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Visual representations for communication in geographically distributed new product development projects

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ABSTRACT

This study addresses the role of visual representations in supporting communication between an R&D team and geographically distributed suppliers for a new product development (NPD) project. It specifically focuses on the design and use of visual representations as a feasible way for communication between the distributed actors when they face communication challenges originating from differences in skills in the English language, but also from differences in work experiences. Relying on empirical materials from a Swedish manufacturing company in the mechanical engineering industry, this paper makes the following contributions to the literature. First, it shows that visual representations are effective boundary objects able to support process-oriented and product-oriented communication in distributed NPD projects. Second, it illustrates that visual representations do not necessarily have to follow graphic design principles, but can still be effective if distributed actors share the same project context. Finally, it highlights the need for a dynamic and context-dependent perspective on communication in NPD projects.

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geographical distribution;
communication; visual
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1. Introduction

Effective communication is essential for new product development (NPD) projects because it provides the capabilities for manufacturing companies to develop, produce, and deliver lucrative products to the market (Frishammar 2005; Kleinsmann and Valkenburg 2008; Kleinschmidt, De Brentani, and Salomo 2010). For example, communication between different actors involved in NPD, such as R&D and manufacturing engineers, is important to ensure the transfer of a newly designed product from the laboratory environment to production but also challenging (Lakemond et al. 2012). The underlying reason is that communication may be disrupted by the coexistence of differences in goals, perspectives, use of terminology, among others, between actors (Bechky 2003; Hisarciklilar and Boujut 2007), which results in effects such as late product design changes, tolerance problems, need for extra testing, and product re-design cycles (Ulrich and Eppinger 2016).

Shorter product life cycles, intense competition, the diverse geographic location of R&D teams and manufacturing sites, and globally distributed suppliers are a reality for

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many manufacturing companies today (Gustavsson and Säfsten 2017). Therefore, the geographical distribution among actors involved in NPD projects has the tendency to amplify communication challenges (e.g. Lakemond, Berggren, and Van Weele 2006; Kleinsmann and Valkenburg 2008; Säfsten et al. 2014) by complicating communication during an NPD project due to absence of physical proximity, differences in time zones and cultures, as well as differences in linguistic skills among the involved actors (Barczak and McDonough 2003; Marheineke, Habicht, and Möslin 2016). Further, information and communication technologies (ICT), such as tele- and videoconferencing, have been emphasised as means to support communication in distributed contexts (e.g. Ceci and Prencipe 2013). However, extant studies also show that ICT cannot overcome all communication challenges originating from the geographical distribution between actors (e.g. Dooley and O'Sullivan 2007).

Other studies (e.g. Hietikko and Rajaniemi 2000; Crilly, Moultrie, and Clarkson 2004; Goldschmidt 2007; Cash, Dekoninck, and Ahmed-Kristensen 2017) show that visual representations, such as sketches (either handmade or computer generated) or drawings and photographs, have key roles in supporting communication during NPD projects. Researchers (e.g. Carlile 2002; Boujut and Blanco 2003) refer to visual representations as intermediary or boundary objects that have the capacity to support communication in NPD projects. As research indicates that ICT does not overcome all communication challenges in distributed contexts and since visual representations have the potential to support communication, it seems plausible to assume that such representations may be relevant to use in distributed NPD projects. Still, literature offers limited insights regarding the use of visual representations to support communication in geographically distributed NPD projects. The study presented in this paper is situated in such a distributed context, where an R&D team is located in Sweden and actors at the manufacturing site and the suppliers are based in China. The involved actors experienced communication challenges originating from differences in skills in the English language but also from differences in work experiences. In the studied project visual representations were used to deal with the communication challenges between the actors, leading to our first research question (RQ1) is: *How can visual representations be used in a distributed context to support communication in NPD projects?*

As the visual representations used were not produced by professionals in graphic design, a question can be raised whether the design of the visual representations per se influences their effectiveness in supporting communication. The literature on the visual perception and representation of data asserts that visual representations should rely on specific principles of graphic design to work in a specific context (Lupton and Phillips 2015). Well-designed graphics can be defined as visual representations that follow elementary principles that support the perception of visual information such as hierarchy (the most important issues to address), clear distinction of colour, lines, shape, and size of typographs (Lupton 2010; Mollerup 2015). To ensure that visual representations work correctly in a specific context, the use of colour and icons need to be consistent when series of visual representations are devised. As such, the design of visual representations affects their potential to act as boundary objects and support communication in distributed NPD projects. In other words, visual representations need to be legible to support communication (Lupton and Phillips 2015). This leads to the second research question (RQ2): *How does design of visual representations influence their potential to act as boundary objects in a distributed context to support communication in NPD projects?*

By addressing the two research questions, this paper makes the following contributions. First, it argues that both process- and product-oriented visual representations are effective means to support communication in distributed NPD projects via their roles as boundary objects. Prior research has mainly addressed the roles of boundary objects when actors are co-located (Bechky 2003; Majchrzak, More, and Faraj 2012). Second, it illustrates that visual representations do not necessarily have to follow graphic design principles to be effective if the distributed actors share project context. Finally, it highlights the need for a dynamic and context-dependent perspective on communication in NPD projects.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature on visual representations and their design. Section 3 explains the research design and empirical materials used. Section 4 outlines the findings. In Section 5, the analysis is presented, and the final section draws conclusions.

2. Literature review

Here, the challenges related to communication in distributed NPD projects and potential use of visual representations as communication means are first addressed, while a second subsection focuses on the design of visual representations, including principles of graphic and annotation design.

2.1. Communication challenges and use of visual representations

Studies on communication in geographically distributed NPD projects have received attention among scholars as well as practitioners because of the increased globalisation in manufacturing industries (e.g. Eris, Martelaro, and Badke-Schaub 2014). Geographical distribution is associated with actors residing in different cities, countries, or continents, and working interdependently to accomplish a task (Barczak and McDonough 2003; Hinds and Bailey 2003). Research revealed communication frequency is reduced with increased geographical distance (Allen, Tushman, and Lee 1979; Sosa et al. 2002). Moreover, communication is disrupted not only by geographical distribution but also poor organisational bonds (Allen, Tomlin, and Hauptman 2008), which decreases the probability of communication among actors even if they are in proximity.

Bergiel, Bergiel, and Balsmeier (2008) emphasise that communication in a distributed context is disrupted by a lack of facial expressions, vocal inflections, verbal cues, and gestures. Researchers argue that distribution brings about heterogeneity and is associated with a lack of shared context, familiarity, and friendship among distributed actors (e.g. Hinds and Bailey 2003; Hinds and Mortensen 2005). According to Cash, Dekoninck, and Ahmed-Kristensen (2017), the lack of proximity also reduces the possibility for visual observation and informal contact, hence constrains learning across locations. Shared references to objects of interest are thus more challenging to establish, which might in turn obstruct effective communication on work tasks (Lakemond and Berggren 2006; Ceci and Principe 2013). Some researchers even show that differences in work norms, cultures, behavioural expectations, and technologies disrupt communication patterns (Kleinsmann and Valkenburg 2008; Eris, Martelaro, and Badke-Schaub 2014). Other studies stress the importance of using ICT to communicate in geographically distributed contexts (Marheineke, Habicht,

and Möslin 2016). While it is claimed that the use of virtual post-it notes and text chats support the efforts to convey information and establish mutual understanding among actors in a distributed NPD context, research on ICT does not address how visual representations can be used to support communication among actors in a distributed NPD context. Prior research explored the use of visual representations in various domains, such as architecture and construction (Goldschmidt 2007; Ewenstein and Whyte 2009), mechanics (Carlile 2002; Boujut and Blanco 2003; Goldschmidt 2007; Eris, Martelaro, and Badke-Schaub 2014), electro-mechanics (Cash and Maier 2016), or even furniture design (Crilly, Maier, and Clarkson 2008). For instance, Luck (2014) shows that visual representations are used to support communication at review-type meetings attended by co-located multidisciplinary actors. Such meetings rely on gestures and verbal messages to support the use of visual representations in negotiating and establishing effective communication (Becvar, Hollan, and Hutchins 2008; Mortensen and Lundsgaard 2011; Cash and Maier 2016).

Communication using visual representations aims at improving NPD processes by supporting coordination and cooperation among all actors and between the R&D team and other stakeholders, such as suppliers (Letens, Farris, and Van Aken 2011). Studies adopting an interpersonal communication perspective elaborate on how visual representations mediate senders' intentions and receivers' understanding. However, they also show that transmitted messages are not always understood by the receiver as intended by the sender (Crilly, Moultrie, and Clarkson 2004; Crilly, Maier, and Clarkson 2008). According to Goldschmidt (2007), sketches are the media through which communication among multidisciplinary actors occurs, allowing convergence to a single, mental model of product concept. Sketches are traditionally accompanied by explanatory verbal comments. Furthermore, visual representations should have clearly defined purposes and be properly used (by both senders and receivers) to support effective communication.

Some researchers refer to visual representations as intermediary objects, which represent an intermediate state of the finished products and facilitate upstream or downstream actors' participation in NPD projects (Boujut and Blanco 2003). Visual representations also have been addressed in the literature on boundary objects (Star 1989; Koskinen 2005; Marheineke, Habicht, and Möslin 2016). Boundary objects are means of translation used to form shared understanding between actors from different organisational functions, i.e. boundaries, such as R&D and manufacturing (Carlile 2002, 2004). Boundary objects are interpreted differently by the actors that belong to different boundaries, and it is an acknowledgement and discussion of these differences that ensure establishment of shared understanding (Bechky 2003; Gustavsson and Säfsen 2017). To be effective the boundary objects need to possess certain features such as providing shared language and concrete means of translating and learning about the differences and interdependencies between the actors (Dougherty 1992; Majchrzak, More, and Faraj 2012).

Sketches, drawings, or simulations can be used to reconcile the diverse meanings implied by multidisciplinary actors (Bechky 2003; Majchrzak, More, and Faraj 2012). Prototypes can reconcile different actors' viewpoints and thus support communication in NPD projects (Moultrie 2015). Physical tangibility allows defining differences and interdependencies when actors with different skills, knowledge, or locations communicate. Furthermore, researchers (Carlile 2002; Boujut and Blanco 2003) indicate visual representations are used to negotiate interests and trade-offs among actors.

To conclude, prior research has emphasised the potential use of visual representations in NPD projects. However, less attention has been paid to the use of visual representations to support communication in geographically distributed NPD projects.

2.2. Design of visual representations

The literature on the visual perception and representation of data states that, for a visual representation to work in a context, its design needs to be based on certain conventions (Lupton and Phillips 2015; Mollerup 2015). These conventions are based on the principles of how to attract attention in visual representations, namely: (i) line (helps direct the eye); (ii) scale (creates emphasis); (iii) colour; (iv) repetition (helps place individual elements together); (v) symmetry; (vi) balance; (vii) hierarchy (helps user navigate); (viii) contrast (creates emphasis); (ix) direction; (x) typography (distinct font). Kostelnick and Hassett (2003, 163) elucidate how conventions structure visual language and emphasise that social dynamics, which actors develop and sustain in a given context, need to be investigated rather than the nature of those conventions.

Some studies propose using annotations combined with visual representations (sketches and pictures) to establish effective communication (e.g. Goldschmidt 2007). For instance, Hisarciklilar and Boujut (2007) refer to semantic annotations as reusable (interpretable) by individuals in certain settings. Annotations together with graphical or textual representations (e.g. computer-aided design drawings or reports) typically complement a main document and are interpreted only in its context (Agosti, Bonfiglio-Dosio, and Ferro 2007). An annotation has two basic elements: (i) content, referring to the information it conveys, and (ii) anchor, indicating the reference point it is located (Li, McMahon, and Newness 2009; Marshall 2009). Annotated documents and visual representations can be used for different purposes, such as indexing for technical information and support for cooperation and communication in NPD projects (Hisarciklilar and Boujut 2007). According to Boujut (2003), annotations resemble the boundary objects defined by Star (1989) because they stimulate negotiations between actors, which help establish a shared understanding of a situation or object. Annotations comprise not only another dimension of verbal communication but also a system of signs that assist in materialising the discipline-specific knowledge and cross-learning among various disciplines (Boujut 2003). However, the relationships between visual representations and textual communication are complex because verbal language influences the interpretation and main message of any visual representation. Further, visual representations and verbal language are described by different symbol systems. Specifically, verbal language is crucial for interpreting shared information, where the sender must verbalise the content and purpose of the visual representation and the action required by the receiver (Eriksson, Johansson, and Björndal 2011).

To conclude, prior literature states that, for a visual representation to work in a specific context, its design needs to follow certain conventions. These conventions follow principles of graphic and annotation design.

3. Research design and empirical materials

This section first introduces the research design, followed by a presentation of the empirical materials.

3.1. Research design

This study's underlying idea is to engage in knowledge co-production (Chen, Wu, and Wu 2013), where researchers and practitioners collaborate to identify solutions to real-world problems and, in parallel, generate new theoretical insights (Beech, MacIntosh, and MacLean 2010). The research approach reflects engaged scholarship, defined as 'a collaborative form of inquiry in which academics and practitioners leverage their different perspectives and competencies to coproduce knowledge about a complex problem or phenomenon that exists under conditions of uncertainty found in the world' (Van de Ven and Johnson 2006, 803). This paper is thus co-authored by a team of three researchers and one industry representative, who acted as project manager for the studied project. The project is denoted as Project Beta to avoid disclosing the developed product. The involvement of the project manager as co-author and in the analysis allowed for firmly rooted findings, based on the collected empirical material and knowledge co-production that have both scientific relevance and practical value.

The empirical materials were collected through an exploratory, in-depth case study of an NPD project run by the co-authoring project manager, which was carried out in a distributed context where the R&D team, led by the project manager, was engaged in collaboration and communication with actors from a geographically distributed manufacturing site, as well as suppliers from the same region as the site. The product's complexity, which implied interdependencies among the involved actors was a key motive for selecting the project as case study. In the studied project, a complex new product based on mechanics and combustion technology was developed and, due to the geographical distribution, it entailed communication across geographical boundaries.

The study design allowed for detailed insights into the activities, happenings, communication patterns, among others, of the project (Eisenhardt 1989; Voss, Tsikriktsis, and Frohlich 2002; Miles, Huberman, and Saldaña 2014; Yin 2018). One such happening, described in more detail below, was that the R&D team devised visual representations to overcome communication challenges with the distributed suppliers.

Project Beta was carried out by the Husqvarna Group, which is a globally leading producer of outdoor power products for forest, park, and garden care. The project was studied over a period of 3.5 years. Empirical data were continuously collected during the project and encompass the period from its initiation to the start of full-scale production. The dataset is therefore substantial and provides insights into different aspects of the project, including technological matters, product design structure and parameters, project organisation, development process, among others. Another aspect relates to how communication takes place, which is the focus of this paper. Data from multiple sources were collected by the researchers, including interviews, observation of numerous R&D team meetings, observation of meetings between the R&D team and representatives from the distributed manufacturing site, and company documents (Yin 2018). This allowed triangulation to strengthen the internal validity of the findings (Gibbert, Ruigrok, and Wicki 2008; Yin 2018). An overview of the collected data is presented in Table 1.

The analysis in this paper, focusing on communication during the project, involved two consecutive phases. The first phase addressed how visual representations were used for the communication between the R&D team and geographically distributed suppliers. This phase relates to RQ1, focusing on how visual representations became boundary objects in

Table 1. Data collection methods.

| Method | Number and Duration (min) | Comments |
|----------------------------------|---------------------------|---|
| Interviews | 29 (60–120) | Semi-structured, open-ended interviews at different stages of the project, with actors from the Swedish product development and Chinese manufacturing sites. The interviewees represented different roles, such as product manager, project manager, design engineer, laboratory engineer, manufacturing engineer, quality engineer, and purchaser. The interviews were recorded and transcribed. |
| Observations at project meetings | 59 (120) | Observations at project meetings at the Swedish product development site, as well as conference calls between the Swedish R&D engineers and engineers from the Chinese manufacturing site. Notes were taken during the meetings. |
| Informal conversations | Approximately 60 | Following the project meetings at the Swedish product development site, informal conversations were primarily held to further discuss issues of interest (between one of the academic researchers and the industry representative). Notes were taken after the meetings. |
| Workshop | 1 (420) | The workshop involved the R&D engineers in Project Beta and representatives of another company, where experiences from communication in globally and organisationally distributed product development projects were shared, discussed, and analysed. |
| Company documents | Numerous | The researchers had free access to project documentation (e.g. project meeting agendas and minutes, pictures with annotations, communication procedure with suppliers etc.). |

the communication between distributed NPD project actors. The second phase addresses RQ2 and analysed visual representation design, which provided insights into how the design of visual representations influenced their potential to act as boundary objects to support communication in NPD projects in distributed contexts.

Each phase resembles Miles, Huberman, and Saldaña's (2014) idea of how to analyse qualitative data through data condensation, data display, and drawing/verification of conclusions. Data condensation aimed at selecting, simplifying, and organising the transcribed interviews and other data types. A case narrative was written by the researchers and its accuracy verified by the co-authoring project manager (Riege 2003). The narrative was used as an input for a workshop during which the researchers and the co-authoring project manager jointly analysed how visual representations were used as means for communication in Project Beta between distributed actors. The literature on communication in dispersed contexts, as well as that on boundary objects, were used as theoretical lenses for analysis. Thereafter, the design of the visual representations per se was analysed in relation to the literature on the design of visual representations in accordance to the principles of graphic design and design of annotations. In each phase, interview transcripts, field notes, and documents were studied and related to the literature.

3.2. Empirical material

Husqvarna Group develops, manufactures, and delivers equipment for outdoor use. In Project Beta, a new product was developed, targeting professional consumers and being sold under four brands. Low cost and light weight were among the most important criteria. The project had a tight deadline because the market had a seasonal pattern, implying

product launch would be critical. Corporate management decided that the product should be manufactured in a newly acquired manufacturing facility in China. This product was the first, together with a related product, to be produced in this facility.

The R&D team in Sweden included a project manager, two design engineers, and two test engineers. At the Chinese manufacturing facility, engineers representing several competencies, such as R&D, manufacturing, purchasing, and supplier quality assurance were involved. Whereas the Swedish R&D team were experienced in the development of products for professional users, their Chinese counterparts were primarily experienced in manufacturing low-cost products. The company's R&D management model, which resembled a stage-gate process, guided the project. The model outlined several process stages, including state specification, development, industrialisation, and production.

The Swedish R&D team was keen to receive feedback from suppliers regarding component manufacturability to ensure quality criteria were met, stipulated lead times kept etc. However, the suppliers did not speak nor read English, which had not been foreseen by the R&D team and came as a surprise. Hence, the R&D team could not have conventional design review meetings with the suppliers. Instead, it sent so-called engineering change request (ECR) drawings to the manufacturing team who were able to communicate in English. Then, the Chinese colleagues communicated the technical issues to the suppliers. Suppliers' feedback was collected by manufacturing site colleagues, translated into English, and sent to the Swedish R&D team. This communication procedure, with the manufacturing team as intermediaries, differed from the conventional (direct) way of communication with suppliers, resulting in an lengthier procedure than usual. This 'new' communication procedure was not planned for as the communication procedure was not devised at the outset of the project but had to be implemented when the language issue became apparent, it initially caused confusion about roles and responsibilities in the communication with suppliers. Therefore, the project manager specified and visually illustrated the communication procedure that involved the Swedish R&D team, purchasing representatives in China, and suppliers.

The communication procedure is exhibited in Figure 1, showing how the information should flow and be exchanged between involved actors. According to the project manager, after the introduction of the procedure, communication became smoother and questions

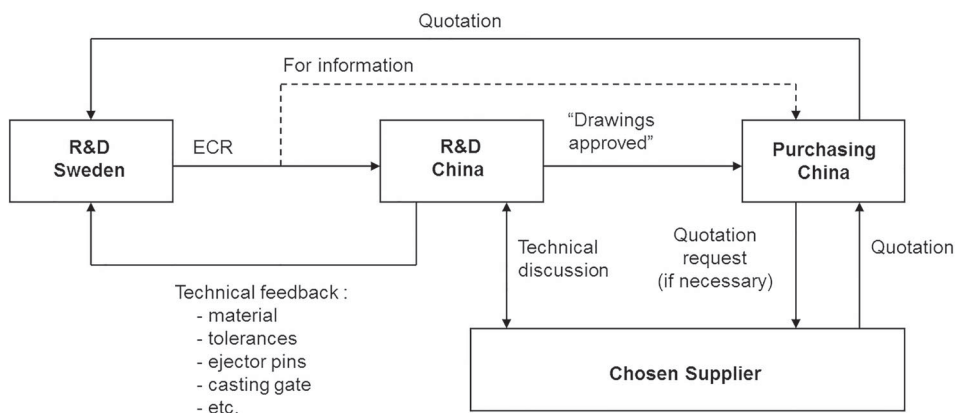


Figure 1. Procedure of communication between the Swedish R&D team and Chinese suppliers.

on how information should flow and who was responsible for collecting and sharing information subsided.

Despite the communication procedure, challenges occurred in receiving the correct information and correctly produced components from the suppliers. The R&D team experienced that when engineering change orders (ECOs), that is, modifications of tooling to secure component tolerances, were sent to the suppliers and the modifications were incorrect or not implemented at all. Therefore, the components delivered by the suppliers often failed to meet the specified requirements.

The R&D team was not sure about the reasons the ECOs were not fulfilled, but the use of conventional means for information sharing via revised product models, drawings, and updated bill-of-materials was clearly not enough to initiate the requested modifications. The R&D engineers from the Chinese manufacturing site also confirmed that the suppliers struggled to understand which modifications to implement based on the revised product models and CAD drawings (e.g. complex geometrical tolerances). The suppliers were unfamiliar with existing drawing conventions and standards used by the Swedish R&D team. One of the Swedish R&D team members stated, 'If they [Chinese suppliers] don't understand, maybe they do not say that ... so they just ignore it and go ahead ...'. To deal with the ECOs, the Swedish R&D team started to take photos of delivered components that were not produced according to specifications. The team also made drawing print-outs of components to which annotations, including text and arrows, were added to explain what was produced incorrectly and what must be modified in the next series of components. The team then sent these to the suppliers and denoted all visual representations as *picture books*. According to the team, this became a simple but effective way to communicate with the suppliers. In other words, the picture books became an essential element of the devised communication procedure, where Chinese engineers were engaged in translating the text on the photos and print-outs from English to Chinese. As a result, the suppliers started to implement the requested modifications, ultimately producing and delivering components that fulfilled the ECOs. According to the R&D team, the introduction of the picture books became a key means to convey the requested modifications.

Despite the different challenges of Project Beta, it was ultimately successful. The launch of the first product was slightly delayed, but it became a market success. The tests conducted by a consumer organisation showed several valuable features of the product: it was aesthetically pleasing, of high quality, had low environmental impact, and was easy to operate. After market entry, its sales volume increased substantially and profitability almost doubled compared to the product it replaced on the market.

4. Analysis

This section first addresses how visual representations were used as means for communication among actors in the Project Beta and then analyses the design of these representations.

4.1. Use of visual representation in distributed geographical context

Literature shows that visual representations in various formats (e.g. sketches, drawings, or simulations) have the potential to support communication and ensure that multidisciplinary actors understand each other (Bechky 2003; Majchrzak, More, and Faraj 2012). It

also reveals that visual representations are concrete means that facilitate translating and learning, as well as identify the dependencies between actors (Carlile 2002, 2004).

Our findings show how differences in understanding the English language and in work experience among the actors involved in a distributed NPD project disrupted communication. Further, the use of conventional boundary objects, such as external design review meetings, revised product models, drawings, and updated bill-of-materials, could not be used as initially intended in the project. To facilitate communication between the Swedish R&D team and geographically distributed Chinese suppliers, the following visual representations were devised by the team: (i) *process-oriented* communication procedures and (ii) *product-oriented* picture books. The value of using such types of representations was not envisioned when the project was planned, but the team devised them as a response to challenges in communication that occurred during the project. The first representation clarified information flows, as well as the roles and responsibilities of the involved actors, whereas the picture books ensured component modifications were correctly implemented by suppliers. Therefore, both types served as effective boundary objects (c.f. Carlile 2002, 2004; Bechky 2003; Majchrzak, More, and Faraj 2012). Both representations were found to play similar roles as intermediates to overcome the potential difference among actors in terms of language and experiences. Interestingly, the simple yet effective visual representations add to the use of ICTs to overcome the potential communication challenges originating from geographic distribution of actors (c.f. Dooley and O'Sullivan 2007). That is, communication in distributed NPD projects is not only facilitated by the use of ICTs (cf. Boutellier et al. 1998) but also by visual representations.

Prior research demonstrated the use of visual representations as starting points to support discussions and that of *product-oriented* communication to align actors' understanding of product design (Kleinsmann, Valkenburg, and Buijs 2007; Ewenstein and Whyte 2009; Luck 2014). Tjell and Bosch-Sijtsema (2015) also show that visual representations can play a *process-oriented* role in project management, for actors obtain a transparent overview of the project and decisions to be made. However, the literature primarily addresses the use of visual representations where actors are co-located (either temporary or full-time) and face-to-face interactions possible for both formal and informal communication. The findings from Project Beta thus indicate that visual representations play a significant role in facilitating communication among geographically distributed actors.

4.2. Design of visual representations

The study of Project Beta did not only reveal how the visual representations were used to overcome communication challenges, but also provided insights into how visual representations were designed and their potential to act as boundary objects in to support communication in NPD projects. As Project Beta was undertaken in a geographically distributed context, it was difficult to use gestures, such as pointing to critical parts, to support communication (cf. Mortensen and Lundsgaard 2011). Instead, visual representations, including a formalised set of conventional symbols (i.e. arrows, circles, frames etc.), were used to support communication with suppliers. Annotations and colour plates were added to photos and drawing print-outs to indicate incorrectly produced components. Colour plates in white, red, yellow, or green were used to direct suppliers' attention to their correctly, incorrectly, or incompletely performed modifications by the Swedish R&D team via ECOS.

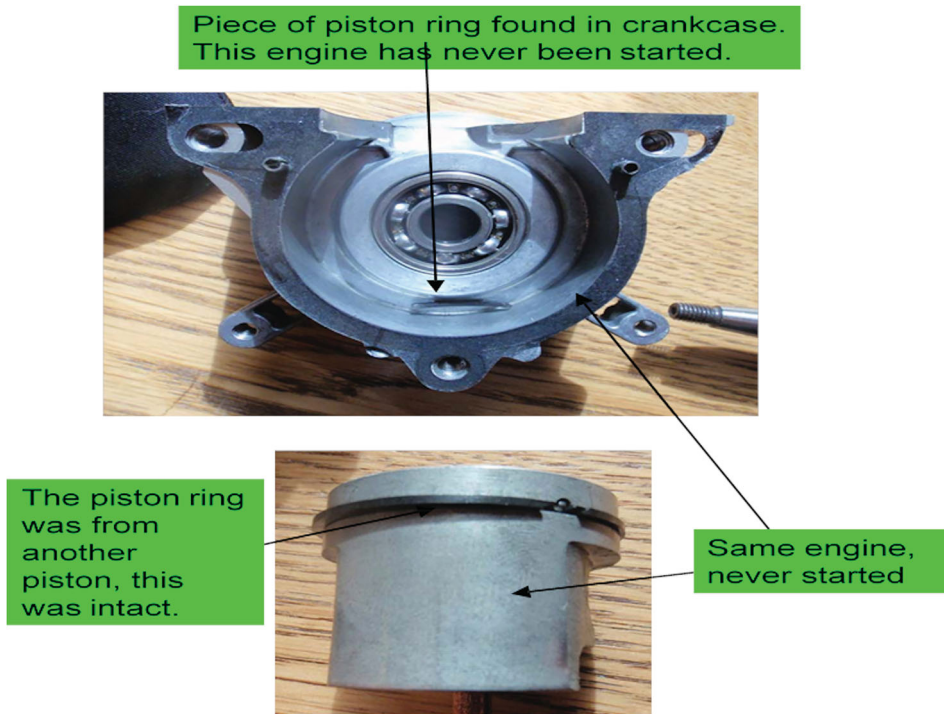


Figure 2. Engine assembly.

However, the visual representations in the picture books were not consistently designed. The original figures, as they compose the unique picture books, are presented below. For example, different colours were used for indicating the status of requested modifications as illustrated in Figures 2–5. Another aspect of visual representations was that annotations were inconsistently used. As exemplified by Figure 2, the arrow overlaps one letter in the annotation. In Figure 5, the abbreviation ‘dept.’ is used instead of spelling out the word ‘department’ in full, and part of the annotation is repeated. Despite the ad hoc design of the annotated picture books and their inconsistencies and poor quality according to principles of well-designed graphics, they served as means to ensure that the requested component modifications were implemented. That is, the visual representations with annotations helped suppliers understand and decode the information initially sent via ECOs.

A closer look at the picture books shows that the various instructions regarding the required modifications were also used as clarifications. Figure 2, titled *Engine assembly*, shows top-view and side-view pictures of a mechanical part, stating, ‘This engine has never been started’, that is, the engine had not been tested. It also provided information on how the R&D team could ensure that it had not been tested: a piece of the piston ring has been found in the crankcase.

Similarly, Figure 3, titled *Clutch*, displays a close-up photo of a clutch taken from above. The text pointed to a problem with a ‘spring missing’. The white-coloured plate indicated a requested modification, with the line pointing to the spot where a spring should have been inserted.



Figure 3. Clutch.

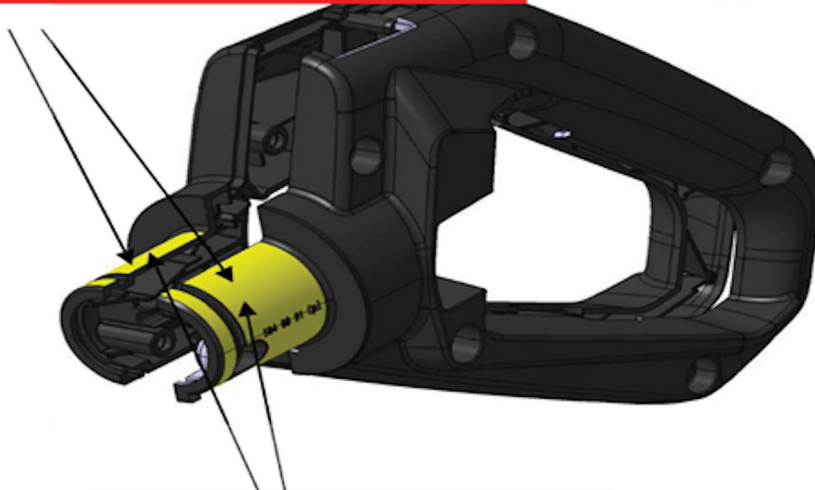
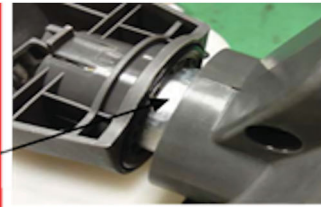


Figure 4. Gear wheels.

Figure 4, titled *Gear wheels*, contained an annotation on ‘too many burrs in the holes’. The lines were used to indicate that some holes required modifications. Although both Figures 3 and 4 showed similar designs, they differed in content and level of details. The clutch photo did not provide information on how the missing spring should be assembled. By only

Our Quality Dept. found that the diameter of the inserted axle is approx. $\varnothing 0.8$ too small.

Also, when we add 0.4 mm thick tape on the axle at the lab, we achieve a much better function and feeling! - SVL



Also, when we add 0.4 mm thick tape on the axle at the lab, we achieve a much better function and feeling! - SVL

Figure 5. Rear handle.

indicating the missing spring, the receiver of the message had to assume that the left part of the clutch with the spring was correctly assembled. In Figure 4, which shows the gear wheels, the R&D team indicated not only the problem, but also which holes were drilled correctly. However, the lines indicating the burr-free holes were barely distinguishable from those pointing to the holes with too many burrs. The text placed in the red plate (Figure 4) emphasised the required changes.

Figure 5, titled *Rear handle*, includes text that not only indicated the required change or the identified problem ('the diameter of the inserted axle is approx. $\varnothing 0.8$ too small') but also explained this requirement was based on test results. The annotation further offered a possible solution: 'when we add 0.4 mm thick tape on the axle at the lab, we achieve a much better function and feeling! - SVL'. Figure 5 shows a red plate and picture, linked by an arrow pointing to a barely visible axle. The figure also contains a print-out of the 3D CAD model, with two additional arrows anchored to the part of the rear handle covered with yellow tape.

Overall, the representations did not follow any principles of graphical design (Hansen 2000; Mollerup 2015). The R&D team was not familiar with such principles and could not apply them when devising the representations. For example, colour plates were used inconsistently, as illustrated in Figure 4, where the white plates indicate both correctly and incorrectly drilled holes.

As such, the question is why did the visual representations work although they were designed ad hoc and not according to graphic design principles? A key reason is that the suppliers were familiar with the components requiring modifications because they had already produced the incorrect or incomplete ones. That is, the R&D team and suppliers shared a common project context, under which the R&D team had designed the components and knew their functionality, materials, tolerances etc., whereas the suppliers had become familiar with the components. This shared project context made it possible for the suppliers to decode and interpret information in the intended manner by the annotated picture books.

Although the picture books were not designed according to graphic design principles, they supported communication in the context of Project Beta by illustrating the components exposed to modifications from different perspectives. The combinations of photos and drawing print-outs with annotations created concrete modifications that could be understood by the suppliers due to their familiarity with the components in the picture books as hands-on and tangible visual representations. Arguably, this was an essential aspect of the communication in Project Beta as due to the differences in language skills, direct and synchronous communication between the R&D team and suppliers was not possible.

5. Discussion and implications

Research asserts the use of advanced ICTs (e.g. tele- and video conferencing) and temporary relocation (face-to-face meetings) to support synchronous communication in distributed NPDs (Barczak and McDonough 2003; Ceci and Prencipe 2013). Based on empirical materials from Project Beta, this paper addresses the design and use of visual representations in NPD projects in distributed contexts.

The findings reveal that, when actors share project context, the use of visual representations is effective for asynchronous communication in a distributed context. Specifically, visual representations in the form of photos and drawing print-outs with annotations can support communication between an R&D team and geographically distributed suppliers, even though the representations do not follow graphical design principles.

Despite prior studies' emphasis on the use of visual representations (e.g. sketches, drawings, CAD models) as means to communicate (Hietikko and Rajaniemi 2000; Goldschmidt 2007) and establish shared understanding (Carlile 2002; Marheineke, Habicht, and Möslin 2016; Cash, Dekoninck, and Ahmed-Kristensen 2017), research has mostly been conducted in co-located cross-functional NPD contexts. As claimed by Lindlöf (2014, 75), there is a need for the 'design of boundary objects for communication in geographically distributed teams'. Furthermore, prior research emphasised the use of visual representations to support negotiations and joint decision making during NPD projects (Carlile 2002; Boujut 2003; Maier et al. 2009; Marheineke, Habicht, and Möslin 2016). As the findings of this paper are based on a study of an NPD project in a distributed context, the capacity of visual representations to convey messages that can be understood and foster the requested actions is highlighted by using picture books.

The findings indicate that the differences in linguistic skills, work experience, and lack of experience in working together pose communication challenges between actors representing different functions and organisations. The findings also show these challenges

cannot be entirely overcome by using ICTs and designated boundary objects such as external drawing reviews and updated drawings/documents. Designated boundary objects are means of communication assigned to cross the boundaries of various functions based on designs and properties (Levina and Vaast 2005). In line with Levina and Vaast's (2005) findings, we also highlight the importance of 'in-use' boundary objects, corroborating the argument of prior research that boundary objects' capacity is contextual (Carlile 2002; Bechky 2003). The findings of this study extend the prior research by indicating that it is not the graphic design quality that made the boundary object, i.e. visual representations, effective but rather the shared close engagement with the object's details.

This study also shows how specific boundary objects are devised as responses to the challenges from the differences in actors' linguistic skills and work experience. Arguably, the *process-oriented* communication procedure devised by the Swedish R&D team to visualise the flow of information to and from Chinese suppliers worked well because the actors shared the same project context. Similarly, the *product-oriented* picture books also served as means to support communication because component modifications, as indicated in photos and drawing print-outs with annotations, were transmitted to the suppliers, being based on their prior familiarity with the components. That is, the suppliers recognised the components and could relate the information conveyed in the picture books to their previous experiences.

As shown by Project Beta, the relevance of using specific boundary objects is linked to the unique NPD project context, where boundary objects were useful due to the shared context, which acted as 'a glue' between actors. As the boundary objects were not designed at the outset of the project but later as responses to communication challenges, the R&D teams should consider contingencies and be open-minded about new means of communication for particular projects. However, Project Beta provides evidence that visual representations can be effective in transmitting information that fosters action. That is, there is a need for flexibility in selecting and switching between the methods to communicate within NPD projects. In other words, the findings imply the need for a dynamic and context-dependent perspective of communication in NPD projects.

This study shows that, in a geographically distributed context, graphical elements (e.g. arrows, colour blocks) can fulfil a role that would normally be fulfilled by gestures in informal communication, that is, facilitate the use of visual representations during face-to-face communication, such as by pointing to a critical section of a drawing (Mortensen and Lundsgaard 2011; Cash and Maier 2016). Arguably, the use of visual representations with annotations can, to a certain degree, complement or even replace face-to-face communication, where gestures are frequently used.

6. Conclusions

This paper focused on how visual representations support effective communication in a distributed context for the development of a complex new product based on mechanics and combustion technology. Specifically, it investigated the design and use of visual representations to support communication between an R&D team and geographically distributed suppliers. Communication challenges in a distributed NPD context arising from differences in linguistic skills and work experience cause frustration and insufficient communication flows, ultimately resulting in delayed product development. However, it can be

concluded that visual representations designed ad hoc and used in a shared project context are conducive for communication, although they are not designed according graphic design principles. Here, the use of picture books was effective and added to the use of ICTs. One explanation is that teams sharing project context can create internal conventions about the visual representation.

The main practical implication of the study is that it reveals the need for a dynamic and context-dependent view on communication in NPD projects, where project managers allow the emergence of new means of communication that best fit a specific project situation. The authors acknowledge the limitations of the study due to the use of a case study approach. However, the findings were related to the literature to achieve analytical generalisation (Yin 2018). While case findings are useful for theory extension (Voss, Tsikriktsis, and Frohlich 2002), additional empirical data from similar and other research contexts should be used to reinforce the results' validity and provide more examples of the roles and designs of different boundary objects in distributed NPD contexts. An interesting avenue for future research would be to compare the findings of this study with scenarios where the visuals are based on graphic design principles (Lupton and Phillips 2015).

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