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Product development as reading and writing doings within sociotechnical practices: the reciprocity between engineers and artefacts

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This ethnographic study aims at understanding how product development of wind turbine controls unfolds as ongoing engineer-artefact reciprocity. We adopt a Deweyan constructionist and Science-Technology-Society approach to contribute to product development and sociomaterial studies by emphasising the role of reciprocity between engineers' experience and artefacts through reading and writing doings. Reading doings involve texts such as specifications, minutes, sketches and components. Writing doings create/modify the same type of texts. In one project, convergent reciprocity enabled the development. Another project's development was blocked, restarted and completed internally at the producer. Enablers included repositioning of working practices, application of various artefacts/tools, heterogeneous engineers and creation of common ground. Constraints involved lack of openness, too malleable artefacts, no common ground and radical change of the development trajectory. The engineers' learning depends on these constraints and enablers. Three types of reciprocity occur: convergent, faded away and blocked.

Keywords: Product development, reciprocity, reading and writing doings, Dewey

Introduction

Wind turbine manufacturers collaborate with suppliers to develop wind turbine sub-systems, such as wind turbine control (WTC) systems. Engineers use artefacts to conduct development activities within and across working practices. Artefacts are a 'matter' for engineers' thinking (Henderson 1999), but context, time and applied language (Bucciarelli 2002) influence the thinking, which implies that an artefact causes different understandings; this complicates the collaboration within working practices. Collaboration across working practices is influenced by the level of common knowledge at a functional boundary (Carlile 2004).

Researchers have studied this engineer-artefact bidirectionality from an agency perspective; e.g. as sociomaterial assemblages (Orlikowski and Scott 2008) or as imbrication (Leonardi 2011). However, within situated practices, it is difficult to make out where the agency is; consequently, Pentland and Singh (2012) and Carlile et al. (2013) follow the principles of pragmatism and suggest focusing on context and the consequences of actions to understand the matters influencing the bidirectionality. By bringing Dewey's pragmatic inquiry to the fore, it becomes possible to study the bidirectionality as ongoing reciprocity involving engineers and influencing matters.

The purpose of this paper is to develop an analytical framework that facilitates a study of reciprocity as 'reading' and 'writing doings' and to explore how the engineer-artefact reciprocity

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unfolds within working practices. Subscribing to pragmatism, the research questions guiding this study emerged gradually: Which matters influence reciprocity when conducting a development activity? Which characteristics of the matters enable or constrain reciprocity?

Every time an engineer conducts a development activity, matters '*enter into the means-consequence relationship and in doing so take on added meaning*' (Dewey 1933, 233). Matters acquire meaning when engineers use them to cause consequences, implying that matters influence and are simultaneously influenced by the ongoing meaning creation process. The engineers' experience is pivotal for the meaning creation process and for conducting an activity. Successful completion of a development activity creates new experience for the involved engineers, however the engineers and the artefacts reciprocally evolve (Dewey 1938); this reciprocity implies interdependence and bidirectionality between engineer and artefacts within working practices.

Social and technical matters are co-shaped within working practices (Bijker 2010) and fuse into a composition of a sociotechnical practice when engineers conduct a development activity.

Product development is framed as 'reading' and 'writing doings'. A doing is an act conducted by an actor (Dewey 1938).

An ethnographic study of two development projects focuses on the engineer-artefact reciprocity and follows the collaboration within different sociotechnical practices.

The paper contributes with a combined pragmatism and Science-Technology-Society study of the development of WTC applications, and it aims to contribute to the understanding of how the reciprocity influences the completion of a development activity and the creation of experience. Furthermore, by adopting and adapting the principles of pragmatism in relation to the creation of experience (Dewey and Peirce), we conceptualise three types of reciprocity labelled 'convergent', 'blocked' and 'faded away'. The latter is our addition to the two former, which stem from pragmatism.

The paper starts with a discussion of theories followed by methodological considerations. We then describe, analyse and discuss two cases and, finally, present our conclusions.

Theory

In this section, we discuss our main concepts: the understanding of agency, the bidirectionality between human and artefact, and the reciprocity between them and the approach of reading and writing text to study reciprocity. We do this by visiting other contributions close to our constructionist pragmatist framework, which we summarise at the end of the section.

Constructionism (Crotty 2012) posits that the situated practice influences agency. The relationship between humans and technologies (artefacts) is enacted in practice (Orlikowski and Scott 2008). Leonardi's (2011) concept of imbrication emphasises that human and material (artefacts) have agency, which becomes interlocked in a particular sequence; however, they are distinct, and the relationship between the two kinds of agency overlaps in a regular pattern. Because people have intentionality (Leonardi 2011), they decide how the two kinds of agency become imbricated. Likewise, the imbricated agency forms a sociomaterial practice (Leonardi 2013), which shapes and is simultaneously shaped by action in a trajectory manner; this implies that time matters (like Dewey 1938). According to Leonardi (2013), structural properties (here matters) predate the

actions that transform them. In contrast, Dewey (1938) posits that even though people have intentionality and that time matters, the influencing matters do not predate action, rather matters unfold alongside the meaning creation process. Thus, we interpret agency as being inseparable from an engineer's meaning creation, the doings, and that humans and artefacts are interdependent (Pentland and Singh 2012), even to a degree where it becomes difficult to separate or distinguish them (Pentland and Singh (2012, 288), with their pragmatism approach and notion of an agency "stew").

The bidirectional interaction between engineers and artefacts influences the development process, during which specifications are gradually added to drawings, meaning that artefacts follow a trajectory that starts as a handmade sketch and ends as a final product (Henderson 1999). A sketch/diagram/drawing is a thinking tool (Henderson 1999) and a boundary object (Carlile 2004), yet these artefacts are 'stand-ins' for the engineers' object of design within object worlds (Bucciarelli 1994), and they emerge later as physical prototypes. Given that engineers read drawings like maps (Henderson 1999), handmade sketches and final drawings overloaded with symbols/specifications facilitate different kinds of interaction; i.e., the degree of completion of the artefacts influences the interaction. However, engineers do not have the same educational/practical experience (Carlile 2004); they speak various languages (Bucciarelli 2002), and they demonstrate different levels of experience and commitment (Elkjær 2004). This implies that engineers are heterogeneous and individuals.

The meaning created in the bidirectional interaction differs '*depending upon context and who is doing the reading*' (Bucciarelli 2002, 229); yet again, meaning creation is inseparable from the engineers' doings. To achieve convergent meaning creation, the engineers have to establish a shared proper language (Bucciarelli 2002). This common knowledge can, however, constrain the meaning creation across functional boundaries (Carlile 2004); common knowledge embedded in the trajectory of past developments hinders the collaborating engineers in understanding the level of differences and dependence they are facing. Thus, to conduct product development within and across functional/organisational boundaries, the bidirectional interaction should facilitate a convergent meaning creation.

As noted, matters are not predetermined by ontological/epistemological issues (Leonardi and Barley 2010); the influencing matters are just as epistemological as they are ontological (Bijker 2010). Indeed, Dewey (1938) reminds us that pure ontological interpretations should be abandoned. For this reason, this study brings the engineer-artefact reciprocity to the fore in order to elaborate on the bidirectionality of the interaction.

Reciprocity

Reciprocal interaction between an engineer's experience and artefacts influences both the individual and collective creation of meaning. Since it is not possible to think without a preceding observation (Dewey 1938), the meaning creation always starts with an observation followed by a thinking process drawing on experience. Meaning creation is an iterative process enabled by ongoing reciprocity involving engineers' experience and artefacts.

The composition of the sociotechnical practice influences and is influenced by the reciprocity. The doings and the consequences of the doings are the focal point (Pentland and Singh 2012; Carlile et al. 2013). In Dewey's (1938, 32) terminology, each organic function (here an engineer's doing) is enabled by '*intra-organic and extra-organic energies*'. An engineer's experience is the '*intra-organic energy*', while artefacts constitute the '*extra-organic energy*'. These two '*sources of energy*' are inseparable and embedded within the sociotechnical practice; this bidirectionality conceptualises reciprocity and also the embodiment of experience.

Every time an individual is about to manage an activity, his/her observations of and thinking about matters enter into the means-consequence relationship (Dewey 1933); matters acquire meaning when applied to cause consequences. Dewey (1938) explicates this as a progressive five-phased inquiry process; the first phases being precognitive, implying that thinking becomes increasingly reflective during the five phases. It is a '*controlled transformation of an indeterminate situation into a determinately unified one*' (121). 'Control' highlights the fact that both the observations and thinking of humans should be related to each other (109). This convergence facilitates transcending the precognitive phases, thus guiding human thinking; if not, it will '*cause subsequent inquiry to be irrelevant or to go astray*'... '*there is blind groping in the dark*' (112). The inquiry fades away, which means that humans fail to transcend the precognitive phases, and their thinking thus wanders without direction and gradually becomes aimless. Likewise, '*when a suggested meaning is immediately accepted, inquiry is cut short.*' (115). Indeed, Peirce (1955, 54) posits that humans should avoid blocking the road of inquiry, as it brings the handling of the problematic situation and the meaning creation process to a halt.

In adopting these principles of pragmatism, the conceptualisation and labelling of reciprocity encompass three situations, two of which are derived from pragmatism and the last is our contribution:

'Convergent reciprocity' makes it possible for the actively involved engineers to contribute to the meaning creation process and, thereby, to a successful completion of the development activity and thus the creation of new experience; this would involve most, if not all, the engineers present.

'Blocked reciprocity' is a deliberate doing; it results in the engineers not managing the development activity successfully and the meaning creation process not generating new experience.

'Faded away reciprocity' occurs if the engineers' thinking fails to transcend the precognitive phases, entailing that they unwittingly and gradually become unable to maintain attention on the issue(s) being discussed; consequently, the development activity is neither handled successfully, nor does it generate new experience.

To examine whether the reciprocity converges, becomes blocked or fades away, this study focuses on doings and the consequences of the doings; i.e. reading and writing doings.

Reading and writing doings

Glock (2003) views designers as 'authors of stories'. Design involves interaction between thinking and artefacts (reading) aimed at manipulating the material (writing). Engineers' interpretations differ due to embodied abilities (Glock 2003), and their literacy in relation to reading and writing

drawings is situated in practice, which implies that thinking is not purely endogenous to engineers (Henderson 1999). Rather, their reading and writing are influenced by the sociotechnical practices. Hutchins (1995) demonstrates how the pilots' reading and writing doings of instruments/artefacts depend on the situation within the 'sociotechnical cockpit'; these different reading and writing doings facilitate the coordination among the pilots.

Our research subscribes to the idea that, when conducting doings within sociotechnical practices, reading and writing doings are inseparable from the engineers' meaning creation. Accordingly, just as reading text in articles facilitates new experience and thereby the ability to write new texts in articles, the 'reading doings' of artefacts make it possible for engineers to conduct 'writing doings' in artefacts, i.e. develop a product. However, artefacts do not initiate meaning creation *per se*, but when an engineer conducts reading doings and interprets artefacts the sketches/drawings influence the meaning creation (Mathiasen 2012). Thus, the textual metaphor refers to reading doings of artefacts (interpretation) and writing doings of adding text into artefacts (development).

Summary - analytical framework

Agency is placed somewhere between a passive entity and a voluntary conduct of doings. The meaning creation starts with the engineers' observations of artefacts followed by thinking based on the engineers' experience (the leftmost dark grey area in figure 1 below).

The composition of the sociotechnical practice unfolds in a space, such as a meeting room or production area (the light grey area in figure 1).

The development activity being studied has a start-up and a completion, represented by the two big dots in the figure. The start-up initiates the meaning creation and completion implies a successful meaning creation process. This is facilitated by doings. A doing is defined as an act. We distinguish between reading and writing doings (the small dots between start-up and completion in the figure). A reading doing is an interpretation of the artefact(s) (e.g., reading a sketch), and a writing doing is the development/modification of an artefact. These doings are the focal point for studying reciprocity.

Reciprocity is illustrated by the two-way arrows attached to the five small dots. The framework operates with convergent, blocked and faded away reciprocity.

Figure 1. The analytical framework

Method

The research is an ethnographic field study and originates from constructionism (Dewey 1938; Crotty 2012). The approach extends a Deweyan conceptualisation of inquiring and Science-Technology-Society regarding the sociotechnical practices (Bijker 2010).

The data collection extended over 12 months – on average, three working days each week; it was divided into two steps. The first phase lasted four months and encompassed observations of four meetings and 14 unstructured interviews documented by notes. Subsequent to this fieldwork, two development projects were identified for further study. The second phase lasted eight months and focused on these two projects. Multi-sited ethnography (Marcus 1995) was applied. Data collection in the second phase comprised observations within open-plan offices/production areas (lasting, on average, six hours per day, three working days a week), observations of 31 cross-functional and 25 interorganisational meetings (each lasting, on average, 95 minutes) and 16 semi-structured interviews. Observations during the meetings were recorded directly in MS Word documents. They encompassed the engineers' dialogues and body language, how they used artefacts, mobile phones, laptops and the blackboard, the characteristics of the room, whether or not the IT network was functioning, whether or not a person was reachable by mobile phone etc. The 16 semi-structured interviews were recorded on tape.

The selection of the two cases draws on Stake's (2000, 447) viewpoint that '*opportunity to learn is of primary importance*'. Rather than paving the way for a comparative analysis, the intention is to achieve a well-founded understanding of the empirical phenomenon/phenomena. Stake's variety criterion for identifying instrumental cases is used. The interorganisational development in one of the cases draws on three decades of close collaboration, while the other case addresses a new collaboration.

The analysis has two elements: Due to varieties between the two cases, the first analysis addresses the characteristics of the matters influencing the reciprocity in each of the two cases. The second analysis is a cross-case analysis designed to learn from rather than strictly compare the cases (Stake 2000).

By gradually juxtaposing the observations/interviews with our theoretical understanding, data are coded. The coding reveals two topics: A chronological analysis of the development trajectory and an analysis of the spatial context (like Elkjær 2004). Our micro-sociological framework, facilitating an analysis of each single doing as either a 'reading doing' or a 'writing doing', is applied to analyse the coded data. Therefore, conducting a development activity is considered to be a series of doings; in Dewey's terminology, handling a problematic situation presupposes that '*a series of interactions intervenes*' (1938, 117). By focusing on how engineers' 'reading' and 'writing doings' unfold, it becomes possible to grasp the reciprocity between an engineer's experience and artefacts.

In order to condense the chronological description of the development processes, we have selected important episodes, including some cross-functional and interorganisational meetings

between the supplier and two different customers (Oldtimer and Newcomer). However, this introduces a limitation of this paper, as daylong engineer-artefact reciprocity is not described even though it contributes to our understanding.

Cases

Two cases are presented, 'Oldtimer' and 'Newcomer'. They constitute examples of collaboration between engineers with different functional/organisational affiliations. The supplier and Oldtimer are well-established within the market for wind turbines, and the development activities involve the creation of a circuit breaker for a new 3.0 megawatt wind turbine. Newcomer's experience with wind turbines is rather limited, and the case focuses on the activities involved in developing the technical-specifications for an entire 2.0 megawatt Wind Turbine Control (WTC). After each case has been presented, a timeline summarises the development.

Oldtimer case

The development of the circuit breaker is introduced rather late in the development process by Oldtimer's Project Manager (PM). The planned delivery date is agreed to be one month later, and Oldtimer is supposed to develop the overall-specifications within a week.

At the following weekly interorganisational meeting, PM-supplier asks about the overall-specifications. They had not yet been developed: *'There are many interfaces to other components in the wind turbine, which we struggle with at the time being.'* (PM-Oldtimer).

Despite the lack of overall-specifications, PM-Oldtimer and PM-supplier agree that the circuit breaker should be divided into two breaker panels; i.e., the technical-clarification evolves.

At the next interorganisational meeting, the overall-specifications are still not finished, but a 3D drawing of the circuit breaker is available. PM-Oldtimer displays it from various angles, revolves it and 'dismantles' cover plates. The PM-supplier's body language clearly indicates that he is reflecting on something, and he asks, *'Oh...what about the cabling in and out of the breaker panels?'* PM-Oldtimer answers, *'The cables between A3 [A3 is another breaker panel] and A24 and 215362MO [the two breaker panels in the circuit breaker]; yes, how to connect them? Can we take these four cables here?'* (PM-Oldtimer points at the laptop screen). PM-supplier is doubtful about this idea: *'Yes, we can...no, it is not a good idea, because the A3 is finished, and the terminal block and all the documentation are finished, so it will give too much hassle. Can we connect 215362MO to these two connections?'* (PM-supplier points at the screen). After a while and a close look at the 3D drawing depicted on the screen, PM-Oldtimer turns down this proposal: *'No, it is no good because one of them is an earth cable.'*

Gradually, the engineers shift their attention to another issue. This dialogue deals with the current intensity in a circuit entered in an electrical-diagram. PM-Oldtimer questions it and examines the details in the diagram. He then looks at the laptop screen and says, *'I can see you have three ampere here... You have three ampere here, and the brakes are not included'*. PM-supplier

agrees, causing PM-Oldtimer to suggest: *'We have as much as nine ampere to use. Why not increase it to 4.5 ampere?'*. The two PMs agree implying that the technical-clarification evolves, yet the issues of cabling/ interfaces are noted as problems in the minutes and in the PMs' notebooks.

At the interorganisational meeting a week later, PM-Oldtimer accounts for a major revision:

'We have decided to change it all, but unfortunately I only have the external measurements at present. The reason why we have to change the design is due to a problem with the crane in the nacelle.... We have just realised it.'

PM-Oldtimer really tries to expound the changes by using oral and body language, and he constructs a comprehensive sketch on the blackboard. This does not result in any technical-clarification.

An interorganisational meeting is held four days before the planned delivery date. Due to the above-mentioned radical changes of the design, no overall-specifications are available. Instead, PM-Oldtimer goes to the blackboard and makes a highly informative sketch of the circuit breaker. The sketch and explanations facilitate a dialogue, but it is not possible to reach a technical-clarification, not even at an overall level. For instance, when PM-supplier asks about the placement of one of the two breaker panels, the answer from PM-Oldtimer is undecided.

At the next interorganisational meeting, the technical-clarification evolves again. An updated version of the 3D drawing is accessible. PM-supplier connects his laptop to a TV screen, and he zooms in and out, turns the 'virtual circuit breaker' at different angles and uses the mouse cursor to highlight his statements. In the same way, PM-Oldtimer points with his finger at the screen and explains his ideas. A great many technical issues are handled. Some are written in the participants' notebooks, others in the minutes. The technical-clarification appears from handmade sketches or from the coloured corrections added to drawings/electrical-diagrams.

At a later interorganisational meeting, it is decided to join the two breaker panels into one circuit breaker (again). This second revision prompts some modifications to the specifications, which are recorded in the minutes. Moreover, the delivery date is postponed to a month later than originally planned.

At the interorganisational meeting a week later, the technical-clarification is still pending.

In contrast to preceding meetings, the interorganisational meeting at the planned delivery date takes place in the production area. The meeting results in the technical-clarification evolving again. PM-Oldtimer takes a close look at the bottom plate of the circuit breaker and comments to the prototype-worker that a hole is placed 'upside down'. A little later, PM-Oldtimer takes a close look inside the breaker panel and says emphatically, *'I really do not know what our engineers were thinking when designing these copper bars; they have to be tipped.'* PM-supplier agrees, and while

pointing with his finger at the copper bars, he says, ‘*Yes, you are right, something is wrong. Can we straighten them by mounting a washer there?*’

Hence, this meeting results in the breaker panel having to be reworked, further postponing the delivery.

The circuit breaker is in complete operation at the time. Overall, the development process was extended by nearly two months.

Table 1 summarises the themes of the doings; the rightmost column indicates the period characteristics.

Table 1. Timeline: Oldtimer – development of the circuit breaker

Date	Themes of the reading and writing doings	Period of
3 Sep	Supplier introduced to the development	
10 Sep	No overall-specifications were accessible for the readings, yet readings resulted in dividing the circuit breaker into two beaker panels → minimal writing	Evolving 1
17 Sep	As all overall-specifications were not finished readings were often impeded, yet readings facilitated to clarify current intensity → writing in progress	
24 Sep	Major revision of the design implied that to no overall-specifications were accessible for readings → no writing	Major revision
2 Oct	No overall-specifications were accessible for readings; drawing made on the blackboard did not lead to any clarifications → no writing	
8 Oct	A 3D drawing were accessible for readings, which resulted in a great many technical clarifications → writing in progress	Evolving 2
21 Oct	The two breaker panels were joined into one; consequently readings revealed some modifications of the technical-specifications → no writing	Revision 2
29 Oct	Readings addressed two crucial components, but did not result in further technical-clarifications → no writing	
5 Nov	Readings of physical breaker panel, drawings and diagrams in the production revealed some modifications to the breaker-panel → writing in progress	Evolving 3

Newcomer case

The development process was divided into two phases: first, preparation of the pre-clarification document; and second, preparation of the detailed specifications. The pre-clarification document caused the supplier-engineers to doubt the pre-clarifications during the preparation of the detailed technical-specifications; this is the focus here.

Four days after the supplier received the approved pre-clarification document from Newcomer, a cross-functional meeting is arranged to hand over the development task from the sales department to the development group. The salesman shows selected pages on a TV screen and uses the blackboard to explain his interpretation of the pre-clarifications. Immediately after, PM-supplier asks the salesman, ‘*What have you sold? Is it a standard WTC or is it a customised solution?*’. The

interpretations of the pre-clarifications are divergent. The salesman emphasises that *'the miniTS [pre-clarifications] precisely defines the scope of the project...'*, while the employees from the development group have a different take on the pre-clarifications: *'Are we allowed to utilise our 25 years of experience to create a WTC for Newcomer?'*.

Apparently, the supplier-engineers doubt the pre-clarification.

During an interorganisational meeting one week later, the content of the pre-clarification document is discussed. PM-Newcomer interprets the pre-clarifications to involve a high level of customisation. However, PM-supplier's interpretation of the pre-clarifications is: *'I disagree, since we have sold a standard WTC'*.

The meeting is characterised by a great deal of doubt. The different perceptions of the pre-clarifications dominate, and technical-clarification is minimal.

In an attempt to handle this doubt, a cross-functional meeting is arranged; all employees working on the Newcomer project participate. The supplier-engineers have received additional technical-information, but still, as supplier-engineer 1 emphasises: *'Some issues have been clarified but there are still many doubts, and some of them are comprehensive. Compared to the CSIC [a standard/well-known product], we can see some considerable changes.'* Supplier-engineer 1 goes to the blackboard, where she draws comprehensive sketches and explains all changes in comparison with the standard product. One of the other engineers asks, *'What has been written down in the minutes from the meetings? What have we promised them?'*. This comment causes the Vice President of Development to emphasise that *'the minutes must not be used to interpret what we have sold. We have to be guided by the content of the miniTS [pre-clarifications]'*.

Three days later, another interorganisational meeting takes place. Each of the two PMs argues for their understanding of the pre-clarification. Arguably, both have 'misunderstood' the pre-clarifications. While PM-Newcomer has considered the pre-clarification document to be non-binding, PM-supplier has interpreted the pre-clarification document to be too precise. Consequently, although some technical issues are clarified, a great deal of information is still missing.

Accordingly, the focus of the next interorganisational meeting is to retrieve this information. Four employees from supplier and four Newcomer engineers participate. As usual, supplier-engineer 1 uses a laptop to depict the technical-specification document on the TV screen. Topics to be discussed are highlighted with red letters. For instance, an issue regarding when to connect/disconnect the wind turbine to/from the grid is highlighted:

'What are the minimum and maximum generator speeds?' (supplier-engineer 1). 'I don't understand. What do you want to know?' (PM-Newcomer). 'Number 1 is the minimum generator speed, and number 11 is the maximum speed. All the 11 figures are used as input to the software, and hence, it will result in a given reaction. Number 1 will cut off the wind turbine from the grid if the speed is too low, and number 11 is used to cut off the wind turbine when the speed is too high. And we really need this information.' (supplier-engineer 1).

Still, PM-Newcomer does not understand and continues asking fundamental questions. Supplier-engineer 1 attempts to explain that the information is needed by the software engineers, but fails to get the message across. Consequently, first, one of the software engineers is requested to participate in the meeting, and later on, one more; the latter is a converter specialist who has huge experience. Then, PM-Newcomer goes to the blackboard to illustrate his understanding and argues:

‘Why do you need these data? My idea is that kk [supplier] examines and defines these data... I cannot understand the problem with the minimum speed... My point is: why do you need a small band between the minimum speed and the cutting off of the wind turbine?’

The supplier’s software engineer explains that it is rather easy to calculate when the speed is within limits; the voltage at the rotor side increases. Beyond doubt, PM-Newcomer is not satisfied with the situation. He emphasises, *‘How do you make these calculations? I would like to know that... I would like to understand the idea behind how to calculate it...’*.

After six hours of arguing, the meeting ends without any clarification. The supplier-engineers did not succeed in their effort to retrieve the missing information.

Prior to the next interorganisational meeting, PM-supplier sends a draft version of the technical-specification document to PM-Newcomer. However, the technical clarifications/-specifications did not evolve during the interorganisational or cross-functional meetings. Instead, they are internally developed by the supplier-engineers; the supplier’s PM and all the supplier’s draughtsmen and engineers sit together in an open-plan office and develop the needed clarifications/specifications during their daily work practices.

At the next interorganisational meeting, a discussion of a new draft version of the technical-specification document involves a long-lasting argument that deals with the transparency of the technical-specifications written in the document. PM-Newcomer emphasises:

‘If we continue with this kind of TS-document [technical-specifications], I am not able to come up with any suggestions. The present way of working forces me to merely follow your solutions and ideas... I am unable to learn about the functionalities.’

PM-supplier argues: *‘We are a supplier of a WTC, not a supplier of detailed specifications.’*

Despite these challenges, the product for Newcomer is created within the agreed time frame. But PM-supplier says: *‘I doubt they [Newcomer] have read the TS-document closely and how much they have been able to understand of the document.’*

Table 2 summarises the themes of the doings and the working practice. The rightmost column indicates the period characteristics.

Table 2. Timeline: Newcomer – preparation of the technical-specifications

Date	Themes of the reading and writing doings	Working practice	Period of
23 Aug	PM/engineers' readings of the pre-clarification document started	Daily working	
27 Aug	PM/engineers' readings doubted the pre-clarifications; standard or customised WTC → no writing	Cross-functional	Doubting
2 Sep	Newcomer's and Supplier's readings diverged; standard versus customised WTC; thus minimal clarification → minimal writing	Interorganisational	
7 Sep	Engineers' and management's readings diverged; considerable changes or maintain the pre-clarifications → no writing	Cross-functional	
Sep – 7 Oct	Readings of artefacts resulted in clarification of technical-specifications → ongoing readings and writing	Daily working	Evolving
10 Sep	Newcomer's and Supplier's readings diverged; precise versus non-binding pre-clarifications. Readings revealed that a great deal of information was missing → minimal writing	Interorganisational	Arguing
18 Sep	Readings diverged; Newcomer strove to understand issues, Supplier strove to retrieve information → minimal writing	Interorganisational	
25 Sep	Readings diverged; Newcomer strove to understand issues, Supplier strove to retrieve information → minimal writing	Interorganisational	
7 Oct	Readings diverged; Newcomer strove to understand issues, Supplier strove to retrieve information → minimal writing	Interorganisational	

Analysis and discussion

This research sets out to explore matters influencing the engineer-artefact reciprocity when artefacts are 'in-the-making'. The analysis and discussion appraise the learning acquired from both cases and compare them in order to highlight findings in each case.

In both cases, the engineers successfully conducted the development activities. The cases explicate how ongoing reading and writing doings unfolded within mutable sociotechnical practices. Reading doings of the artefacts guided the engineers' thinking, while writing doings resulted in a reshaping of the artefacts.

First, we analyse the development trajectory, then we analyse the sociotechnical practices and, finally, we juxtapose and synthesise our analyses. These findings are presented in table 3.

Development trajectory

The analysis reveals that artefacts became more complex and also more physical toward the completion of the Oldtimer project (see also Henderson 1999). This was enabled by convergent reciprocity within daily working, cross-functional and interorganisational sociotechnical practices; albeit, due to the '*major revision*' and '*revision 2*', not in a complete linear fashion, and thus short time periods characterised by faded away reciprocity. The Newcomer project involved faded away and blocked processes. Faded away and blocked reciprocity involved a restart of the reading doings, mostly carried out internally the supplier's daily working sociotechnical practices during the period of '*evolving*' (from the beginning of September until 7 October).

As PM-Newcomer was involved in drawing up the pre-clarification (activities conducted prior to the timeline in table 2), he often referred to the content of this document. However, during the period of *'doubting'*, the technical platform became radically changed. This radical change of the development trajectory made the reflective thinking of the two groups of engineers follow divergent tracks. As it was not possible to find common ground at subsequent interorganisational meetings (period of *'arguing'*), the two groups of engineers maintained different positions. It bordered on a war of positions (divergence at a boundary (Carlile 2004)), and it resulted the two groups of engineers to carry out divergent reciprocal interaction; the reciprocity was blocked.

Accordingly, the reading and writing doings of drawing up the technical-specifications were mainly conducted by the supplier-engineers within the daily working sociotechnical practices in the middle part of the development process (period of *'evolving'*). The starting point for these reading doings was sketches, drawings, electrical-diagrams, documents, components placed on desks within the open-plan office, physical breaker panels in the production area and, finally, technical standards. The writing doings addressed the creation and/or modifications of the constituents in these texts (artefacts), supplemented by more texts such as comments written down in minutes and in notebooks.

Crucial information for these doings was needed; therefore, during the period of *'arguing'* at the interorganisational meetings, the supplier-engineers strove to retrieve information. The supplier-engineers used the laptop to display an artefact on the TV screen within the interorganisational sociotechnical practices; the depicted artefact was the technical-specification document under preparation. The application of the 'track changes' feature in MS Word highlighted the focal point(s) for the reading doings; issues related to the needed information were enhanced by red markings. This approach to retrieve information influenced the social interplay between the supplier-engineers and Newcomer-engineers. Seen from Newcomer's perspective, their reading doings of the pictured artefact focused on understanding technical issues. Often, PM-Newcomer conducted writing doings on the blackboard or on paper and raised his voice to elaborate a viewpoint, but as a rule, these doings became deliberately blocked by a supplier-engineer/PM.

Thus, the reciprocity involving the supplier's engineers and the artefact was focused on preparing the technical-specification document, whereas the pivotal focus of the reciprocity involving Newcomer's engineers and the artefact was an attempt to improve their understanding of technical issues. I.e. the artefact depicted on the TV screen facilitated different readings (see also Henderson 1999; Bucciarelli 2002), resulting in the two groups of engineers not reaching common ground. The reciprocity was blocked.

Within the Oldtimer interorganisational sociotechnical practices, the application of artefacts and tools was different. Drawings/electrical-diagrams were depicted on the TV screen by using a laptop (period of *'evolving-1'* and *'evolving-2'*). Application of IT systems made it possible to follow a connection from one component to another component. Simultaneously with this interactive use of IT systems, both groups of engineers drew sketches 'in the air', on paper or on the blackboard, indicating an intense social interplay (also apparent in the period of *'evolving-3'*). These reading facilitated writing doings, which spurred a gradual completion of the technical-clarification. However, the changes introduced (period of *'major revision'* and *'revision-2'*) resulted in the

artefacts becoming too malleable in some of the following meetings. These too malleable artefacts entailed that the engineers were not able to transcend the precognitive phase; they were not capable of controlling their thinking. It caused the reading doings to wander without direction, and gradually these became aimless, making the reciprocity faded away.

Comments were written down in minutes and notebooks. The minutes and the engineers' notebooks played a specific role. This kind of artefact – a written document – was used to refresh the engineers' experience in case previously achieved agreements/technical-clarifications had been fogged by time; i.e. notebooks and minutes acted as a written trajectory of the development project that highlighted the consequences of previous doings. Likewise, handmade sketches were added to the artefacts (see also Henderson 1999). Thus, during the three periods of '*evolving*', the engineers made a serious effort to reach sufficient common ground that could result in convergent reciprocity involving both groups of engineers.

Matters influencing reciprocity comprise: too malleable artefacts entail faded away reciprocity; application of a combination of artefacts and various tools as well as the achievement of common ground result in convergent reciprocity; failure to achieve common ground and a radical change of the development trajectory results in the reciprocity becomes blocked. These interorganisational findings echo Carlile's (2004) cross-functional findings suggesting that a lack of common knowledge constrains to bridge to functions' domain specific knowledge. However, our findings illustrate that despite the fact that the customer was a large global enterprise, the (comparatively smaller) supplier was able to achieve a more powerful position in representing and thereby increasing its domain-specific knowledge.

Sociotechnical practices

Engineers applied a combination of artefacts and tools to encourage the social interplay. The social interplay among the involved engineers, verbally and nonverbally, influenced the reading and writing doings. The verbal language was technical; e.g., the hardware engineers talked about 'isolators to avoid short circuits' and the software engineers spoke about 'pitch strategies'. Additionally, voice and body language were continuously adapted to highlight viewpoints; the engineers often made sketches in the air. However, the combination of artefacts/tools and also the social interplay within Newcomer and Oldtimer's interorganisational sociotechnical practices were poles apart.

As for Newcomer, the interorganisational sociotechnical practices only unfolded within one meeting room and neither laptop nor mobile phone was applied to retrieve missing information. Additionally, the social interplay between the supplier's engineers and Newcomer's engineers was characterised by a lack of openness, which meant that only few, if any, artefacts were accessible for the reading doings during the period of '*doubting*' and '*arguing*'. Consequently, Newcomer's engineers were not capable of controlling their thinking; their reading doings often wandered without direction and gradually became aimless. According to Henderson's (1999) findings, if a sketch/drawing is not brought to a meeting, someone will create a facsimile or ensure the

accessibility of the sketch/drawing when communication begins to falter. This, however, was not apparent in the Newcomer analysis. Thus, the engineers unwittingly gradually became unable to maintain attention on the issue(s) being discussed. The reciprocity faded away.

The Oldtimer sociotechnical practices draws on three decades of close collaboration. Mobile phones and/or laptops were applied several times during a meeting to access missing information. Furthermore, the sociotechnical practices unfolded within various physical locations; meetings took place in meeting rooms and in production areas, which meant that the sociotechnical practice was repositioned during the meetings.

The repositioning of the sociotechnical practices influenced the reading doings. For instance, the circuit breaker was an issue in a number of interorganisational meetings (period of '*evolving-1*' and '*evolving-2*') at which different kinds of electrical-diagrams, sketches and drawings were used to guide the engineers' reading doings. The reading doings, however, failed to expose design flaws as the artefacts were too malleable (see also Orlikowski 2000). Yet, when the engineers took a close look at the physical breaker panel in the production area (period of '*evolving-3*'), the reading doings revealed drawbacks in the current design. The engineers' doings involved more than looking at various texts: they touched the product; they requested prototype-workers with experience in assembling breaker panels to take part in the practice, meaning that prototype-works were temporarily a part of the social interplay; they measured the product; and replaced components in the physical breaker panel. The social interplay and various reading doings enabled the engineers to transcend the precognitive phase and gradually expose design flaws in the physical breaker panel.

The engineers utilised the composition of the sociotechnical practices to simultaneously enhance the reading doings of the artefacts and encourage the social interplay among heterogeneous engineers with different experience and organisational affiliations; the composition of the sociotechnical practice is mutable.

This ongoing repositioning and temporary involvement of engineers/workers were also applied to the daily working practices in both the Oldtimer and Newcomer projects; i.e. the open-plan offices and production areas.

Matters influencing reciprocity are: lack of openness results in faded away reciprocity; repositioning of the sociotechnical practices, and also different levels of experience among the engineers, implies convergent reciprocity. The latter viewpoint has some similarities to Bucciarelli's (2002) findings in relation to how engineers' language competencies across object worlds influence the negotiations among participants with different responsibilities and technical interests.

Juxtaposing the analyses

The empirical findings corroborate our conceptualisation and labelling of reciprocity as convergent, faded way and blocked and reveal that the reciprocity is influenced by: the composition of the

sociotechnical practices, heterogeneous engineers, common ground among the engineers and too malleable artefacts.

The mutable composition of the sociotechnical practices - repositioning of the sociotechnical practice and application of a combination of artefacts and tools - encouraged social interplay and was seen to have a positive influence on reciprocity. Likewise, heterogeneity among engineers and common ground impacted positively on reciprocity, meaning that engineers having different levels of experience were capable of guiding (controlling, Dewey 1938) their thinking. Too malleable artefacts (Oldtimer case) and a composition of a sociotechnical practice characterised by lack of openness (Newcomer case) illustrated situations where engineers mobilised all resources to maintain attention on the issues being discussed. However, incapable of guiding their thinking, the reciprocity gradually faded away. A lack of common ground and also a radical change of the development trajectory (Newcomer interorganisational sociotechnical practices) blocked the reciprocity.

The characteristics influencing reciprocity appear in the second column of table 3. The leftmost column illustrates three types of reciprocity while the rightmost column refers to the timelines and periods.

Table 3. Characteristics influencing reciprocity

Reciprocity	Characteristics influencing reciprocity	Examples from the timelines
Convergent reciprocity	<ul style="list-style-type: none"> ➤ Repositioning of sociotechnical practice ➤ Application of a combination of artefacts and various tools ➤ Different levels of experience among the engineers ➤ Engineers achieve common ground 	<p><u>Oldtimer</u>:</p> <ul style="list-style-type: none"> ➤ Period of evolving-1, evolving-2 and evolving-3 <p><u>Newcomer</u> (only daily working practice):</p> <ul style="list-style-type: none"> ➤ Period of evolving
Faded away reciprocity	<ul style="list-style-type: none"> ➤ Too malleable artefacts ➤ Lack of openness 	<p><u>Oldtimer</u>:</p> <ul style="list-style-type: none"> ➤ Period of major revision and revision-2 <p><u>Newcomer</u>:</p> <ul style="list-style-type: none"> ➤ Period of doubting and arguing
Blocked reciprocity	<ul style="list-style-type: none"> ➤ Radical change of the development trajectory ➤ Engineers do not achieve common ground 	<p><u>Newcomer</u>:</p> <ul style="list-style-type: none"> ➤ Period of arguing

Our findings have much in common with those of Bucciarelli (1994; 2002), in that they emphasise human abstraction and reflection within and across ‘object worlds’, and with Carlile (2004) with respect to the necessity of achieving convergence (common ground) rather than divergence at the boundary. Bucciarelli’s study, especially the notion of engineers’ ‘object worlds’ being different, is parallel to our finding on heterogeneity. Also, even if Bucciarelli and the present study theoretically conceptualise the individual, both studies find quite a lot of social interplay among engineers.

The findings also resonate with Orlikowski’s (2000) enactment perspective which indicates that materiality is not some prefabricated stuff ‘waiting out there’ for engineers’ readings. Rather, materiality unfolds in the doings (see Dewey 1933) and influences a particular course of action (Pentland and Singh 2012), meaning that the influential role of materiality unfolds alongside the

engineers' meaning creation process when conducting doings. This is maybe even more prevalent in our micro-sociological study examining 'technology-in-the-making' rather than in the 'technology-in-use processes' (adoption of information systems) studied by Orlikowski and Scott (2008). Moreover, our position and findings addressing reciprocity subscribe to the viewpoint that humans have intentionality and that time matters (Leonardi 2011), but differ from the notions of imbrication in relation to structural properties predating the actions that transform them (Leonardi 2013). In our ethnographical study of product development, we apply a different perspective and thus focus on how doings unfold and the consequences of these doings.

Conclusion

This paper sets out to understand how a development activity unfolds as engineer-artefact reciprocity. The research questions focus on matters influencing reciprocity when conducting an activity and the characteristics of the matters enabling or constraining the reciprocity.

To examine reciprocity this study focuses on reading and writing doings. Reading doings were of text such as sketches, drawings, documents and components. Writing doings addressed the creation/modifications of the constituents in these texts; i.e. reshaping the artefacts.

Over time, the socially read and written materiality gradually increased in the Oldtimer project, enabled by convergent reciprocity, but Oldtimer's introduction of two revisions implied too malleable artefacts and thus short time periods characterised by faded away reciprocity. Mainly due to a lack of interorganisational openness, the Newcomer project involved faded away and blocked reciprocity, prompting a restart of the reading and writing doings, which was mostly carried out within the supplier's daily sociotechnical practices.

The composition of the sociotechnical practices differs in the two projects. As for Newcomer, the interorganisational sociotechnical practices unfolded in only one meeting room, while the Oldtimer interorganisational sociotechnical practices unfolded within various physical locations, thus introducing other artefacts and workers/engineers contributing to the engineer-artefact reciprocity and social interplay.

Overall, the reciprocity is influenced by: the composition of the sociotechnical practices, heterogeneous engineers, common ground among engineers and too malleable artefacts. Our analysis revealed three types of reciprocity – convergent, faded away and blocked – indicating that engineers' learning and successful completion of a development activity cannot be taken for granted when carrying out development. Rather, learning and a successful completion of a development activity are dependent on overcoming a range of constraints and successfully mobilising the right enablers. Characteristics of enabling matters include heterogeneity of the engineers' experience, achieving common ground among engineers, repositioning of the sociotechnical practices and application of various tools and artefacts. Constraining matters involve too malleable artefacts, engineers failing to achieve common ground, lack of openness and a radical change of development trajectory.

By developing a framework that combines Dewey's approach to learning, which acknowledges that engineers possess different levels of experience and commitment, with Science-Technology-

Society studies' elements of sociotechnical practices, and using this micro-sociological framework in an ethnographic study of engineers doing development, we hope that our study contributes to diminish a prevalent limitation of sociomaterial studies that have '...a tendency to grant relatively equal footing to all actors' contributions...' (Leonardi and Barley 2010, 24).

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