The Missing “Turn to Practice” in the Digital Transformation of Industry

Myriam Lewkowicz, Romain Liron
Université de Technologie de Troyes (UTT) – CNRS, Institut Charles Delaunay (ICD)/Tech-CICO
myriam.lewkowicz@utt.fr; romain.liron@utt.fr.

Abstract. This paper reports on a “Industry 4.0” project supported by the government through the French public investment bank. This project was launched by a major industrial actor in the gas domain and aims at equipping its factories with digital technologies, and at connecting all these factories through a centralized supervision center, named Operational and Optimization Remote Center (OORC). Based on our observation in production sites and the OORC, we present the new organization of work that takes place in this context and the digital artifact that was introduced to support it. We analyze its use and identify some failures related to the gap between its features and the existing documentation practice in the factories. We then claim that industry has to “turn to practice” to accomplish its digital transformation. This paper contributes to what we foresee as a research agenda for CSCW researchers wishing to contribute to the fourth industrial revolution and the related digital transformation of work in industrial settings.

1 Introduction

1.1 Motivation

Industry 4.0 is a concept that defines itself as the new industrial revolution (Bartodziej 2016; Brettel et al., 2014), after the first revolution in the eighteenth century, transitioning from craft to mechanized work with the use of steam energy, the second in the nineteenth century, related to mass production, permitted by the automation of production and the use of electricity and oil, and the third one in the seventies, concerning the automation of production, driven by electronic and computing technology. During these three previous industrial revolutions, a lot of work has been conducted in the field of industrial engineering targeting the efficiency of the production systems, increasing the speed, the safety and the quality of production, and lessening its environmental impact. The fourth revolution relates to the digitalization of processes, and the use of “big data” techniques to support management processes.

We find this context interesting for CSCW for several reasons: First, the raise of “industries of the future” gives us a new opportunity to conduct workplace studies in industry, which has been overlooked in the last fifteen years of CSCW research (Schmidt 2009, 2010). Secondly, it gives CSCW researchers an occasion to observe workplaces where technology is embedded in a different way as before this fourth industrial revolution. Indeed, the industry of the future is an information system of great complexity that produces a large amount of digital data. In order to be useful, these data must be treated in an "intelligent" way. The success of the new forms of empowerment, claimed by the advocates of this new form of organization, also qualified as "data-centric", depends on the ability of the organization to deploy the computer-based system that allows this intelligent treatment. In fact, this deployment issue is addressed by researchers interested in the factories of the future; they have raised concerns and solved issues from a technical and economical point of view (Brettel et al., 2014; Petrick and Simpson, 2013). However, the social and human dimensions have been neglected so far. This is problematic because if the industry of the future composes a very complex information system, this is exactly because it cannot be reduced to its technological artifacts or its computer-based part. Moreover, most economic and political players are aware of the importance of human and social factors in the successful development of Industry 4.0 (Kassner et al., 2017). Nevertheless, the understanding of the latter has so far been the subject of little research.

We are claiming that CSCW researchers conducting practice-centered research have a key role to play. In fact, one of the most important question for CSCW researchers is how to address "the socio-technical gap" ("the great divide between what we know we must support socially and what we can support technically" (Ackerman 2000)). However, despite several "waves" of digitalization, this gap still exists, as evidenced by all the papers in CSCW-related conferences each year describing social findings that cannot be supported by technical mechanisms.

1.2 Research Problem

In the "industry of the future" context in which we have been included, Industrial Internet of Objects allows collecting data in production plants, then machine learning algorithms are implemented to analyze this data in order for the organization to be able to anticipate machine failures and to predict their obsolescence. The issue here is then less labor power than calculation and decision-making. We then think that it is worth asking whether the question about "what to automate and what to leave to human skill and ingenuity" - that has been at the center of CSCW research - will be any different for the latest incarnation of technology: for AI systems, sensors, and machines.

We raised this reflection while being included in a project supported by the French public investment bank. This project was launched by a major industrial actor in the gas domain and aims at transforming their factories to participate into the fourth industrial revolution. The goal is to connect the nineteen production sites that are spread over the country to a centralized supervision center, named

“Operational and Optimization Remote Center” (OORC) (Figure 1). This center is a physical place that has been built specifically for this project, and for which technicians from production sites, so as new workers, have been recruited.

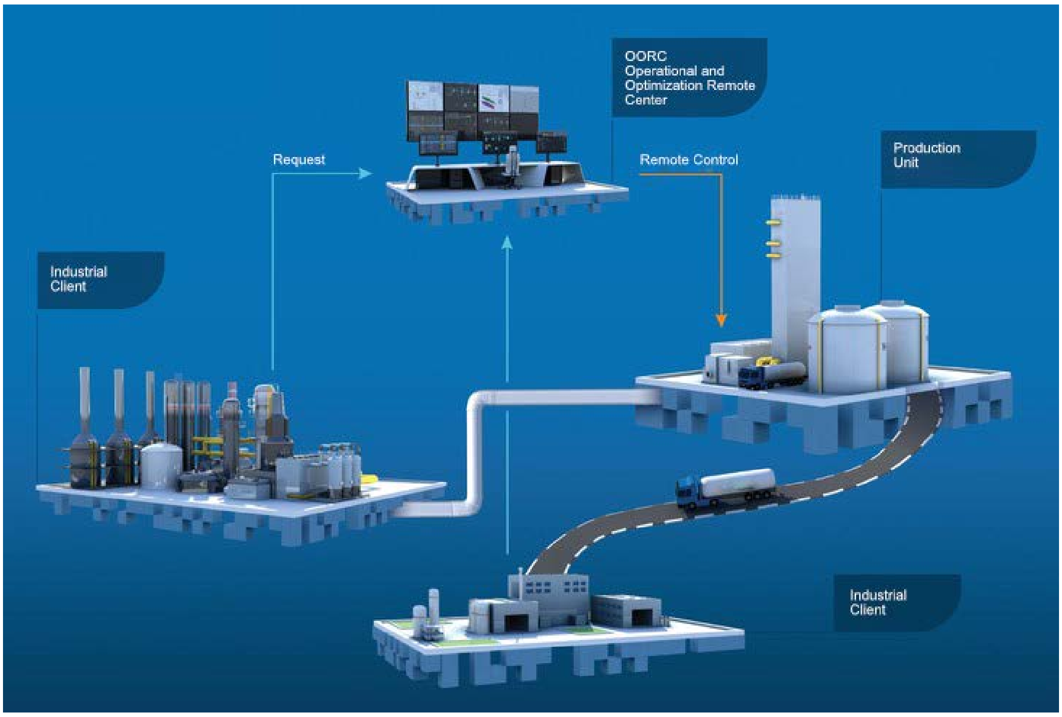

Figure 1. The organization targeted by the company, and for which the project we followed has been put in place (schema adapted from an illustration produced by the company).

Before the start of the project, each production site was managing its production and logistics at its local level, working in the following way: they buy energy to a provider, which they use to extract air products from ambient air; this extraction can be made by several production units on the same production site. Each site then sends its production to clients (mainly metallurgy, food and drinks industries), via pipes for gas products, or via land transport for liquefied gas products. The objective of the project we have observed is that the OORC takes over the control of the production in all the sites, in order to ensure a flexible and adaptable production that will optimize production and logistics at a national level. The overall objective is to decrease the amount of energy that is used during the production of gas.

This evolution of the production goes with an integration of several technologies and a new definition of work in the production units. The technologies that have been put in place are: (1) sensors that collect data in the units and transmit it to the OORC, (2) machine learning algorithms to process this data in order both to define the volume of production for each site and to predict the failures of machines, (3) complex systems to control the production sites at a distance, (4) digital tools to support coordination between the OORC and the production units and sites, as it was acknowledged that despite all the previous technologies put in place, some interaction was still needed before launching production. The deployment of all these technologies goes with an evolution of the work in the production units: technicians are no more responsible of defining and running the production, but of maintaining the installation so that the production can function.

We were interested in observing this transition, and in particular in analyzing how the digital artifacts that were put in place to support the coordination between the OORC and the different sites were used. One digital artifact (the LogBook – name was changed) was put in place explicitly to support this coordination between each site and the OORC. We then followed the definition, deployment, and use of this artifact in six sites during seventeen months (March 2017- August 2018).

In this paper, we start by referring to some recent work in CSCW that has looked at the current evolution in the industry. Our work is clearly situated within this CSCW perspective on the “Industry 4.0”, that is rejuvenating discussions that started more than twenty-five years ago about the importance of understanding cooperative work practices to design tools to support them (Hughes et al., 1992; Harper 2000; Karasti 2001). We also position our work towards the practice theory and its use in CSCW. We then present the complex industrial context in which our work is situated and indicate how we collected data. This is followed by a presentation of the LogBook and its use. We then propose an analysis of the issues raised by the lack of use of the LogBook, based on the comparison of the documentation practice before and after the introduction of the LogBook. We then reflect on this analysis and claim that this failure is related to the overlook of practices, and we then put forward the need to turn to practice (Kuutti and Bannon, 2014) when supporting the digital transformation of industry.

2 Related work

2.1 CSCW and the Digital Transformation of the Industry

The rise of new digital industrial technologies is addressed by a lot of research, mainly focusing on data analysis, optimization, and automation, so from a very technically-focused point of view. As was discussed in a panel at ECSCW 2018: “CSCW in Manufacturing Environments: Towards a European Research Agenda”, the impact of this new digital era on the work practices is overlooked. The existence of a workshop on “CSCW and the new wave of digitalization”, organized during the same edition of the ECSCW conference, demonstrates a rising interest for this topic by CSCW researchers, including us.

The few papers that have been published so far in this domain, are either addressing the evolution of work and the workplace from a worker perspective, or are looking at new opportunities to support their work.

In particular, De Carvalho et al. (2018) claim that augmented reality and sensor technology allow us to enter the third generation of knowledge and expertise sharing, relying on the capture and sharing of knowledge embedded in the action. In their paper, they discuss the potential of augmented reality and sensors to support the set-up of a machine in a manufacturing process. This is a good example of the evolution of the industrial infrastructure that has an impact on the work routines.

This new vision of the industrial workplace has been discussed in several papers. Wurhofer et al. (2018) have conducted a qualitative study based on interviews with operators and maintenance engineers, discussing the impact of the evolution of their factories towards “smart” ones. Their results show that increasing automation and digitalization lead to a feeling of losing the control over the machines, an evolution of skills, and an increased difficulty to distribute the workload. Several challenges are suggested in order to cope with this evolution of work routines and practices. The same kind of perspective was adopted in the work of (Ludwig et al., 2018) who have investigated the socio-technical change in small and medium sized enterprises. Through a workshop and an interview study, they were able to identify six areas of conflicts related to implementing the ‘Industry 4.0’ vision in mid-sized manufacturing companies. These areas of conflicts are close to the issues raised by Wurhofer et al. (2018), in particular the qualification of employees, the human-machine cooperation, and the occupational safety and health. In order to address this evolution of the workplace and the work routines, Fuchsberger et al. (2017) have used fictional job postings to launch discussions on the futures of work with stakeholders of a production site and the public. Their results show that the evolution of work leads to controversial discussions, and they confirm the need for the workers to be involved in the definition of the future of work and the workplace.

In the project that we have followed, we have also noticed the challenges related to the evolution of work, and the discussions around the new industrial processes. But compared to existing work that has analyzed the discourse and the representation of this evolution, we actually observed this evolution taking place it in real settings. We then aim at contributing to this research area by describing and analyzing a case of digital transformation, and by suggesting a research agenda addressing the fourth industrial revolution from a CSCW perspective.

2.2 The “Turn to Practice”

The interest into the link between technology and work is of course not new. If we go back to the early days of CSCW research, we could say that in the eighties and the nineties, the main goal was to demystify technological determinism, as we can see in the studies conducted on socially-embedded technology at work by ethnomethodologists, sociologists, or organization scientists (Suchman 1983; Orlikowski 1992; Heath et al., 1994). In the 2000’s, several researchers acknowledged that the practice approach has influenced researchers in Information Systems and Human-Computer Interaction domains, that it is embraced in CSCW research - especially in its European tradition - and they discussed the growing interest in practice theory (Wulf et al., 2011; Nicolini 2012; Kuutti 2013; Kuutti and Bannon, 2014; Schmidt 2014):

> "The appeal of what has been variably described as practice idiom, practice standpoint, practice lens, and a practice-based approach lies in its capacity to describe important features of the world we inhabit as something that is routinely made and re-made in practice using tools, discourse, and our bodies. From this perspective the social world appears as a vast array or assemblage of performances made durable by being inscribed in human bodies and minds, objects and texts, and knotted together in such a way that the results of one performance become the resource for another" (Nicolini 2012, p. 2).

In this paper, we follow this tradition in two ways:

First, we embrace the practice lens to describe the situation we have observed. Indeed, the practice lens is particularly pertinent for the case we have studied, because it allows us to look at the recursive interaction between people, technologies and social action. We adopt the distinction made by Orlikowski (2000) between *technological artifact* and *technology-in-practice*, that avoids making any assumption about the stability of the technology, but instead focuses on what emerges as people interact with the property of a technology; as has been shown in a large number of studies, users can use a technology as it was designed, but they can also ignore certain properties, work around them, or invent new ones. *Technologies-in-practice* reflect this non stability as they are defined as a "set of rules and resources that are (re)constituted in people's recurrent engagement with the technologies at hand" (Orlikowski 2000, p. 407). In the project that we have followed, we were able to observe how a technology (the LogBook) was designed, but also this LogBook-in-practice, focusing on the different enactments of this technology in the OORC and the production sites. Orlikowski (2000) suggests three types of enactment: inertia, application, and change. *Inertia* reflects users showing little interest to the technology, not integrating its use in their working practice; *application* means that users use the new technology to improve their work practices without radically changing them; and on the contrary, *change* characterizes situations where the technology-in-practice transforms the practice.

Secondly, we will show in our analysis that the enactment of the LogBook-in-practice is inertia, and that this form of enactment is due to the ignorance of practices in their socio-material dimensions when designing and deploying the LogBook. We will then envision what would it mean to adopt a practice approach in such a project.

3 Context

3.1 A production spread all over the country

The company we have followed during its digital transformation process designs, builds and manages production units that produce gas for industries and healthcare. It has four hundred and forty-two sites all over the world, each site comprising one or more production units. We have studied the industry branch of this company in France, which comprises nineteen production sites: twelve with air separation units (ASUs) and seven with Steam Methane Reforming (SMR). An ASU functions this way: it sucks the air in, filters it, separates water and carbon dioxide, and compresses it. The pressurized air is cooled down to -173°C and liquefied. The different compounds of the air are then separated by distillation. The result is nitrogen, oxygen and, in some installations, argon and liquefied noble gases. These gases are then conveyed either directly via pipelines, or in liquid form by road transport. The gas can also be transported to packing centers for bottling. These "chimney-free" factories do not use any combustion process. They consume almost only electrical energy and emit almost no carbon dioxide, sulfur oxides, nor nitrogen oxides. In a SMR, natural gas is processed to remove sulfur and heavy hydrocarbons. The methane that is obtained is then introduced into a steam oven. The generated product, synthesis gas, or syngas, consists essentially of hydrogen and carbon monoxide. The hydrogen is purified, then distributed by pipes, or conditioned in semi-trailer batteries or in bottles, and sent by trucks.

The ASUs and SMRs spread over the country can be classified in three categories according to their volume of production: big, medium and small sites. Among the nineteen sites over the country, three are considered big (two of them are ASUs), seven are considered medium, and nine are considered small. In our observation work, we focused on six sites (two big and four medium ones) because they are at the same time complex (because of their size), and are following a standardized process, whereas smaller sites rely more on ad-hoc procedures.

3.2 A locally-managed production

Before the start of the project, the nineteen production sites were managed mainly locally, and were reporting to the global production department. Due to their history and local culture, each of the sites had its own practice. In particular, on the three big sites, shift work was adopted (three shifts of eight hours), whereas in smaller sites or more modern ones, an on-call duty was put in place.

In the big production sites, the work was organized as follows: a team of technicians was dedicated to the production, and another one to the maintenance. the production team was composed of productions managers and "pilots". The production managers were in charge of defining the production orders (the amount of gas that has to be produced) according to the demand of the clients and their wish to optimize their production. The term “pilot” is used in the industry to reflect the fact that a production unit is managed by a production system that employees have to “pilot”. In other words, the pilot has to ensure that the production unit delivers what has to be produced; it starts with the launch of production, and throughout the process, the pilot monitors everything that is happening on screens and analyzes the data. The pilot also conducts quality checks that allow him to detect any anomaly and to rectify the situation as quickly as possible. Pilots were then responsible of launching the production orders on the machines. In smaller sites, technicians were more flexible and not strictly affected to a “maintenance” or a “production” role.

The material artifact supporting the exploitation was different from one site to another; in one (small) site where shift work is applied, not any artifact is used to document the activity and share information. All the coordination work is orally supported, with a discussion during the shift. In most of the other sites, the technicians are using a paper-based notebook to collect what they call “the story of the site”.

As indicated before, the goal of the industrial project that we have followed is to connect all the production sites to a supervision and optimization center (OORC), which implies that the launch of production is decided by the OORC and not anymore by a local manager or a pilot.

4 Data collection and method

In order to understand the impact on the production and maintenance work of this shift from a locally managed production to a centralized production, and the role the artifacts that were put in place to support this new organization of work are playing, we have followed the project while it was progressing, during an entire year. We had the opportunity to observe the “participatory” design and the deployment of the LogBook, the digital artifact that was put in place to support the coordination between each site and the OORC.

As the project involves the OORC and the production sites all over the country, we adopted a multi-sited ethnography (Marcus 1995). We started with an observation of a design workshop that lasted two days in March 2017, in the company’s headquarters. This workshop gathered twenty-five participants from the OORC and the nineteen production sites, and was aiming at designing mock-ups of the LogBook. The mock-ups were related to features supporting the exchange of information about security and maintenance between the OORC and the production sites. This first observation allowed us to understand the supervision principles, and to interact with workers from both production sites and the OORC. We then spent forty days into the field, during which we conducted and recorded interviews and meetings, and took notes about the production and maintenance practices in the OORC and production sites (Table I).

Table I. Comparative table of observations on OORC and production sites.

OORC	6 sites (2 big and 4 medium)
23 days of observation	17 days of observation
Shadowing of 4 pilots and 3 analysts	Shadowing of 4 pilots and technicians
Recording and transcription of 74 min of meetings between OORC and sites	

These observations can be distinguished in three steps:

(1) a phase of contextualization in which we were able to understand the previous and the new organization of the production, both in the OORC and the six sites. We visited the OORC five times. The first visit took place at the end of March 2017, during which we conducted two interviews, lasting one hour each. The first one was with one of the pilots, who presented us the excel spreadsheet they were working with. The second one was with one of the analysts, and focused on the way the OORC was built and how the visualization interfaces were designed with the pilots and the analysts to present a global vision of the status of the production sites. Our second visit of the OORC took place one month later, and lasted 3 days, during which we observed all the remote meetings taking place between the OORC and the five connected sites. The third time, in July, we focused on the practices of the technicians. These series of observations lasted 3 days (18 hours). The first and the last day we interviewed technicians on their role and their interaction with the sites. The second day, we followed a pilot. During the fourth visit, we followed technicians during 4 days: the first and the last day, we followed two different pilots, the second day, we focused on a supply chain technician, and the third day, we observed the practice of the analyst. The fifth visit took place mid-October, during 5 days. We globally observed the OORC operating. This visit allowed us to assess previous analyses done on the previous observations we conducted. During our last visit (one day), we participated in a meeting between fifteen technicians in charge of production, which goal was to improve communication and interaction between sites. This first phase of observation and analysis allowed us to understand the new organization of work that we depict below.

(2) We then focused on three sites (one big and two medium ones, identified below as sites 3, 4 and 5) where we were confident to be able to collect precise data about the activities performed by the technicians, and about their use of the LogBook. During all these visits, we took notes and photos, recorded meetings and

interviews, that we transcribed. When looking at the corpus, we focused on the activities that are performed by the different actors, the artifacts that are used to perform these activities, and the type of information that is transmitted or exchanged through these artifacts.

(3) The last step concerned the use of the LogBook and consisted in collecting data from the system, on which we applied some statistical tools.

5 A new organization of work

In the newly created OORC, we can find two major roles: analysts that define the amount of gas that should be produced, and in which production units, and pilots that decide if the production can be launched.

Each week, the analysts collect all the data about the current situation (energy cost, production capacity, stock capacity, supply chain) and the clients' needs, for the whole country. To treat this complex situation, each analyst is focusing on a particular area: one analyst looks at energy, aiming at minimizing the consumption of energy by seeking an optimum, using the evolution of the cost of energy, the demands of the client, and the on-going production. Other analysts look at the production of liquid and gas, aiming at optimizing the production among the nineteen sites to cover the demands of the clients for gas and liquid. Finally, an analyst focuses on the supply chain, aiming at optimizing the delivery of gas products to the clients by tankers. These analysts aggregate all the collected data and run some optimization algorithms to define the production that should be launched (the amount of gas that is needed by the clients), and in which units it should be launched.

Pilots have then to decide if it sounds possible to launch the production that was defined by the analysts. In order to support this decision, "supervision interfaces" that allow to visualize the production in the different sites have been developed (Figure 2). These visualizations aggregate data coming from sensors put on production machines in the different units that, in particular, indicate the physical position of the controller and the levels of product coming out of the controller. When the pilots make a decision, they launch the production in the different units and inform the sites that manage these units.

Figure 2. Supervision interfaces in the OORC.

However, some data that is needed to check if the production can be launched does not come from the existing sensors, and some information is impossible to be sent automatically. This information can be perceived and analyzed only by a technician on site: indeed, for now, the fact that a machine cannot produce at its maximum capacity can be analyzed only by a technician that is hearing a strong noise, noticing some unusual temperature, some parts that are not functioning well … In the same way, only the local technicians have the necessary expertise to analyze the impact of the weather on the production capacity of the production unit.

Facing this need to collect information from the site and to coordinate the work between the OORC and the sites, several coordinative practices and related artifacts (Schmidt 2011) have been put in place:

- Weekly meeting (each Thursday) between the OORC and each site, lasting from 5 minutes to 1 hour depending on the complexity of the situation and the size of the site: the pilot from the OORC calls the pilots on site to discuss if the production order that has been defined by the analysts is feasible.
- Ad-hoc phone calls from the OORC to a site in two situations: when the production order has to be changed during the week, or when they need the site's perspective to be able to interpret something that they have noticed on their supervision interfaces.
- The LogBook that has been developed in order to support this interaction between the sites and the OORC.

6 Supporting the digital transformation through the LogBook

6.1 LogBook: the technological artifact

The LogBook has been designed by the gas company, with the help of a start-up specialized in UX Design, following an agile method and involving workers from the production sites during design workshops. The aim of the design workshops was to gather technicians from production sites and from the OORC in order for them to define the "ideal" graphical user interfaces to support their work, following the new organization that we described in the previous section.

As we indicated above, we took part in one of these design workshops, and got access to the document describing the intended features of the LogBook that was written after the workshop took place. Three objectives were identified in this document:

- Centralizing, reporting, and easily sharing the information that is needed for the exploitation of the sites;
- Sharing crisis information for exploitation (security, availability of equipment ...);
- Making use of this information to decide which are the appropriate actions (creation of a maintenance intervention, adjusting the production plan, dispatching liquid etc. ...).

To reach these objectives, five main features were defined, and implemented in the LogBook that was deployed:

1. *Profile management*. There are three profiles on the LogBook: SITE, OORC, and VARIOUS. A user with a SITE profile can create an event and read the events created by the OORC that concern this site; the OORC profile allows to create an event and read all the events created by all the sites; the VARIOUS profile does only permit to read events.
2. *Community management*. A group of workers from a same business function (analyst, energy buyer, supply chain manager, direction…), or from a specific site is called a "community". Each member of a community can visualize flows of events related to her/his community.

3. *Posting an event*. The creation of an event is done by filling in a form with mandatory and non-mandatory fields, some of them being pre-filled, editable or not (Figure 3). When creating an event, one has to first select a category (client, incident, liquid event, maintenance, energy, billing, efficiency) and then select one or more communities. The events are editable and the history of editions is visible. An event can be associated to an action, that defines a task that has to be done to solve the problem that was described in the event. For instance, a leak of gas can be reported as an event, and the need to close a valve can be recorded as an action related to this event. Documents can be attached to an event in order to better describe it (picture, scan...).

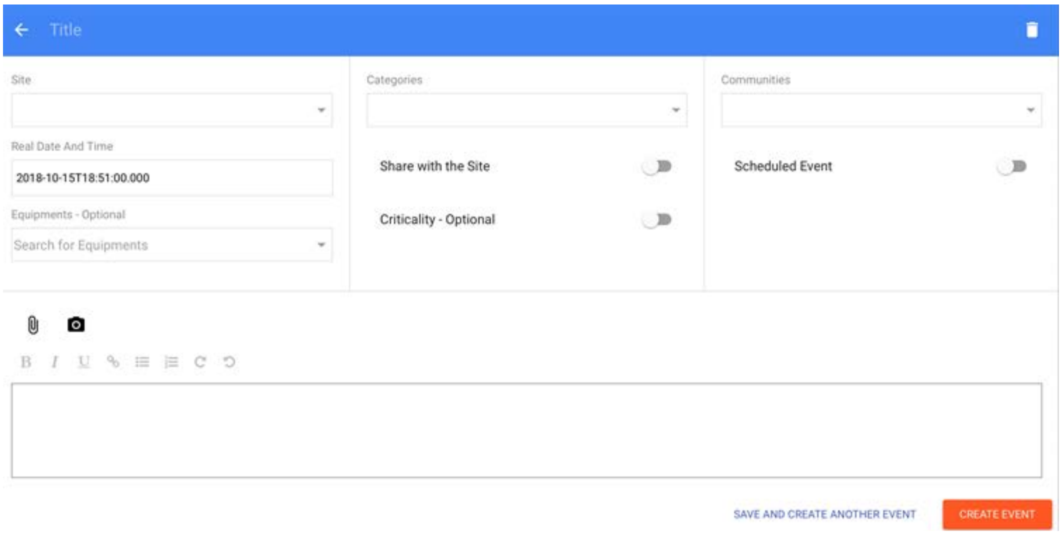

Figure 3. Form for creating an event.

4. Visualizing events. The LogBook lists all the events that can be filtered by author (OORC or SITE) or can be sorted by the date of creation of the event in the LogBook, or by the date of the event itself. In fact, an event can be documented some hours after it happened, and some events document actions that are scheduled for later on. (Figure 4).

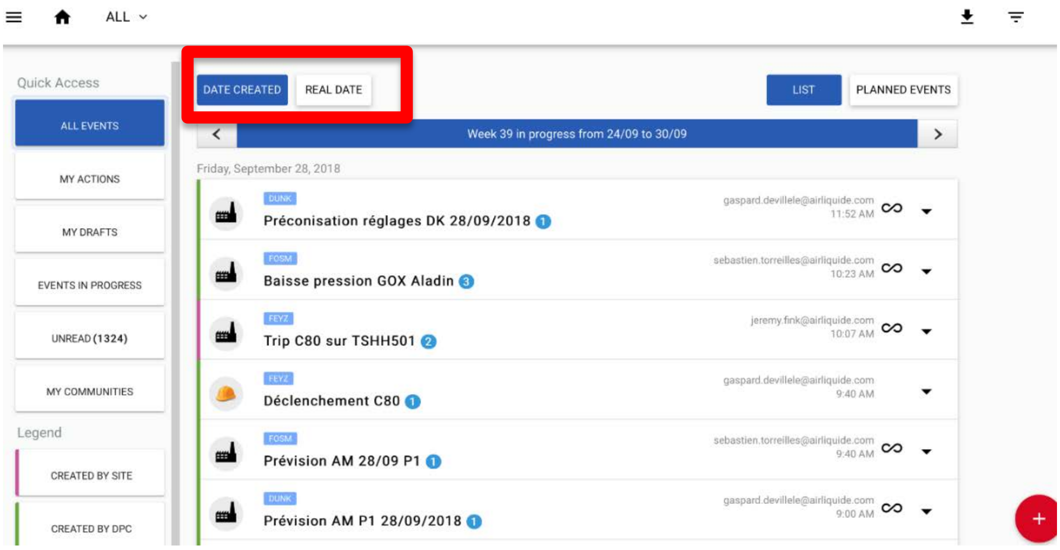

Figure 4. List of events (OORC profile) that can be organized by the date they have been created of the real date of the event.

5. Searching an event. Events can be searched by keyword, by the name of the event, by its number, by author, date, category, site, status (to come, to do, action completed...), equipment.

6.2 LogBook-in-practice

When the LogBook was deployed in the different production sites, training sessions were conducted by the project manager, but no written manual was distributed.

It was planned that the technicians on sites will use the system via a tablet to report on the way they manage the machines to face the production orders: the availability of the equipment, their conditions, limitations and information relating to ongoing or future maintenance activities. For example: which valve has been closed or opened, which cooler or which pump has been stopped or started, which incidents arose, and, depending on the moment of the incident, which calls have been done to technicians, which maintenance operation has been done ... On site, technicians must always share information between different teams and specialties, and for so doing they are using different means, depending on the sites (see section below for a description of documentation practices before the introduction of the LogBook). The management team has presented the LogBook as the only documentation tool, even inside a site, replacing other existing documentation practices such as paper-based notebooks, post-it notes, or shared spreadsheets.

6.2.1 LogBook-in-practice in the OORC

The OORC is the first contributor in the LogBook. Indeed, since its launch, 4410 events were created, among which 2644 were posted by the OORC, with the remaining ones from the production sites (Figure 5). That represents more than fourteen posts per day for the OORC (and less than six for the nineteen sites).

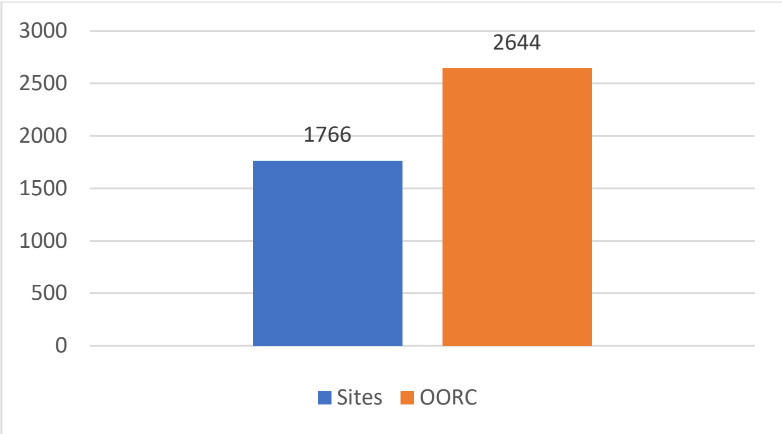

Figure 5. Comparison of the number of events created by the OORC and the 19 sites over a period of 304 days (from nov. 2017 to sept. 2018).

During our visits in the OORC, we noticed that the LogBook is one of the main tool for the pilots,: they post all the important changes in the settings of the sites' machines, and they frequently have a look at the LogBook, in particular during the phone calls with the sites. The analysts and the manager use the LogBook to get an understanding of the current state of a site and define the production order.

On the week 14 of 2018, it was decided that the OORC will apply shift work (3*8) in order to be constantly available. We noticed that it was followed by a new way of using the LogBook: the pilot now creates a report to transmit the information from one team to the following one. This report contains a description of everything that happened (all the incidents, calls from clients…) during their shift and if they had to change values of some of the machines in a production unit. They start this report with some words for the next team (e.g. "Good morning").

We can notice the impact of the evolution of the organization of work (the adoption of shift work) on the use of the LogBook while looking at the evolution of the number of events created; more events are created since this change (see the grey line on Figure 6), but these events are addressed to their colleagues in the OORC (see orange line on Figure 6).

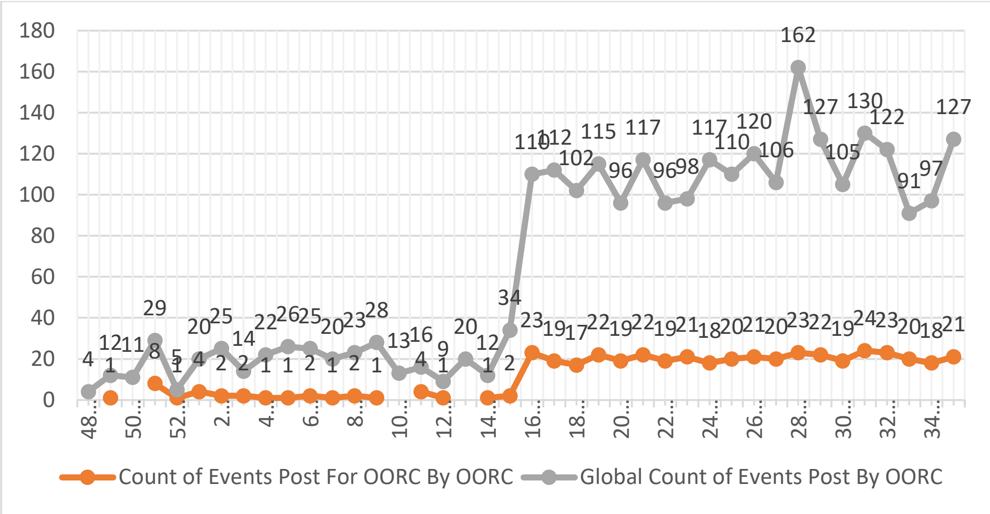

Figure 6. Comparison between the total number of events posted by the OORC and the part of these events that are addressed to itself.

By looking at the statistical dispersion of the events posted by the OORC, we also notice that after week 14 of 2018 (when shift work was put in place), the events tend to be posted at the same hour each day (Figure 7). This reinforces the previous observation: the evolution of the organization of work in the OORC had an impact on the use of the LogBook. So despite the LogBook being presented as a tool to support communication and coordination between the OORC and the different sites, the LogBook-in-practice in the OORC is supporting coordination from one OORC team to the next one.

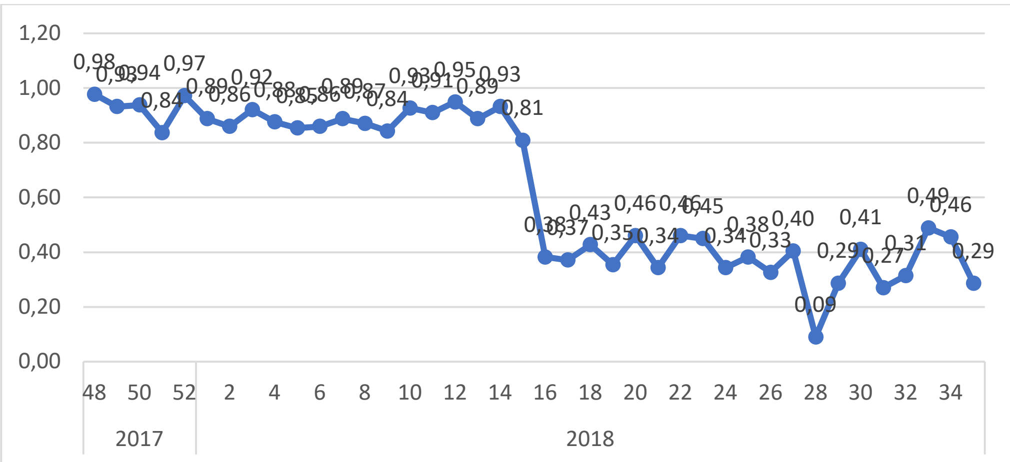

Figure 7. Gini index of dispersion by week. The Gini index varies from 0 to 1, where 0 means perfect equality (regularity) and 1 means perfect inequality (irregularity) (Nisbet et al. 2009).

6.2.2 LogBook-in-practice in the sites

On site, we have observed three different reactions after the introduction of the LogBook: (1) a direct transition to this digital artifact, (2) the use of a paper-based notebook (see below) in parallel with the LogBook, or (3) no use at all.

When looking at the data from the LogBook (from the 45th week of 2017 to the 35th week of 2018), we see a different use among the nineteen sites, in particular: the big sites post more events than the small ones, six sites (sites 2, 8, 11, 17, 18, 19) have not posted any event, and four sites (7, 9, 15, 16) have shared very few events (less than 25 in the observation period) (Figure 8).

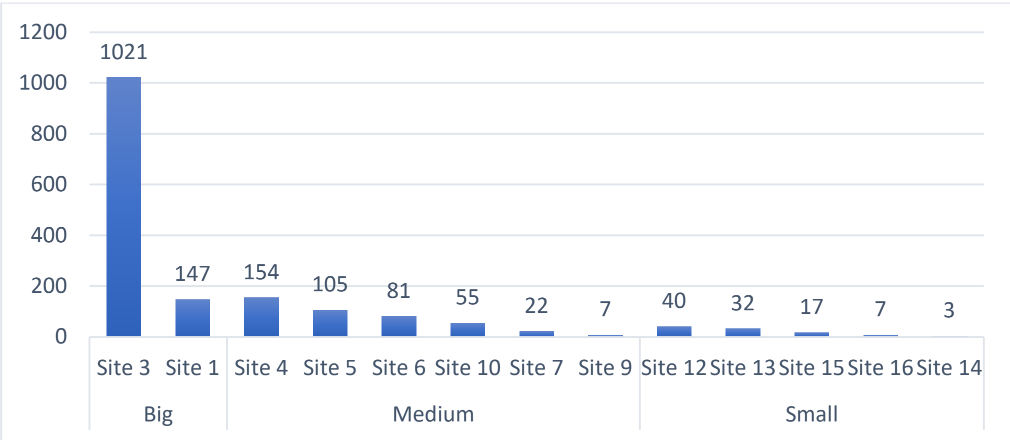

Figure 8. Number of events shared by the different sites.

We then looked at the mean number of characters used in the posts, to check if the sites that post less events are, on the other hand, posting more detailed events. If so, it would mean that some sites do not post often, but wait and submit longer posts that present a synthesis of the activity on site, whereas other sites post more often, as they create an event each time it occurs. But we did not notice any significant difference in the mean number of characters in the posts: the sites that do post less event do not post longer and more detailed events (Figure 9). We can then conclude that the use of the LogBook to report the activity of the production sites is different from one site to another.

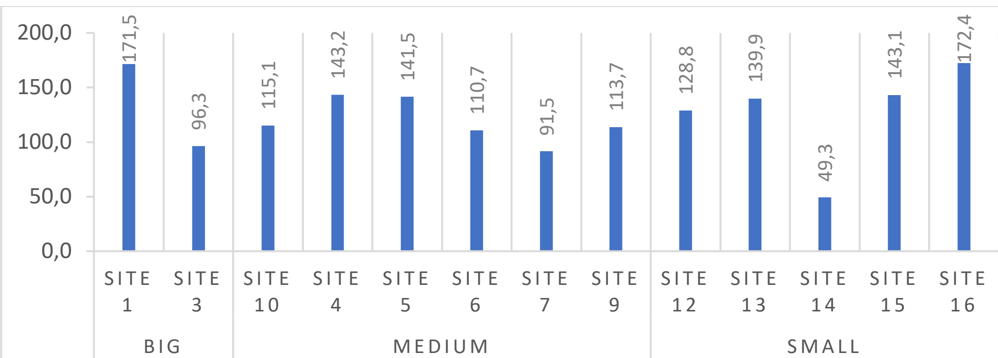

Figure 9. Mean of the number of characters to describe an event for the different sites.

In our observation work, we were able to notice the characteristics of site 3, that explain the larger amount of posts. First, site 3 benefits from a higher staff level, thanks to the evolution from shift work to call-on-demand work without any reduction of the workforce. This allowed the management of the site to dedicate time to the use of the LogBook, which is now integrated in the activity of the site in two ways: (1) the pilot of the site is responsible of a new task that consists in writing down everything that occurs on site; (2) after each morning meeting during which all the workers on site update their knowledge on the production unit(s), minutes are written and are shared on the LogBook.

This contrasts with site 5, in which the technicians are still using a paper-based notebook to keep and share all the information about the functioning of the site. It is only when the technicians estimate that an information is important for the OORC (because it has a potential impact on the supervision of the production), that they create an event on the LogBook.

Concerning the sites that post less events, two issues were collected during the interviews, that we describe below. These issues are related to the way the LogBook captures the activity of a production site; the first one is related to the accuracy of the information to be found in the LogBook, and the second one is related to the ability of the LogBook to depict an up-to-date situation of a production site.

As we mentioned earlier, it is possible to post an event after it occurred, and to indicate its real date, which means that, when it is needed, an event posted on the LogBook has two dates: when it occurred and when it was posted. This feature was added to the LogBook after its deployment because the sites asked for it; the technicians used to write down on their paper-based notebook all the events at the end of the day, indicating at which moment each event took place, and they asked the new feature in order to be able to stick to their existing routine, even if the way the production is managed has changed drastically. The data from the LogBook confirms that for some of the sites, the practice has not changed even if the LogBook was introduced: there can be a seventeen hours' difference (site 9) between the moment an event occurs and the moment it is posted into the LogBook (Figure 10). It then means that the LogBook cannot be used by the OORC to get an instant picture of what is going on a production site.

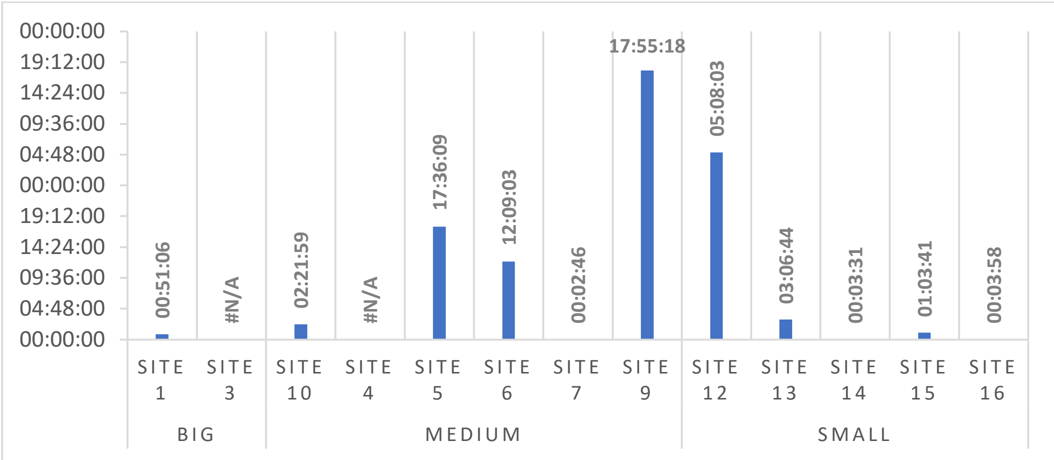

Figure 10. Average time difference between the exact time of the event and the moment it was posted on the LogBook by the production site.

The other issue was raised by a manager in the OORC and concerns the use of the LogBook by the technicians on sites to get a clear picture of what happened to a production unit when they start their day. Technicians look at the LogBook in order to understand the state of their production unit, and the events that may have occurred, in particular if they were called for an incident during the night or over the week-end. However, during an incident, they have to intervene as fast as possible, and they do not have a lot of time to read the LogBook, so they check the current state of the unit without looking at the previous events that were recorded. This can have consequences on the functioning of the unit:

> "[…] I just had a call with [SITE]. […] [SITE] has just started calls-on-demand and at the same time to use the LogBook. […]. They realized last week that someone has stopped and restarted a piece of equipment in the morning and the team in place noticed that only after midday, when one of them decided to create an event. He then saw the previous event that has been created. […]. The control room remains the center of the production unit, the place where information is shared so it is necessary to set up a large screen depicting the LogBook so that every member of the team can stay informed without having to log into the LogBook (like it was done with the paper-based notebook that was in the control room). […]" (a manager of the OORC)

Finally, whereas site 3 has integrated the use of the LogBook in its daily activity, its manager gave us negative feedback when comparing the use of the paper-based notebook and the LogBook:

> "The LogBook is not usable: you cannot easily navigate and find your way, you cannot edit your posts, nothing is predefined. If I am looking for a particular call-on-demand, I cannot find it, and we should be able to find these events. It is important that we define and use a shared syntax. Between the paper-based notebook and the LogBook, we have lost a huge amount of information. When the paper-based notebook will have disappeared, it will mean that the LogBook is appropriate. Sometimes, if you do not have the time to post an event, then the things that will be posted will be wrong (and you cannot edit them afterwards). I was the first one suggesting a shared notebook…"

The fact that less information is put in the LogBook, or that this information is not accurate, not up-to-date, or not accessed, implies that the OORC can collect less information about what is going on in the sites, and is less able to remote control it, and still needs to call the sites on the phone and to schedule meetings, which is time-consuming and does not allow a good traceability of the negotiations and decision-making processes. We then tried to understand why, even if the coordination and traceability are needed, the digital tool that was user-centered designed is not really enacted in practice.

7 Analysis – a design process that ignored the existing documentation practice

When we started visiting the different sites, they were not all connected to the OORC, and the LogBook was only deployed in one site. We were then able to observe the documentation practice before the organizational change. When following the deployment of the LogBook and collecting the problems related to its use as reported in the previous section, it became obvious that the workers had issues with the fact that the design of the LogBook ignored the existing documentation practice. Designers clearly adopted a "solution-first approach" (Rosson and Carroll, 2009) in which they have simplified the problem space, and have generated a solution quickly, by reusing familiar solutions (a form), without analyzing the actual documentation practice. Yet, "even if users constitute a technology-in-practice through their present use of a technology, their actions are at the same time shaped by the previous technologies-in-practice they have enacted in the past" (Orlikowski 2000, p. 410).

As we described earlier, before their connection to the OORC, each site was autonomous, and had its own history (some sites were bought from other companies). The way they were managing their exploitation was then different from one site to another. In only one (small) site, not any artifact was used to document the story of the site and to share information, and all the coordination work was orally supported, with a discussion during the shift. In most of the other sites, the technicians were using a paper-based notebook. We noticed the use of this paper-based notebook in the six sites that we visited. We are now going to describe the documentation practice involving this paper-based notebook, followed by the first experiment of its digitization in three sites.

7.1 The documentation practice before the introduction of the LogBook

7.1.1 Keeping track of all the events

In the paper-based notebooks, the events were written in a chronological order, with a different page for each day (Figure 11).

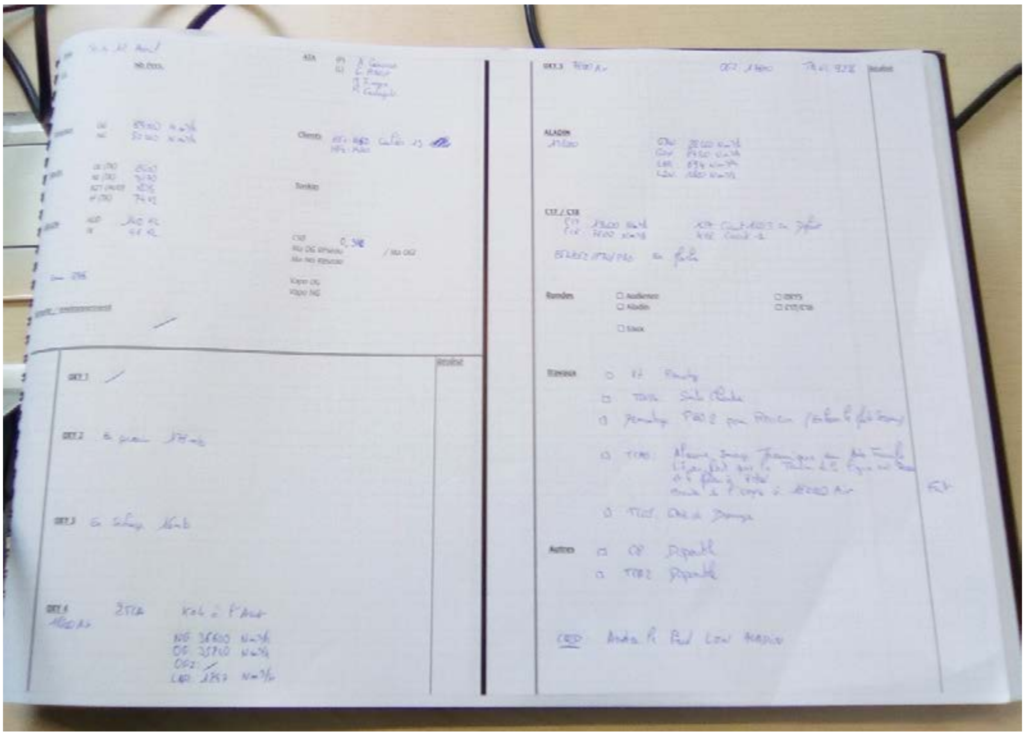

Figure 11. Paper-based notebook for site 1.

If we compare this traceability to the LogBook-in-practice in the sites, in which in average less than six events were created each day (Figure 5), we can say that the paper-based notebook allowed to keep track of all the details of the activity on site, whereas the LogBook does not allow that.

7.1.2 Identifying the striking elements of the activity

To complement this “story”, documents were added to fully describe an event. For example, each time a team had to stop the production unit, they collected documents describing the event: a problem with resetting an engine, a new process, a state of the machine… and stuck them to a page (Figure 12). On top of adding a level of description, the interesting feature of this collage was that it allowed the technicians on site to easily go back to this event to look at what happened. They used the attached documents as bookmarks to find the striking moments of the site.

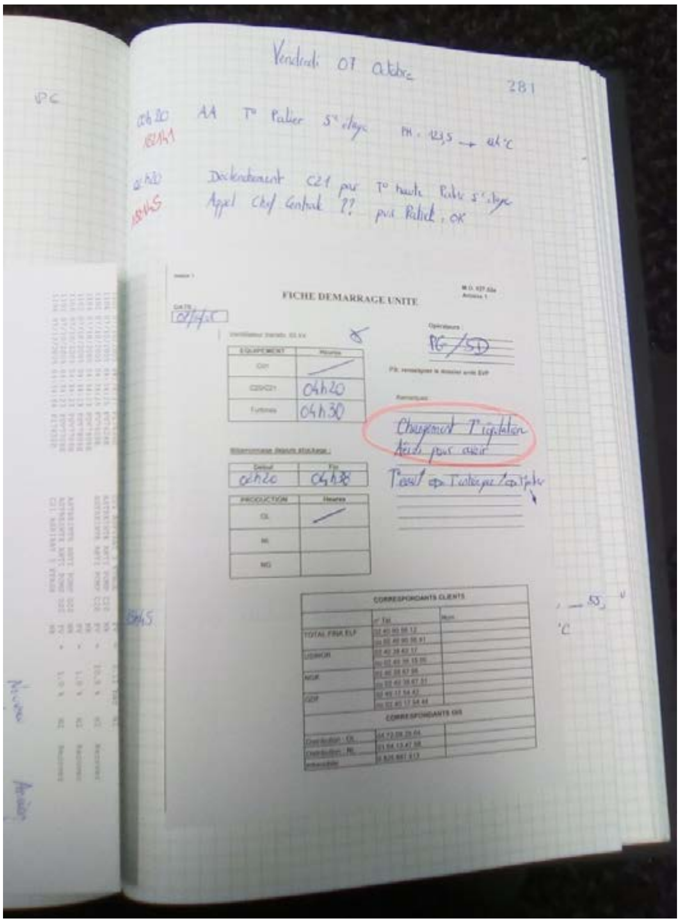

Figure 11. Paper-based notebook from site 5 with a glued card about the reboot of a unit.

In site 3, we noticed that to complete the page on the right which was used to list all the events that happened during a day in a chronological order, the page on the left was used to write a summary of the day, listing the most important events, like the production launches, the shutdowns, ... On this site, the production manager also had his own notebook, and was using it in order to keep track of the different production orders he was deciding to launch.

7.2 A bottom-up digitization of the paper-based notebook

At the beginning of the project, in order to conduct a proof of the concept of remote supervision of production, the site 10 (a medium one) has been connected to the sites 13 and 15 (small ones that are situated no longer than five kilometers away) in order to supervise them. We were able to observe how information was documented and transmitted among these three sites during this transition, so before the introduction of the LogBook. Before the connection, each of the three sites was using a paper-based notebook.

As soon as site 10 started to supervise the two small sites, the three teams were combined in one, and technicians felt the need to be aware of what has been done in each of the three sites, without having to be on the site.

For so doing, they decided to create a shared spreadsheet (the company is using G Suite) among the three sites (Figure 13). This spreadsheet had four tabs, one for each site, plus one called “recap”. The tab for a site allowed the technicians to report all the events that occured on this site, at any moment, whereas the recap one allowed to write a summary of each day, for the three sites, and then provided an overview of the activity.

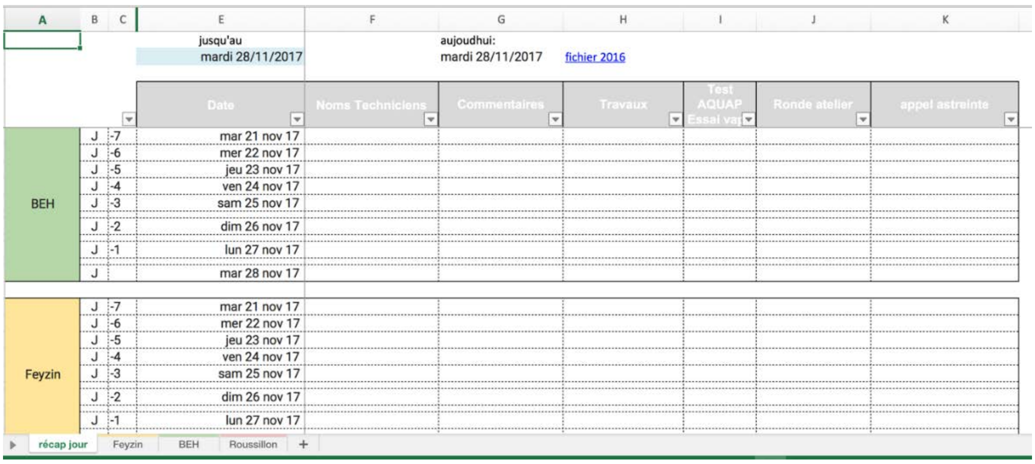

Figure 12. Shared spreadsheet between sites 10, 13 and 15. We can see the “recap” tab.

We can notice here that when the technicians of three sites had to coordinate their work, they felt the need at the same time to keep track of all the events on each site, which digitized the practice that we described in section 7.1.1, and to define what should be synthesized to transmit information from one team to another, which digitized the practice of site 3 that we described in section 7.1.2. So, in other words, when the technicians decided to create a digital artifact to support their evolving work, they were inspired by the existing documentation practice, contrary to what was done when the LogBook was designed.

8 Discussion

When comparing the existing documentation practice and the LogBook, we identify that the design process of the LogBook, with the related design workshops that were conducted, focused on defining which type of information has to be collected and in which form, rather than on defining how this information would support the coordination between the OORC and the sites, and moreover, how the shift from a paper-based notebook to a digital artifact would still support the management of a production site.

As we depicted above, one of the directors of a site, and all the technicians we met, told us that their major issue with the LogBook is that it does not allow to get an overview of what has been done in the production site for the last weeks, or months. They used to look for events in the paper-based notebook to identify what has been done in a similar situation, or to identify patterns; in other words, they were looking for the *story* of the sites. For the moment, the story is obviously not there because the sites have just started to use the system, but more importantly, its users have identified that their existing documentation practice conflicts with what the OORC is waiting for in terms of traceability.

More precisely, the notion of *event* seems to be conflicting: for the pilots in the OORC, an event that has to be posted in the LogBook by the production unit describes what has been done by the technicians to launch the machines. Pilots in the OORC want to know if the production instructions have been executed, and want to get the updated status of the site. Indeed, they are constantly connected to the LogBook, and follow the events in real-time, in order to get a confirmation of the actions that are undertaken in the units. On the contrary, as we showed above, the technicians in the units were used to document every action that happens on site. For instance, any part of the machine (valve, pump, …) that has to be repaired, who has fixed it, and how it was fixed, was recorded. In other words, the vision of what needs to be documented differs between the OORC and the technicians from the sites. We discuss these outputs of our analysis below.

8.1 A standardization issue

In our understanding, this conflicting assumption of what is an event relates to a standardization issue (Ellingsen et al., 2007). In fact, even if it was not communicated this way to the sites, the supervision of the production by the OORC implies a standardization of the production process in all the nineteen connected sites. For CSCW research, standardization should not boil down to a technological issue, but should rather be seen as a negotiation process between technical artefacts, social dynamics, and physical places where people work (Pedersen 2012), (Orlikowski 2007). However, we have noticed that the design workshops with the technicians did not include any discussion about the differences in the physical layout of the production sites (in particular the place of the control room where the technicians meet and share information), nor the differences in the documentation practices. Therefore, the issue of the standardization of the production has been limited to the definition of the features of the artifact that could support it. Consequently, the LogBook that was designed to complete the formal information collected through sensors in order to avoid relying on local interpretive work from the sites (as described in section 5) failed to play this role; indeed, during our stays in the OORC, we noticed that before remote-launching the production in a site, the OORC always calls this site to check the feasibility, because they cannot rely on the events documented in the LogBook.

So, even if the initial goal of the organization was to provide an artifact supporting the coordination between the OORC and the sites, and tracing all the events that can influence the production launches, the introduction of the LogBook clearly struggles with the documentation practices of the exploitation and maintenance technicians in the sites; our analysis highlights that the OORC and the sites do not have the same definition of *what* to trace and *when* or *how* to trace it. In other words, the key relationship between the design of the system and the design of the organization (Button and Sharrock, 1997) has not been considered.

8.2 The LogBook, a compilation artifact that is not integrated in a practice

The conflicting definition of an event, and the limited use of the LogBook-in-practice in the sites can be analyzed further: we are facing collaborators from different communities of practice (pilots from production units vs from OORC) who are using material artifacts to collaborate: the paper-based notebook and the LogBook. But while the paper-based notebook supported the collaboration in one place (the site), the LogBook aims at supporting the collaboration between two places, the site and the OORC. The project for the digital transformation of the factories then replaced an artifact by another one, but what was overlooked is the fact that the perimeter was not the same. To go further, if we follow the categorization proposed by Charlotte Lee in the “boundary negotiating artifacts” framework (Lee 2007), the LogBook is a *compilation artifact*, supporting an alignment process between two or more communities of practice in order for them to “develop a shared and mutual understanding of a problem and to pass crucial information from one community of practice to another.” (Lee 2007, p. 323). But we are facing exactly the same phenomenon as the one Lee noticed: “the practices surrounding compilation artifacts were not well-developed and required the development of new practices. This resulted in confusion and conflict.” (p. 333).

In conclusion, what is missing is the definition of the new documentation practice that fits the new organization of work.

8.3 The need to “turn to practice”

In the case that we described, we observe different communities of practice; the practice of “piloting” a production is performed differently in the different production units and in the OORC. We are facing a network of practices (Button and Harper, 1995) rather than a single practice. This complexity was clearly not acknowledged in the project, and the intermediary position that is adopted when conducting practice-based research (Wulf et al., 2011) is missing. In fact, in this “Industry 4.0” project, the new organization of work has been clearly defined in terms of roles and decision-making processes, and some design workshops have been conducted, with mock-ups, in order to collect the “needs” of the users (technicians, analysts, production pilots). However, these approaches “privileging individualistic “user needs” or macro-level “organizational systems” are no longer sufficient, as we grapple with the complexities of digital ecologies and usage practices” (Kuutti and Bannon, 2014, p. 3550). Adopting a practice-based approach would mean to focus on “normatively governed contingent activities” (Schmidt 2014, p. 9) in the production units, and the “routinized way in which bodies are moved, objects are handled, subjects are treated, things are described, and the world is understood” (Schmidt 2018). By so doing, the materiality of the documentation practice that was overlooked in the project that we have followed would have been tackled, and it would be possible to accompany the dynamics of the digital transformation of this company.

8.4 Implications of a turn to practice

By adopting a practice lens, we mainly decenter the human, and include materiality, which means first to not focus the analysis on the workers, but on their practice that becomes the basic unit of analysis, and secondly to not focus on the technological artifact but rather on the technology-in-practice, so how the technology is enacted.

As we presented in section 2.2, Wanda Orlikowski has identified three different forms of enactment of a technology-in-practice: *inertia* and *application* that do not transform the practice, and *change* that implies that the intense use of the technological artifact is accompanied by the adaptation of the artifact by the users, and a modification of their work practices.

Among the nineteen sites, only one (site 3, see section 6.2.2) could be considered as having *applied* the LogBook-in-practice; the artifact has been integrated into the work practice, is used, and the previous documentation practice was transformed (they do not have any paper-based notebook anymore). In twelve sites, we can characterize the enactment of the LogBook-in-practice of *inertia*, as the use of the artifact is limited, conflicts with the use of the paper-based notebook, and workers express an incomprehension of how, when, and for how using the LogBook. Finally, six sites do not use the LogBook at all.

In the Industry 4.0 context, it is obviously the *change* enactment that should be aimed at, which means that users should be able to customize and/or adapt the technological artifacts that will, by then, allow to experiment with new ways of working. Indeed, it will only be “through the repeated reinforcement by the community of users that technology-in-practice will become institutionalized [and by then] will be treated as predetermined and firm prescriptions for social action, and as such may impede change” (Orlikowski 2000, p. 411).

To tackle this socio-technical design challenge, we suggest to adopt the “sociomaterial–design” analytical toolkit that consists in treating the Logbook as a sociomaterial artifact, and to examine how it bounds: (1) with other artifacts, (2) with locations (3) with people’s movement (Bjørn and Østerlund, 2014). Adopting this toolkit would involve identifying, for each production unit, the interrelated practices of producing gas and of documenting this production, including the physical locations where these practices take place, the different paths that workers follow in the production unit, and an exhaustive list of the material artifacts included in these practices. This identification should be followed by a negotiation among the different communities of practice (units and OORC) about the intended production practice, and about the different configurations of the LogBook that should be offered to the different sites, according to the different social organizations, physical layouts, and existing material artifacts in these sites. These local adjustments would rely on the organizational context shaping the local practice. By having the possibility to adjust local properties of the technological artifact, users should be able to enact a technology-in-practice that will accompany the transformation of practice, from a local organization of the production to a supervised production of gas.

9 Conclusion

In this paper, we describe and analyze the case of an “Industry 4.0” project supported by public funding in France. We contribute to this area of research by describing, analyzing and discussing the LogBook, a potential transformative artifact (Wulf et al., 2018) which limited use did not permit the transformation of the work practice.

We followed the deployment of the LogBook, that, despite being the result of a user-centered design process, is only partly used and has not widely become a *technology-in-practice*. We compared this digital artifact to the existing paper-based documentation practice that was overlooked during the design process. We discuss our findings by first identifying a standardization that failed because it focused on the deployment of a technological artifact instead of being the result of a negotiation process between technical artifacts, social dynamics and physical places. Secondly, the boundary negotiating artifact framework allow us to describe the LogBook as a digital compilation artifact that was intended at replacing a paper-based compilation artifact, but failed doing so because it is not supporting the negotiation of the same boundary. We finally claim that these issues are related to the fact that the company did not *turn to practice* when trying to digitally transform its activity. We then argue that CSCW researchers have a role to play in the digital transformation of industry, by encouraging this “turn to practice”, that would allow the industry to understand the dynamics of its transformation, and the role of digital artifacts in the emergence and the transformation of practice (Kuutti and Bannon, 2014). We suggest to adopt the sociomaterial-design analytical toolkit that could support the negotiation of the intended practice and the definition of local configurations of the LogBook to permit a different LogBook-in-practice for each community of practice. We claim that this is the only condition to observe an enactment of this technology that would allow a transformation of practice.

To conclude, by this paper we contribute to the discourse on the digital transformation of the industry that claims that practice will change “through” the use of digital technologies. Our posture towards this discourse is to focus on the forms of enactment of these emerging technologies, and to adopt a sociomaterial perspective to find ways of ensuring a negotiation of the intended practice together with a local adaptation of the technology.

Acknowledgement

This research was funded by the project CONNECT, as part of the programme “Investissements d’Avenir” (PIA) from the French government, operated by the Banque Publique d’Investissement (BPI).

We would like first to acknowledge the anonymous reviewers of this paper who led us to clarify our position, by so doing who led us to re-shape the argument we make in this paper.

We also want to mention three inspiring situations for our reflection: (1) the presentation “From leading edge towards blunt edge of technology research: challenges of artefact-based HCI” by Kari Kuutti (research seminar, University of Oulu); (2) the interaction with Richard Harper while writing a workshop proposal on “working in AI environments” for the CIFAR (Canadian Institute of Advanced Research); (3) the discussion among the panelists gathered by Volker Wulf at ECSCW 2018 around the topic: “CSCW in Manufacturing Environments: Towards a European Research Agenda”.

References

Ackerman, Mark S. (2000). The intellectual challenge of CSCW: the gap between social requirements and technical feasibility. *Human–Computer Interaction*, vol. 15, no. 2-3, pp. 179-203.

Bartodziej, Christoph Jan (2016). *The Concept Industry 4.0: An Empirical Analysis of Technologies and Applications in Production Logistics*. Wiesbaden: Springer Gabler.

Bjørn, Pernille; and Carsten Østerlund (2014). *Sociomaterial-Design: Bounding technologies in practice*. Cham: Springer.

Brettel, Malte; Niklas Friederichsen; Michael Keller; and Marius Rosenberg (2014). How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 Perspective. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, vol. 8, no. 1, pp. 37–44.

Button, Graham; and Richard Harper (1995). The relevance of ‘work-practice’for design. *Computer Supported Cooperative Work (CSCW). An International Journal*, vol. 4, no. 4, pp. 263-280.

Button, Graham; and Wes W. Sharrock (1997). The production of order and the order of production: Possibilities for distributed organisations, work and technology in the print industry. In J. A. Hughes, et al. (eds): *ECSCW’97. Proceedings of the Fifth European Conference on Computer-Supported Cooperative Work, 7–11 September 1997, Lancaster, U.K.* Dordrecht: Kluwer Academic Publishers, pp. 1-16.

De Carvalho, Aparecido Fabiano Pinatti; Sven Hoffmann; Darwin Abele; Marcus Schweitzer; Peter Tolmie; David Randall; and Volker Wulf (2018). Of Embodied Action and Sensors: Knowledge and Expertise Sharing in Industrial Set-Up. *Computer Supported Cooperative Work (CSCW)*, vol. 27, no. 3, pp. 875–916.

Ellingsen, Gunnar; Eric Monteiro; and Glenn Munkvold (2007), Standardization of work: co-constructed practice. *The Information Society*, vol. 23, pp. 309-326.

Fuchsberger, Verena; Thomas Meneweger; Daniela Wurhofer; and Manfred Tscheligi (2017). Apply Now!: Fictional Job Postings As an Instrument to Discuss Interactive Futures of Work. In *DIS '17. Proceedings of the 2017 Conference on Designing Interactive Systems, 10-14 June 2017, Edinburgh, U.K.* New York. NY, USA: ACM, pp. 581–586.

Harper, Richard H. R. (2000). The Organisation in Ethnography –A Discussion of Ethnographic Fieldwork Programs in CSCW. *Computer Supported Cooperative Work (CSCW). An International Journal*, vol. 9, no. 2, pp. 239–264.

Heath, Christian; Marina Jirotka; Paul Luff; and Jon Hindmarsh (1994). Unpacking collaboration: the interactional organisation of trading in a city dealing room. *Computer Supported Cooperative Work (CSCW). An International Journal*, vol. 3, no. 2, pp. 147-165.

Hughes, John A.; Dave Randall; and Dan Shapiro (1992). From ethnographic record to system design. *Computer Supported Cooperative Work (CSCW). An International Journal*, vol. 1, no. 3, pp. 123–141.

Karasti, Helena (2001). Bridging Work Practice and System Design: Integrating Systemic Analysis, Appreciative Intervention and Practitioner Participation. *Computer Supported Cooperative Work (CSCW). An International Journal*, vol. 10, no. 2, pp. 211–246.

Kassner, Laura; Pascal Hirmer; Matthias Wieland; Frank Steimle; Jan Königsberger; and Bernhard Mitschang (2017, January). The social factory: connecting people, machines and data in manufacturing for context-aware exception escalation. In *Proceedings of the 50th Hawaii International Conference on System Sciences, 2017.*

Kuutti, Kari (2013). “Practice turn” and CSCW identity. In Korn M. et al., (eds): *ECSCW 2013. Adjunct proceedings: the 13th european conference on computer supported cooperative work, 21–25 Sept 2013, Paphos, Cyprus.* Denmark: Department of Computer Science, Aarhus University, Aarhus, pp. 39–44 (DAIMI PB—596).

Kuutti, Kari; and Liam J. Bannon (2014, April). The turn to practice in HCI: towards a research agenda. In *CHI '14. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 26 April - 01 May 2014, Toronto, Ontario, Canada.* ACM, pp. 3543-3552.

Lee, Charlotte P. (2007). Boundary Negotiating Artifacts: Unbinding the Routine of Boundary Objects and Embracing Chaos in Collaborative Work. *Computer Supported Cooperative Work (CSCW). An International Journal*, vol. 16, no. 3, pp. 307–339.

Ludwig, Thomas; Christoph Kotthaus; Martin Stein; Volkmar Pipek; and Volker Wulf (2018). Revive Old Discussions! Socio-technical Challenges for Small and Medium Enterprises within Industry 4.0. In *ECSCW 2018 Exploratory Papers. Proceedings of 16th European Conference on Computer-Supported Cooperative Work-Exploratory Papers, 4-8 June 2018, Nancy, France.* European Society for Socially Embedded Technologies (EUSSET). Reports of the European Society for Socially Embedded Technologies: vol. 2, no. 1.

Marcus, George E. (1995). Ethnography in/of the World System: The Emergence of Multi-Sited Ethnography. *Annual Review of Anthropology*, vol. 24, no. 1, pp. 95–117.

Nicolini, Davide (2012). *Practice theory, work, and organization: An introduction*. Oxford: Oxford University Press.

Nisbet, Robert; John Elder; and Gary Miner (2009). *Handbook of statistical analysis and data mining applications*. Academic Press.

Orlikowski, Wanda J. (1992). The duality of technology: Rethinking the concept of technology in organizations. *Organization science*, vol. 3, no. 3, pp. 398-427.

Orlikowski, Wanda J. (2000). Using technology and constituting structures: A practice lens for studying technology in organizations. *Organization science*, vol. 11, no. 4, pp. 404-428

Orlikowski, Wanda J. (2007). Sociomaterial practices: Exploring technology at work. *Organization studies*, vol. 28, no. 09, pp. 1435-1448

Petrick, Irene J.; and Timothy W. Simpson (2013). 3D Printing Disrupts Manufacturing: How Economies of One Create New Rules of Competition. *Research-Technology Management*, vol. 56, no. 6, pp. 12–16.

Pedersen, Rune (2012). Standardizing Work in Healthcare Through Architecture, Routines and Technologies. In Dugdale J., et al. (eds). *From Research to Practice in the Design of Cooperative Systems: Results and Open Challenges.* London: Springer London, vol. 17, no. 32.

Rosson, Mary Beth; and John M. Carroll (2009). Scenario based design. In Sears, A.; and J. A. Jacko (Eds.). *Human-computer interaction: Development process*. CRC Press, pp. 145-162.

Schmidt, Kjeld (2009). Divided by a common acronym: On the fragmentation of CSCW. In I. Wagner et al. (Eds.): *ECSCW 2009. Proceedings of the 11th European Conference on Computer-Supported Cooperative Work, 7–11 September 2009, Vienna, Austria*. London: Springer, pp. 223–242.

Schmidt, Kjeld (2010). 'Keep Up the Good Work!': The Concept of 'Work'in CSCW. In *COOP 2010. Proceedings of the 9th International Conference on Designing Cooperative Systems, May, 18-21, 2010, Aix-en-Provence*. Berlin, Heidelberg: Springer-Verlag, pp. 265–286.

Schmidt, Kjeld (2011). *Cooperative Work and Coordinative Practices.* London: Springer.

Schmidt, Kjeld (2014). The concept of 'practice': What's the point? In *COOP 2014. Proceedings of the 11th International Conference on the Design of Cooperative Systems, 27-30 May 2014, Nice, France*. Cham: Springer, pp. 427-444.

Schmidt, Kjeld (2018). Practice and Technology: On the Conceptual Foundations of Practice-centered Computing. In V. Wulf et al.: *Socio-informatics: A Practice-based Perspective on the Design and Use of It Artifacts.* Oxford: Oxford University Press, pp. 47-103.

Suchman, Lucy A. (1983). Office procedure as practical action: models of work and system design. *ACM Transactions on Information Systems (TOIS)*, vol. 1, no. 4, pp. 320-328.

Wulf, Volker; Markus Rohde; Volkmar Pipek; and Gunnar Stevens (2011). Engaging with practices: design case studies as a research framework in CSCW. In *CSCW '11. Proceedings of the ACM 2011 conference on Computer supported cooperative work, 19-23 March 2011, Hangzhou, China.* New York, NY, USA: ACM, pp. 505-512.

Wulf, Volker; Volkmar Pipek; David Randall; Markus Rohde; Kjeld Schmidt; and Gunnar Stevens (Eds.). (2018). *Socio-Informatics*. Oxford: Oxford University Press.

Wurhofer, Daniela; Thomas Meneweger; Verena Fuchsberger; and Manfred Tscheligi (2018). Reflections on Operators' and Maintenance Engineers' Experiences of Smart Factories. In *GROUP '18. Proceedings of the 2018 ACM Conference on Supporting Groupwork, 07-10 January 2018, Sanibel Island, Florida, USA.* New York, NY, USA: ACM, pp. 284–296.