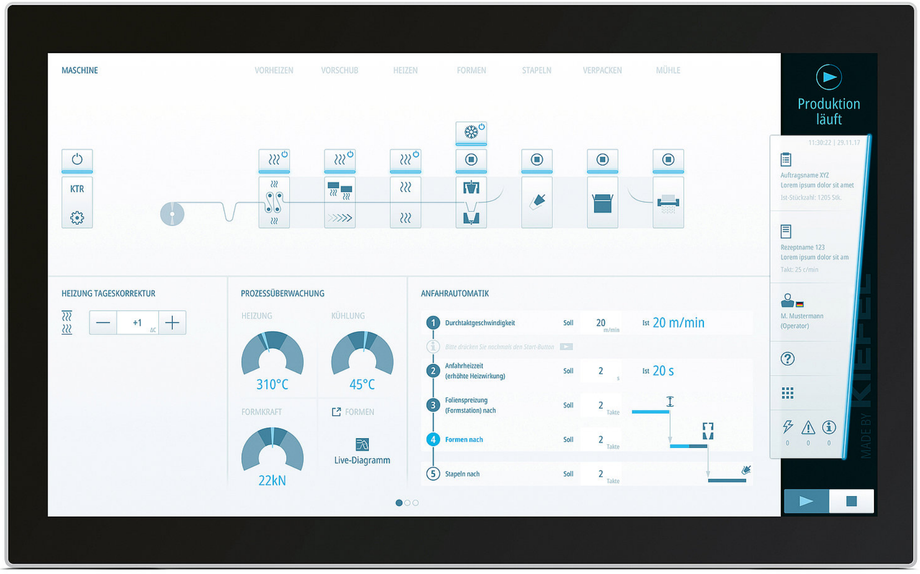


Figure 2. Example of Line 1 data production. It includes general performance, daily effectiveness, top 10 failures, product counter and a summary of machines performance. Retrieved from:

https://ifdesign.com/en/winner-ranking/project/lms-life-next-generation-line-monitoring-system/312701

4.3 Schematics and system representation

In KIEFEL HMI for packaging machines (*KIEFEL – HMI for Packaging Machines*, 2020) the user interface is based on a modular machine visualization that guides the navigation and displays the production status. In Figure 3, illustrations and animations highlight the production process and the program configuration has been designed including only the main important parameters.



Auftragsname XYZ
Lorem ipsum dolor sit amet
Ist-Stückzahl: 1205 Stk.

Rezeptname 123
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Takt: 25 c/min

M. Mustermann
(Operator)

1 Durchtaktgeschwindigkeit Soll 20 m/min Ist 20 m/min

Bitte drücken Sie nochmals den Start-Button

2 Anfahrheizzeit (erhöhte Heizwirkung) Soll 2 s Ist 20 s

3 Folienspreizung (Formstation) nach Soll 2 Takte

4 Formen nach Soll 2 Takte

5 Stapeln nach Soll 2 Takte

Figure 3. Kiefel HMI based on illustrations and animations of the machine components. Each machine component is represented by a specific icon, including a color status, and placed in line with other line components (modular solution). Retrieved from: https://www.red-dot.org/project/kiefel-hmi-for-packaging-machines-49301

4.4 Visual identity

SIG CRUISER (*SIG CRUISER*, 2022) is a user interface design project for filling lines. The visual style reflects the client brand identity for digital environments (eg.: website). The HMI includes graphical elements (eg.: colors, shapes, backgrounds) which has been well balanced to be applied in the industrial domain (Figure 4).

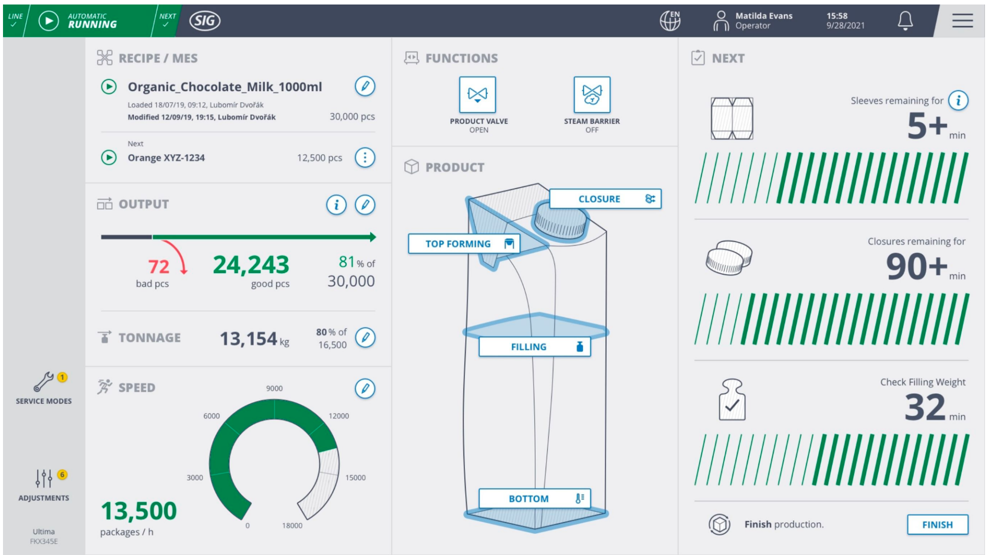

Figure 4. SIG CRUISER interface of filling machines which adapts the visual brand language for the industrial environment. Retrieved from: *https://ifdesign.com/en/winner-ranking/project/sig-cruiser/350131*

4.5 Alarm management

In South Stream project (*South Stream*, 2022), the HMI aims at supporting users in monitoring and tracking anomalies of offshore gas pipelines (Figure 5). This complex system is continuously exposed to several environmental factors which need to be displayed in an efficient way to the operator in order to improve the situational awareness. The approach adopted for the alarms representation focuses on a graphical strategy on different layers of details: from the overall pipeline where anomalies are displayed as circular elements, to a 3D representation of the pipeline in which the alarm occurred. All the data gain the same color of the anomaly priority (eg.: red, yellow).

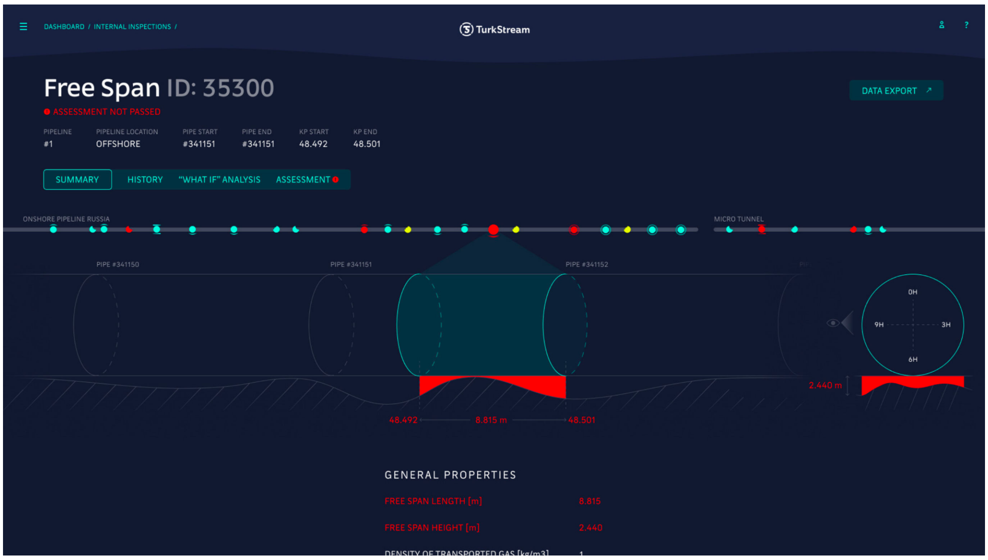

Figure 5. The information displayed contains data that highlights, throughout a consistent color strategy, potential anomalies and risks. Retrieved from: https://ifdesign.com/en/winner-ranking/project/south-stream/346829

5. Case-based analysis results

In this paragraph the main insights from the case-based analysis are being described and discussed.

Visual manipulation: among the crucial aspects emerging from the analysis one is related to the development of an interactive strategy based on simple, ready-at-hand tasks, such as selecting a predefined step from a library to build a machine program, or machine components and process phases on graphical representation in order to get access to more details or to change specific parameters. Feedback and alarms' representations are moving from more conventional abstract messages to visual consistency and material methapors, for example by specific user actions on 3D models through which consistent interaction patterns are built.

Hierarchical navigation of the system: a second aspect to be noticed is the hierarchical navigation structure to access manufacturing process information from a general overview (eg.: plant) to the machine component level depending on the case and the task the user is involved in. The informative structure provided to the users focuses on a clear color strategy which helps users to identify the informative context of each event at the needed level of the structure. These strategies help users in understanding the manufacturing process according to the task and the specific user requirements.

Awareness: it's common to all the cases that process and system representations reduce users' information overloads and increase situational awareness. Visual elements, such as a production graphical representation and machine components illustrations and animations, might support process monitoring and control throughout simple and intuitive access to machine. This strategy also facilitate machine operators in program configuration by reducing complexity and user familiarization time.

Coherence and consistency: industrial HMIs require one consistent visual identity. First, by referring to the manufacturer brand style guide, by using UI elements in balance with ambient lighting and colors of the industrial setting; and second, by defining a clear and well-structured aesthetic design which supports usability and user-performance. These approaches are necessary to guarantee a consistent visual concept to be recognized among different machines and sectors (eg.: digital), delivering contemporary and modern aesthetic appeal and attractiveness for the users.

Cognitive resource saving: alarms' management has been always crucial for industrial machine or process assessment. Successful HMIs load user attention only when risks occur by emphasizing proper color strategies, such as differentiating alarm priorities and severity with colors. When this approach is coherently applied in the different layers of alarm details, and troubleshooting strategies, text descriptions and contextual actions are implemented, then the users are facilitated in solving problems and managing possible errors.

6. Towards a HMI design innovation framework

In today's interface design landscape there are magazines, blogs and communities promoting the user-centered culture, the application of user research methods and the practice with design software. Such widespread of knowledge in the professional domain makes the practical and basic access to interface design very popular and trendy.
At the same time there is a gap in bridging the basic knowledge of consumer electronics interfaces to the advanced design of industrial machines interfaces. In the current scenario an increasing number of local innovators are experimenting for interaction transformations, by exploring technology and novel work practices. However, the scale and complexity of the HMI design challenges discussed in this chapter do force them to constantly acquire and evolve new capabilities in order to advance the current landscape and to evolve it towards systemic change.

We propose to leverage industry innovation upon learning ecosystems and collective creativity in order to increase the value of workers' engagement in the development of new systems for the workplace (Bødker 1996; Binder et al. 2011; Stembert 2017; Halskov and Brodersen 2015). This approach will allow designers/researchers (experts of the systems) and the end-users to work together, and to build on their own experiences and provide them with relevant and useful resources through four key elements: cooperation, experimentation, contextualization, and iteration.

By establishing an infrastructure for engagement and inclusion of all those ones currently working with industrial machines will be possible to understand, revise and simplify their future work. The ultimate goal is to include all those ones that are excluded from work by establishing novel training pathways that will be based through a co-generation process where current and future workers may arise their voices, collecting their instances and engaging them in producing novel interaction scenarios. The history of the first industrial revolution taught that training is the most valuable mean of inclusion since, while grounded on work and human activity analysis, it allow to simplify job tasks and to let all the workforce enter the labour market.

By mean of mission driven industrial innovation pilots, the capacity building framework is intended to result in training activities for industrial innovation and to establish a community of practice sustaining self development journeys and, thus,tackling complex societal, technological, work and experiential issues connected to the evolving nature of human-machine interaction.

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