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Boundary objects, knowledge integration, and innovation management: A systematic review of the literature

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ABSTRACT

Enabling collaboration across disciplines, business functions, departments, organizations, and industries is a critical innovation management challenge. Successful innovation depends on effective knowledge integration among diverse actors. The concept of boundary objects to achieve knowledge integration has gained increasing popularity within innovation management. Despite the growing relevance, existing literature reviews about boundary objects are sparse. This review examines how boundary objects enable knowledge integration through a systematic analysis. An integrating framework of the scholarship on boundary objects links existing contributions to key theoretical perspectives on the study of boundary spanning for knowledge integration. Relevant publications are identified through a systematic literature review and discussed according to three themes: information processing, cognitive, and learning perspective on knowledge integration. Potential contributions to broader theorizing are highlighted in relation to three innovation settings: cross-functional collaboration, open innovation, and staged product development processes.

1. Introduction

It is well established that a critical challenge in the field of innovation management is to realize effective collaboration among experts across business functions and departments, and increasingly often across organizations and industries (2003; Edmondson and Harvey, 2017; Love and Roper, 2009; McAdam et al., 2008; Wang and Hu, 2020). The innovation endeavor thus implies the need to integrate team members' knowledge successfully, overcoming multiple boundaries that arise from the disciplinary specialization and the heterogeneity of cognitive frames (Berggren et al., 2011; Carlile, 2004; Tell, 2017).

A key challenge in organizational processes and practices aiming for innovation – such as new product development projects (Hansen et al., 2000; Schulze and Hoegl, 2006), public hackathons (Almirall et al., 2014; Irani, 2015), or industry-science collaboration programs (Fontana et al., 2006; Perkmann et al., 2013) – is for them to allow for sufficient variety to generate novelty, while at the same time, be conducive for communication across domains that enable implementation. Communal and centrally localized practices favor communication over novelty, but distributed and decentralized practices do the opposite. To innovate, however, it is necessary to be creative yet comprehensible to specialized individuals in communities of – for instance – engineers, managers, academics, salespeople, or end-users.

Literature spanning more than two decades of research has suggested that boundary objects may offer one solution to this innovation dilemma. Leigh Star initially conceived the concept of boundary objects as a way to think about the structure of ill-structured solutions in scientific practices where scientists *"cooperate without having good models of other's work; successfully work together while employing different units of analysis, methods of aggregating data, and different abstractions of data; cooperate while having different goals, time horizons, and audiences to satisfy"* (Star, 1989: 47). In such contexts, Star suggested that a boundary object becomes an important method for problem-solving, as it – like a classroom blackboard – "sits in the middle" between actors holding different points of view without being homogenously omnipresent. While Star's work was embedded in the field of Science and Technology Studies (STS), Paul Carlile introduced the concept to management and innovation research in the early 2000s and suggested additional features of boundary objects. Carlile's work was particularly pertinent to organizational innovation settings such as new product development (Carlile, 2002, 2004). To study how knowledge is structured and integrated in innovation, Carlile (2002: 446) proposed

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that:"*'objects' refer to the collection of artifacts that individuals work with – the numbers, blueprints, faxes, parts, tools, and machines that individuals create, measure or manipulate.*" Carlile's notion of boundary objects has spurred substantial interest among innovation management researchers.

Research on boundary objects served as a continuation of prior literature pointing to the importance of knowledge integration of distributed knowledge as a dynamic process in understanding the nature of firms, competitive advantage, and innovation (Grant, 1996; Kogut and Zander, 1992; Teece et al., 1997). Moreover, boundary objects pointed to empirical instances that could be examined in detailed studies of innovation and challenges pertaining to knowledge integration in concrete organizational practices (Dougherty, 1992; Enberg et al., 2006). It is, therefore, not surprising that Carlile's work has been widely diffused and employed in many studies.[1] More surprising perhaps – given this impact – is the dearth of systematic efforts to bring these findings together into more comprehensive reviews and syntheses. In particular, as Carlile's findings were situated in innovation contexts, knowing more about how boundary objects have been identified, studied and conceptualized should provide a clearer picture of domains of applicability, conceptual refinement, and remaining unresolved issues. In our review of the more general literature on boundary objects, we found only three literature reviews, none of which explicitly zooms in on general implications for innovation management research. While Akkerman and Bakker (2011) review research on boundary objects in relation to the domain of educational research and Kanwal et al. (2019) survey boundary objects with respect to knowledge management research, Marheineke et al. (2016) specifically focus the role of boundary objects in virtual collaboration.

Provided the relevance of boundary objects for innovation research and the number of extant empirical studies applying the notion of boundary objects in innovation contexts, we suggest that a systematic literature review helps to shed light on a set of research questions:

- What are key aspects in which research has identified boundary objects as conducive to knowledge integration in innovation?
- What type of innovation settings could the boundary object approach lend itself useful to in the future?
- What theoretical and phenomenological headway has been made so far in empirical research on boundary objects in innovation processes?

The present article addresses the questions above with a systematic review of the extant literature on boundary objects in innovation management. We reviewed 87 papers employing the concept of boundary objects as a key aspect of knowledge integration in innovation. Our analysis reveals three emerging perspectives on knowledge integration (information processing, cognitive, and learning). In the review, we further show that different categories of boundary objects support different perspectives on knowledge integration. In turn, we warrant the careful selection of boundary objects depending on the knowledge integration requirements of the innovation process at stake. We believe that our findings contribute primarily to the literature on knowledge integration within innovation management. Our work extends prior conceptual work (Van de Ven and Zahra, 2017) that stresses the centrality of boundary objects in the processes of knowledge integration for innovation and we discuss avenues for further conceptual refinement as well as empirical application of the concept.

[1] As of June 14, 2022, The two seminal articles by Carlile (2002) and Carlile (2004) together accounted for 8379 citations in Google Scholar (GS), and 3065 citations in Web of Science (WoS). This means that on average one of the two articles were cited in general (GS) by ca. 400 new publications a year and in high quality research journals (WoS) by ca. 150 new articles per year.

2. Knowledge integration and boundary objects in innovation

The concept of knowledge integration exists to address the problem of coordination between economic agents who retain specialized knowledge (Grant, 1996; Tell, 2011; Zahra et al., 2020). According to Grant (1996), the gains of specialization of knowledge make it important for organizations to rely on the coordinated efforts of specialists in order to build a competitive advantage. While Grant primarily referred to the implications of knowledge integration for firm efficiency, his view on knowledge integration resonates well with innovation research. In particular, the ability of forms to integrate and recombine and integrate knowledge both within and across the boundaries of the firm for innovations is emphasized in seminal contributions by Cohen and Levinthal (1990), Henderson and Clark (1990), Kogut and Zander (1992); Nonaka (1994), Teece et al. (1997) and Okhuysen and Eisenhardt (2002). More recently, concepts such as open innovation (Chesbrough, 2003) and knowledge boundary bridging (Tell, 2017) have been introduced to highlight and analyze organizations as they span boundaries to integrate knowledge in innovation processes. More specifically, Van de Ven (2017) and Van de Ven and Zahra (2017) identify boundary objects as a crucial means to communicate and span across complex knowledge boundaries in innovation.

Knowledge integration requires spanning knowledge boundaries among diverse actors. The concept of boundary object describes artifacts and concepts allowing diverse individuals to span the boundaries of their specializations and integrate knowledge (Bechky, 2003; Carlile, 2002; Majchrzak et al., 2012; Nicolini et al., 2012). Star and Griesemer (1989) define boundary objects as *"objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites"* (Star and Griesemer, 1989: 393). This definition indicates that boundary objects are used as interfaces for knowledge integration that can be *"shared across different problem-solving contexts"* (Carlile, 2002: 451) and do not require deep sharing to be understood by collaborating parties (Nicolini et al., 2012). Examples of boundary objects in the context of innovation management include, amongst others: prototypes, drawings, sketches and designs, simulation models, databases, and software platforms.

The study of knowledge boundary spanning points to a practice perspective on organizations (Carlile, 2002; Champenois and Etzkowitz, 2018; Levina and Vaast, 2005). The practice of using boundary objects (Carlile, 2002; Star et al., 1988; Star and Griesemer, 1989) thereby serves as a theoretical lens to apply to the study of knowledge integration in innovation. Accordingly, the concept of boundary objects (Star and Griesemer, 1989) describe *"the stuff of action"* (Star, 2010: 603). As a baseline, any object that mediates collaboration across heterogenous social actors can become a boundary object through its enactment in practice (Carlile, 2002; Levina, 2005; Levina and Vaast, 2005). However, shared objects that fail to generate a common understanding do not qualify as such (Bechky, 2003). Boundary objects need to afford explicit cycles of contestation and justification by all actors involved in the collaboration (Tuertscher et al., 2014).

3. Literature review process

To enhance our understanding of the concept of boundary objects, we performed a systematic literature review in innovation management studies. The choice of a systematic review – rather than a narrative review or a meta-analysis – was guided by two main rationales: to provide methodological rigor in mapping existing academic research on boundary objects (Tranfield et al., 2003); and to establish a foundation to compare the use of boundary objects in empirical work (Söderlund and Borg, 2018). We followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) to enhance our procedure's reliability (Shamseer, 2016; Williams et al., 2021).

3.1. Data sources and searches

As a first step in our review process, we framed the objective of the review and we selected the main data sources. By reviewing the literature, we aimed to find out: (a) how boundary objects support knowledge integration within innovation studies, and (b) research gaps that could shape future innovation scholarship. The goal was to synthesize the dispersed contributions on boundary objects in innovation management and inform future innovation scholarship. Therefore, we aimed for a comprehensive pool of articles employing the concept.

Following established practices in management reviews (Steigenberger, 2017; Strutzenberger and Ambos, 2014), we chose to include only peer-reviewed scholarly journals in the review. To identify relevant articles within the literature, we used the ISI Web of Knowledge's Social Science Citation Index (SSCI) database (Brown, 2015; Granstrand and Holgersson, 2020; Söderlund and Borg, 2018). SSCI is one of the largest databases of peer-reviewed articles in social sciences, and it offers an ample range of parameters for more focused queries. Finally, we employed Google Scholar as a secondary search engine in accordance with other literature reviews (Berends and Antonacopoulou, 2014; Söderlund and Borg, 2018)

The literature review was carried out the first time in 2017 and updated until May 2022. The review period started in 1989 when the foundational work of Star and Griesemer (1989) was published. We searched for articles using the keywords "boundary object*" in abstract, title, or topic. We did not conduct additional searches using keywords often used to exemplify boundary objects, such as artifacts, prototypes, and concepts, because we wanted to focus on how the label "boundary object" is used in literature.

3.2. Study inclusion and exclusion criteria

The preliminary search yielded 1464 publications. Then, we refined the search by filtering by research area ("management" and "business") and by document type ("article"). At this point, we obtained 317 articles. Finally, we narrowed down the number of publications by selecting source titles. We used the Chartered Association of Business Schools (ABS) Academic Journal Guide (AJG) as a frame of reference. The ABS AJG guide is the foremost reference document for ensuring the quality of academic publications (Nolan and Garavan, 2016). We included in the review all journals belonging to the categories of *General management, ethics and social responsibility*, *Information management, Innovation, Operations and technology management*, *Organization Studies*, and *Strategy*, because of the pervasiveness of studies set in an innovation context within the larger field of Organization and Management Studies. The final selection resulted in 188 references that became the starting point of our manual review.

We exported all 188 references into an Excel list including titles, abstracts, keywords, authors, source, year, and number of citations. We decided to include in the review only articles set in the context of innovation or new product development and that contributed to knowledge integration through boundary objects (Table 1 provides the the full list of inclusion and exclusion criteria). To ascertain whether the articles met our inclusion criteria, we first read through the abstracts and eliminated articles that were not set in an innovation context. Then, we downloaded the full-text of the remaining 101 articles. To assess the articles' theoretical contribution, we carefully read through the article's discussion section. We eliminated articles that mentioned boundary objects, but not as a central topic within the theoretical contribution of the paper. For instance, we did not include articles that referred to artifacts within the innovation process as boundary objects without elaborating on the actual role of such artifacts. Instead, we included articles that critically assess the role of boundary objects in enabling knowledge integration processes and dynamics. After this additional step, we were left with 87 papers.

Table 1
Inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion
Publication Type	Journal (Research article) ranked in ABS list	Review articles, book chapter, book series, conference proceeding
Language	English	Non-English
Timeline	1989–2022	Before 1989
Subject Area	Business and Management (Web of Science) and General management, ethics and social responsibility, Information management, Innovation, Operations and technology management, Organization Studies, and Strategy (ABS list)	Other than Business and Management (Web of Science) and General management, ethics and social responsibility, Information management, Innovation, Operations and technology management, Organization Studies, and Strategy (ABS list)
Context	Innovation or New Product Development	Other than Innovation or New Product Development
Theoretical contribution	Knowledge integration through boundary objects	Other than knowledge integration through boundary objects

3.3. Data extraction and quality assessment

Articles that met the inclusion criteria underwent data extraction by the first author. The following data was extracted:

- Type of knowledge integration: How is knowledge integration characterized in the paper?
- Type of boundary object: What is the nature of the boundary object under study?
- Innovation context: In which context is the article set?
- Method: What research method was employed by the article and what epistemological stance could be discerned?

3.4. Data synthesis and presentation

We used the leading questions presented in the data extraction section to enrich the original Excel list with additional elements, which we used as component codes. We then analyzed the component codes to find component themes. We identified three component themes related to knowledge integration: information processing, cognitive, and learning. The three themes describe different knowledge integration perspectives. As expected, it was not always possible to classify articles in a single theme. Articles focusing on different phases of the innovation process tended to adopt different perspective. In case of ambiguous cases, we included the article in both component themes. When it comes to the identification of knowledge integration types, our process was inductive. In fact, we operate an inductive reasoning based on our findings and only in the labeling we rely on pre-existing categories that we apply to our inference.

We repeated the same process to identify component themes in the "type of boundary object" and "innovation context" categories. As a result, we identified three component themes when it comes to types of boundary objects (infrastructure/representation, concept/narrative, and product/prototype) and three component themes based on innovation settings (cross-functional collaboration, open innovation, and staged product development projects). The first author conducted the review and involved the second and third author in the final identification of themes.

After a first round of open coding, we performed axial coding to compare the three knowledge integration themes with the types of boundary objects and with the innovation context. We observed that articles adopting an information processing perspective most often used boundary objects belonging to the infrastructure/representation category; articles adopting the cognitive perspective used boundary objects belonging to the concept/narrative category; and articles adopting the

learning perspective used boundary objects belonging to the product/prototype category (Table 2). While we found patterns when comparing knowledge integration perspectives and types of boundary objects, it was not the case when analyzing innovation contexts. However, we used the component themes based on innovation contexts to structure the future research section. An analysis of the methodologies applied emanated in a methodological note suggesting that most studies were using qualitative methods, albeit many used the concept of boundary objects rather instrumentally.

The literature review was presented at multiple conferences and bootcamps to validate the themes with experts before submission.

3.5. Results

The search identified 1464 publications. After removing records marked as ineligible because of the publication type and subject area, we screened 188 records and we sought 101 records for retrieval. In total, we excluded 14 publications because their theoretical contributions did not lie within knowledge integration and innovation studies. We scanned reference lists to find additional eligible publications, and we used Google Scholar to check that we did not miss any relevant publication. The final sample covers 87 contributions from over 30 different outlets, reflecting the wide application scope of the concept of boundary objects. Fig. 1 depicts the review process, while a final list of articles is included in the appendix.

Table 2
Overview of the three main themes of the review.

Themes (based on Knowledge Integration)	Category of boundary objects	Description	Sample references*
Theme 1: - *Information processing perspective* - *Trading practice* - *Knowledge integration as use of similar/ related knowledge*	Infrastructure/ Representation	Knowledge is traded through the boundary object. Objects such as project documents and platforms catalyze knowledge. Collaborative agents contribute their perspective on the knowledge representation with the objective of improving the representation. *Example: Use of roadmaps in product development*	Kellogg et al., (2006); Kerr et al., (2012); Seidel and O'Mahony (2014); Tuertscher et al., (2014)
Theme 2: - *Cognitive perspective* - *Sharing practice* - *Knowledge integration as knowledge sharing or knowledge transfer*	Concept/ Narrative	Knowledge is shared around a boundary object. Collaborative agents share their knowledge around joint concepts and narratives with the objective of learning from each other. *Example: Online platforms supporting collaboration in innovation communities*	Rullani and Haefliger (2013); Enninga and Van der Lugt, 2016; Kane and Ransbotham (2016)
Theme 3: - *Learning perspective* - *Knowing practice* - *Knowledge integration as combination of specialized knowledge*	Product/ Prototype	New knowledge is created in the interaction of collaborating agents with an object in common. The object evolves during the interaction to reflect the new knowledge created out of the diverse knowledge bases of the actors. *Example: Prototypes*	Qureshi et al. (2018); Fosstenlokken, 2019; Nagaraj et al. (2020)

4. Perspectives and emerging themes from the review

We identified three different perspectives on the study of knowledge boundary spanning that inform how boundary objects may operate for knowledge integration in innovation to take place: *information processing perspective* (Cacciatori, 2008; Galbraith, 1973; Prado and Sapsed, 2016), *cognitive perspective* (Boland and Tenkasi, 1995; Carlile, 2002), and *learning perspective* (Bechky, 2003; Orlikowski, 2002). These perspectives are closely related to three knowledge boundary spanning practices identified by Hsiao et al. (2012): *trading, sharing*, and *knowing* (Hsiao et al., 2012), and more generally to different views on knowledge integration (Tell, 2011).

Although the three perspectives on knowledge boundary spanning and the corresponding practices of trading, sharing, and knowing are distinct, one does not exclude the other, especially in case of ongoing or long-term collaboration that is expected to produce multiple deliverables along the way. This is often the case within innovation contexts, where knowledge boundary spanning occurs continuously and at different levels to achieve knowledge integration.

We use the three perspectives to organize reviewed articles into themes. Before presenting the themes, this section includes a methodological and epistemological note. The methodology and epistemological stance of innovation studies employing the concept of boundary object indicates the how the perspective is used as an analytical lens.

4.1. Methodology and epistemology of the reviewed studies

From a methodological standpoint, qualitative methods are the predominant empirical approach to study boundary objects. Many contributions draw upon a single case study and rely on ethnographic work. The preference for qualitative methodologies reflects the nature of the concept of boundary objects, which requires in-depth user observations and fine-grained data about the context of use of the objects. At the same time, the review brought forward the challenges in collecting longitudinal data and in quantifying the impact of boundary objects on the process of knowledge boundary spanning.

More complex is the analysis of the articles' epistemology due to the fact the philosophical stance of the articles under review was often left implicit. As posited in the introduction, boundary objects have been initially studied in the context of Science and Technology Studies (STS), a field concerned with understanding the production of scientific and technological knowledge (Zeiss and Groenewegen, 2009). STS considers boundary objects as an emergent property of artifacts that mediate the relationship among independent social worlds (Bowker et al., 2015; Mengiste and Aanestad, 2013). In simple words, according to STS boundary objects cannot be chosen or designed. Every artifact within a collaborative setting may become a boundary object if it gains centrality in establishing a knowledge-based relationship among diverse actors. In time, contributions adopting the notion of boundary objects within Organization and Management Studies (OMS), to which the innovation field belongs, are steadily increasing in number and scope (Zeiss and Groenewegen, 2009). OMS view boundary objects as management tools to be designed and deployed to enable knowledge-based collaboration (Mengiste and Aanestad, 2013; Zeiss and Groenewegen, 2009). The more managerial orientation gives centrality to the effectiveness of boundary objects to span boundaries (Carlile, 2002; Zeiss and Groenewegen, 2009). Many of the reviewed articles employ an instrumentalist view of boundary objects, rather than viewing boundary objects as

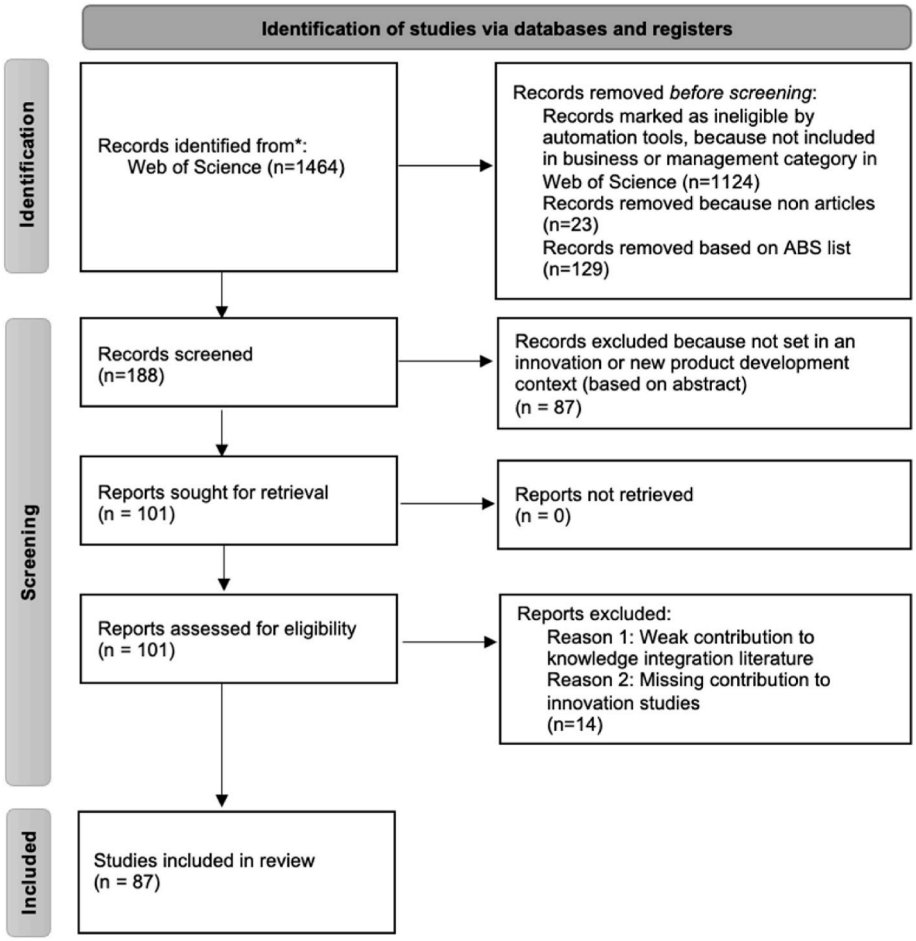

Fig. 1. Prisma diagram.

emergent theoretical concepts. Several articles include recommendations on how managers and organizations can leverage boundary objects to achieve specific ends. This is a specific use of boundary objects that counter the original theorization of boundary objects within STS.

4.2. *Theme 1: boundary objects and information processing*

The information processing perspective (Galbraith, 1973) is the oldest, and it emerged out of a need to overcome the challenges of coordination across different specializations. Studies that adopt this perspective consider knowledge as information that allows for straightforward interpretation without recurring interaction among collaborating actors. The corresponding practice of *trading* entails that, from an information processing perspective, knowledge is treated as a tradable good that can be stored and retrieved (Hsiao et al., 2012) and knowledge integration is viewed as use of similar/related knowledge (Tell, 2011). Despite its long establishment, the information processing perspective is still influential. Advances in digital technology are making information processing through boundary objects more and more sophisticated. While the first papers on the topic studied basic information systems and analog information infrastructures, more recent contributions reflect technological progress. For example, researchers focused on virtual workspaces (Alin et al., 2013), the ATLAS detector (Tuertscher et al., 2014), and BIM (Building Information Modelling) technologies (Papadonikolaki et al., 2019). With the increase in storage capacity and efficiency in retrieving information, the individual ability of social actors to trade knowledge through information representations is becoming more and more important.

Boundary objects support trading when they create zones made of knowledge representations that enable coordination among actors (Kellogg et al., 2006). Austin et al. (2012) describe "trading zones" as grounds for encounters between diverging expectations and knowledge bases of collaborating actors. Normally, trading zones exist when the purpose of collaborating actors emerges through interlacing knowledge within the collaboration process instead of being specified a priori (Tuertscher et al., 2014). For instance, the trading mode works well in the innovation context, where broad targets require continuous dynamic coordination (Seidel and O'Mahony, 2014). While developing boundary objects, collaborating individuals engage in collective thinking (Bowman, 2016). Boundary objects resulting from this process provide representations of problems from multiple perspectives (Simon, 1996). Through negotiating problem representations, individuals align their efforts towards a common end, although the end is initially unspecified (Seidel and O'Mahony, 2014). A typical example of boundary objects affording trading within innovation projects are roadmaps. Kerr et al. (2012) provide an illustration of the use of roadmaps in innovation. In their article (Kerr et al., 2012), they explain how roadmaps result from the process of roadmapping, which consists of three stages: cogitate, articulate, and communicate. While cogitate refers to individual brainstorming of ideas, the articulate and communicate refer to the collaborative act of the roadmapping workshop participants to select and synthetize individual contributions into a shared artifact (Kerr et al., 2012).

New trading zones are produced when knowledge representational modes change. The change in representational modes can be used to identify blind spots in the sense-making or sense-giving of collaborating actors (Garreau et al., 2015). For instance, this happens when power point slides are substituted with 3-D prototypes within project

discussions. Moreover, by integrating multiple representations into single boundary objects, the actors' knowledge can be gathered in one place, making the identification of available expertise, missing expertise, and best practices possible (Eppler and Pfister, 2014).

Trading zones can eventually emerge in a serendipitous manner. Boundary objects favor "accidental outcomes" (Austin et al., 2012: 1518) that occur when independent actors discover common ground through the objects and give rise to "new predictive logics" (Austin et al., 2012: 1518). For example, design thinking laboratories foster projects' cross-fertilization by keeping probes and visuals in sight. This is exemplified by Caccamo's (2020) study of business studios – innovation spaces that employ design techniques to foster collaborative innovation work – discussing space generativity and providing illustrations of how teams sharing the same physical space may be influenced by each other.

4.3. Theme 2: boundary objects and cognition

The uptake of the topic of boundary objects in organization and innovation literature expanded the study of boundaries to several diverse contexts, which sought to leverage distributed knowledge to innovate (Carlile, 2004). This recent stream of literature views knowledge as cognition (Hsiao et al., 2012) and knowledge integration as knowledge sharing or knowledge transfer (Tell, 2011). The practice of *sharing* knowledge among diverse collaborating actors implies transcending the boundaries of individual cognition. The main focus of the cognitive perspective has been the strategic management of knowledge across boundaries to gain competitive advantage (Alexander et al., 2016). According to the cognitive perspective, knowledge boundaries can be classified in three types: syntactic, semantic, and pragmatic (Carlile, 2002). The three types reflect studies of communication complexity (Shannon and Weaver, 1949), which stress different levels of challenge in multi-disciplinary interaction.

The cognitive perspective on knowledge boundary spanning is the most recurrent in the reviewed papers thanks to foundational articles, such as Carlile (2002). Sharing involves knowledge translation (Carlile, 2002) and it rests on the assumption that different occupational communities develop sticky knowledge (Nelson and Winter 1982), which is difficult to transfer via simple communication across contexts (Bechky, 2003). Being socially constructed and situated (Bechky, 2003: 313), knowledge is not treated as a commodity abstracted by local understandings (Brown and Duguid, 1991; Lave and Wenger, 1991). At the same time, a failure to capture inputs from the different collaborating actors might lead to a failure to integrate relevant knowledge (Puri, 2007). Therefore, sharing takes place when boundary objects are employed within and across local contexts as grounds for the establishment of common understandings (Bechky, 2003). When sharing happens, boundary objects are instrumental to the development of a common way of accessing knowledge; they are not mere knowledge repositories (Orlikowski, 2002). Knowledge brokers enhance the properties of boundary objects. For instance, when shared IT systems exist, IT personnel can enhance the systems' usefulness by supporting user communities in making the most out of them (Pawlowski and Robey, 2004).

Boundary objects supporting the cognitive perspective and knowledge sharing are often concepts or narratives. Pivotal to the sharing mode are the linguistic characteristics of boundary objects (Belmondo and Sargis-Roussel, 2015). Boundary objects may curb the influence of spoken language on both the interpretations (conceptual or factual knowledge) and intentions of collaborating actors by enabling exchange through more neutral material representations (Belmondo and Sargis-Roussel, 2015) that afford cycles of clarification and contestation to find alignment. Communication through boundary objects occurs through the content, technology and practice that characterize the object (Puri, 2007). Actors who are interested in the same content and operate through the object's technology develop shared practices. Over time, these common practices support the formation of communities that are fertile ground for effective knowledge sharing (Kane and Ransbotham, 2016). Online innovation platforms are a typical example of development of shared practices around common interests. Rullani and Haefliger (2013)'s study of communities of creation and Open-Source software projects provides insights on how code and virtual discussion can be used as means to define standards of social practice and enable knowledge based collaboration.

An underappreciated, yet emerging, topic connected to the cognitive perspective is the aesthetic component of boundary objects in supporting knowledge sharing (Endrissat et al., 2016). While the topic of "visual material" has achieved increasing resonance in management and organization studies to the point of calling it a "visual turn" (Meyer et al., 2013), boundary objects' scholarship only marginally touched on the issue. Among the few exceptions, Endrissat et al. (2016) studied the role mood-boards in enabling coordination and alignment among interdisciplinary teams. In their paper, Endrissat et al. (2016) emphasized the fact mood-boards allow to share knowledge about the aesthetic and emotional product requirements, which a simple written product brief would not be able to convey. Visual artifacts are especially important to innovation management, which heavily relies on the creativity of very diverse collaborating actors (Endrissat et al., 2016). Somehow connected to the concept of aesthetics, Islam et al. (2016) reinforce the idea that cognition passes through sensory boundaries in their study of perfume making. The visual and broader sensory experiences triggered by boundary objects are likely to impact on knowledge boundary spanning. Researchers have only started to open this black box (Endrissat et al., 2016; Islam et al., 2016).

4.4. Theme 3: boundary objects and learning

The learning perspective differs from the cognitive perspective in that new knowledge is created, hence the label *knowing* to describe the corresponding practice, and new communities are formed around a common issue (Hsiao et al., 2012). The distinction between cognitive and learning perspective highlights the difference between knowledge shared within specialized communities and knowledge transformed in communities that get changed by the transformed knowledge (Qureshi et al., 2018). The learning perspective has achieved considerable success within the communities literature at large (Brown and Duguid, 1991; Cohendet et al., 2014), and more specifically in relation to the concept of "epistemic communities" (Cohendet et al., 2014; Tell, 2017). According to the learning perspective, knowledge integration is viewed as the combination of specialized, differentiated, but complementary knowledge (Tell, 2011).

The learning perspective on knowledge boundary spanning focuses on "acts of knowing" and "communal learning" (Hsiao et al., 2012: 466). In this case, collaborating actors do not engage in deep knowledge sharing (Majchrzak et al., 2012). Instead, boundary objects are transformed into simplified, or symbolic, representations of the whole system to gather specialized knowledge around the issue at stake (Hsiao et al., 2012). Boundary objects act as knowledge catalyzers supporting cross-functional discussion, without the need to fully transfer independent knowledge among the involved parties (Majchrzak et al., 2012). Prototypes, and subsequent products, are a typical example of boundary objects enabling knowing within innovation projects. For example, Nagaraj et al. (2020) present prototypes as external learning probes that clarify meaning and enable shared understanding in teams that use design thinking to develop innovative products. The study places particular emphasis on the usefulness of collaborative representations, such as prototypes, to enhance product's utility and novelty in contexts that are familiar to the collaborating teams (Nagaraj et al., 2020).

The importance of context familiarity explains why many papers adopting the learning perspective study problem-based cross-occupational collaboration. Patients' treatment is a case in point (DiBenigno and Kellogg, 2014; Nicolini, 2011; Oborn and Dawson, 2010). In this context, boundary objects such as patient charts might help translate

meaning across occupational boundaries, coordinate work and derive new understandings of patients' clinical situation (DiBenigno and Kellogg, 2014). However, this perspective is relevant to innovation scholars too. Innovation studies link the learning perspective to the role played by boundary objects in supporting socialization of collaborating partners. For instance, Lobo and Whyte (2017) view digital delivery of complex projects as a learning journey, where socialization through boundary objects such as integrated software plays a fundamental role to create a shared identity across partner firms and enable knowledge work.

Reflexivity is another important component of the learning perspective within innovation studies. Knowledge representations trigger reflexivity in the collaborating group and the production of new knowledge in a spiral of perspective making and perspective taking (Boland and Tenkasi, 1995). In their study of the adoption of digital 3-D representations in architecture, engineering and construction, Boland et al. (2007) leverage the reflexivity within Frank Gehry's architectural firm to develop their findings. The authors find that the introduction of a new representational form allowed the project networks of Gehry's architectural firm to not only integrate more diverse knowledge sources, but also to identify new innovation pathways through the creation of new knowledge. This suggests that a mindful adoption of different boundary objects may boost innovation across specialized communities.

5. Future research avenues in innovation settings

As integrating knowledge across knowledge boundaries is a problem faced in many innovative contexts, we identify three settings where recent innovation research indicate that the concept of boundary objects could enhance both theoretical development as well as managerial practice: *cross-functional collaboration*, *open innovation*, and *staged product development processes*. The three settings emerged from the literature review and focus on the following types of boundaries respectively: intra-organizational boundaries, extra-organizational boundaries, and temporal boundaries (cf. Tell, 2017). In this section and in the table below (Table 3), we point out future research areas based on the knowledge integration perspectives themes and on the three innovation settings.

5.1. Cross-functional collaboration

Research in innovation management has since long identified cross-functional collaboration as a key challenge in innovative efforts, a prime example being the dynamics of new product development teams (Clark and Fujimoto, 1990; Dougherty, 1992; Perea and von Zedtwitz, 2018). In such settings, knowledge specialization into cognitive domains mirrored in organizational functional units serves as both a prerequisite and challenge for innovation, as inter-unit separation into organizational functions serves as both "knowledge containers" as well as "knowledge silos" (Avila-Robinson and Sengoku, 2017; Dougherty, 1992; Tell, 2011). A common feature of these settings is that the innovation practices involved are mediated through Information and Communication Technologies (ICT). For instance, recent research has pointed out potential junctures and bridges between analog and digital expertise that influence innovation (Lanzolla et al., 2021; Pershina et al., 2019). The information processing perspective on knowledge boundary spanning through boundary objects may provide interesting insights on how cross-functional knowledge integration for innovation can be enhanced. Ample room for future studies exists to compare emerging technologies with more traditional boundary objects. To this regard, the notions of trust in new technological development (Okhuysen and Bechky, 2009) and of "Power users" (Massa and Testa, 2005; Volkoff

Table 3
Overview of future research areas applying the three perspectives on knowledge integration and boundary objects to three innovation settings.

Innovation setting	Future research areas based on the information processing perspective	Future research areas based on the cognitive perspective	Future research areas based on the learning perspective
Cross-functional collaboration Intra-organizational boundaries: boundaries among diverse domain expertise	ICT can be studied to ascertain how to enhance knowledge integration in interdisciplinary contexts. The effects of new technologies on knowledge trading can be compared to the effects of more traditional ones. (E.g. extend patent based information trading to non patent based knowledge) - How does the rise of new technologies, such as artificial intelligence, change knowledge integration in interdisciplinary contexts?	Examine boundary objects to obtain a fine-grained understanding of the nature of knowledge sharing taking place in cross functional settings, in connection with the type of innovation. - How does deep and domain-oriented knowledge sharing surface in cases of incremental innovation? - What is the role of knowledge sharing in relation to platforms and architectures in modular innovation processes?	Appraise the role of boundary objects as knowing artifacts in cross-functional innovation settings characterized by substantial heterogeneity. - How do different types of boundary objects enable the creation of different types of innovations based on knowledge recombination? - What boundary objects are typical of diverse cross-functional collaboration settings?
Open innovation Extra-organizational boundaries: boundaries emanating from different organizational identities	Explore the role of innovation intermediaries in open innovation through the boundary object lens to unveil the adoption of practices at the micro-level (E.g. selection of certain boundary objects over others, provision of critical digital infrastructure – such as innovation platforms) - How does the choice of digital infrastructure supporting collaboration in open innovation initiatives affect the scope of the initiative? - What boundary objects support specific types of open innovation activities?	Use a boundary objects perspective to analyze the nature and governance of interorganizational collaborative settings. (E.g. how boundary objects can create a sense of belonging, mutual trust and "soft incentives" to knowledge sharing, when formal governance systems and incentives are less applicable) - How can boundary objects "fill in" the governance gap in open innovation projects? - What can we learn about the governance of open innovation programs by studying boundary objects in use?	Improve the understanding of specific open innovation settings, for example those entailing a temporary set-up (e.g. how does learning among participants and between participants and mentors/facilitators in hackathons and/or innovation contests occur). - How do boundary objects enable swift collaboration in temporary open innovation settings? - What risks do the selection of "unfit" boundary objects entail?
Staged product development processes Temporal boundaries: Boundaries arising out of sequencing or heterogeneous time-orientation	Look at specific features and types of objects that support information processing in relation to the stages of innovation projects and how they are "acted" by stakeholders involved in the process. (e.g. example, timelines, GANTT charts) - Which objects are most suitable at different stages of the NPD process? - What characteristics of specific boundary objects make them more useful at diverse stages of the NPD process?	Explore the correspondence/consistency between different types of objects/evolution of objects and stages of innovation process (e.g. certain stages may require deeper knowledge sharing, whereas in other stages the integration of independent knowledge is key) - How do boundary objects evolve to support different stages of the NPD process? - What characterizes how actors understand temporally embedded boundary objects in relation to boundary objects that are able to transcend NPD stages?	Provide accounts of emerging parallelisms with respect to temporally structuring boundary objects. - How do boundary objects emerge and influence innovation in concurrent and agile NPD settings? - How do systems of boundary objects influence the NPD process? - How can boundary object help balancing tensions between the past, present, and future when developing new products and services?

et al., 2004) heralding the introduction of new boundary objects are important to understand to what extent the introduction of new technological boundary objects impact on their effectiveness to afford knowledge trading. Further, the concept of boundary objects can be used to extend patent-based information trading and technological brokerage in interdisciplinary innovation to non-patent-based knowledge (Huang and Su, 2019).

From a cognitive and learning perspective, boundary objects employed in an interdisciplinary setting and the way they are used may be used to interpret and account with enhanced granularity the depth and breadth of knowledge exchanges (Kobarg et al., 2019), revealing processes where collaborating actors are engaged in incremental vs. radical innovation. In the case of incremental innovation, boundary objects could enable deep knowledge sharing among a limited number of partners, while in the case of radical innovation, they could afford knowledge combination across a greater number of specialized collaborating partners. Again, from a learning perspective, boundary objects could enhance our understanding of the actual problem-solving process within interdisciplinary innovation projects (Brunswicker and Schecter, 2019). Such analyses could signal to what extent collaborative problem solvers, such as developers, use past knowledge existing in organizations to develop solutions to novel problems (coherent strategy) instead of solving problems in new ways (flexible strategy) (Brunswicker and Schecter, 2019).

5.2. Open innovation

The surge in the literature on open innovation, collaborative RandD and external knowledge acquisition indicates the importance of knowledge integration across organizational boundaries in innovative practices (Chesbrough, 2003; Lakemond et al., 2016; West and Bogers, 2014). Drawing upon specialized organizations called innovation intermediaries, open innovation practices often also include a significant element of interdisciplinary work (Lopez-Vega et al., 2016). "Digital" boundary objects are already supporting open innovation in various sectors. For example, a recent literature review by Obradovic et al. (2021) shows that open innovation in the manufacturing industry is supported by technological advancement, such as the development of additive manufacturing. Additive manufacturing allows companies to create prototypes more quickly and speed up their testing, hence potentially boosting open innovation activities and improving performance of NPD teams (Obradovic et al., 2021). In collaborative innovation settings where activities are distributed across the value chain, research points to interactions in overcoming organizational boundaries in the supply chain (Le Dain and Merminod, 2014; Merminod et al., 2021)

From an information processing perspective, boundary objects may provide insights on information and technological brokerage by the practices of intermediaries (De Silva et al., 2018; Lin et al., 2020). For instance, the selection of certain boundary objects over other may reveal the actual degree of human involvement of the intermediaries in information brokerage vs. their involvement as providers of critical digital infrastructure, such as innovation platforms. This would potentially shed light on the micro-level perspective on open innovation (Bogers et al., 2018).

From a cognitive perspective, boundary objects may not only enable knowledge sharing about a practice, but also about the nature and governance of the collaborative setting. This is especially relevant to interdisciplinary and interorganizational projects where sharing is needed, but not compensated with formal incentives and rewards, nor highlighted in a job description. In this case, boundary objects can create a sense of belonging (Thompson, 2005), potentially leading to the creation of knowledge communities (Amin and Cohendet, 2004; Lave and Wenger, 1991). Where interorganizational relationship are stymied by the lack of trust between parties in collaborative product development projects (Bidault and Castello, 2009; Brattstrom and Richtner, 2014; Bstieler et al., 2015) or R&D alliances (Aalbers, 2020; Li et al., 2012) such knowledge communities may support interorganizational governance. Communities can construct boundary objects that are co-designed by the interaction of their members in shaping objectives and practices. Similarly, boundary objects, such as early product concepts, can inform knowledge orchestration in innovation networks and regulate the involvement of lead users (Hurmelinna-Laukkanen et al., 2021).

From a learning perspective, boundary objects can contribute to the growing literature about short-term new open innovation methods, such as hackathons and innovation contests (Bertello et al., 2021). During hackathons, participants with diverse background come together to develop innovative solutions in a short time, usually between 24 and 48 h. Boundary objects, such as probes and prototypes, support hackathon teams as they integrate their individual knowledge to solve the hackathon challenge. Studying boundary objects used by hackathon teams may not only help to illuminate the teams' collaborative work, but also reveal how they integrate feedback from external actors who join hackathons as mentors or supporters without becoming part of any team.

5.3. Staged new product development processes

In addition to the intra- and inter-organizational challenges to overcome complex boundary problems in innovation (Bertello et al., 2022) pointed to above, a key feature in innovation management studies is addressing temporal sequencing of new product development processes with the aim to decrease time-to-market (Eisenhardt and Tabrizi, 1995; Gupta and Wilemon, 1990; Lindkvist et al., 1998). In practice, innovation management implies sequences in temporal orders – albeit with many recurring loops – from the fuzzy front end to commercialization (Gronlund et al., 2010). In product development processes, glitches (Hoopes and Postrel, 1999) occur not only between functions but also between stages and needs to be overcome to integrate knowledge. Moreover, recent research suggests breaking "process windows" in the fuzzy front to resolving knowledge problems as an important activity (Simms et al., 2021). Another central challenge related to intertemporal knowledge integration is the temporary organization of innovation projects (Lenfle and Soderlund, 2019), which requires collaborating actors to quickly produce outcomes and be able to transfer them to established organizational divisions. In any of these situations, boundary objects can be of help. Temporal boundary objects were first mentioned by Yakura (2002) in her study of timelines and organizational temporality. Yakura (2002: 964) indicates that timelines have *"central importance as artifacts for scheduling, allocating, and synchronizing"*. Instead of considering them as mono-temporal, fixed interpretations of time, she presents them as central tenets within the pluri-temporality of organizations (Yakura, 2002).

The reviewed literature on boundary objects shows that boundary objects' role might change and evolve over time (Ewenstein and Whyte, 2009; Nicolini et al., 2012). Given that boundary objects' roles are characterized by emergence and that the same object can play multiple roles, role evolution should be considered. The changes in role occur in response to changes in the context inhabited by the object. As noted by Carlile (2002: 452): *"boundary objects are no 'magic bullet' because their characteristics are hard to sustain as problems and people change"*. Despite the relevance of boundary objects across stages, most of the innovation studies in the review focus on single stages. Some of them directly address the development of the innovation, some look at commercialization, and some look at innovation transfer within and across organizations. Bartel and Garud (2009), who focus on the coordination of multiple organizational actors throughout three stages, is one of few exceptions.

The different objectives of boundary spanning across stages of the innovation process require boundary objects to change and evolve, likewise boundary objects are explained by different theoretical

perspectives throughout the process. The temporality of boundary objects is based on the objects capability to afford retrieval of past knowledge and prospecting of future knowledge de facto acting as intertemporal linkages (Bartel and Garud, 2009). In relation to the different stages of the innovation process, we can expect the information processing and cognitive perspective to be especially relevant during the early stage of innovation development. In this stage, effective boundary objects make knowledge about existing solutions available and facilitate "envisioning" future solutions/products/features to give concreteness to the idea in the making. Later, as the product concept becomes more concrete and new experts with differentiated knowledge join the collaborative effort to create actual prototypes. Working around the prototypes may not require deep knowledge sharing, but rather the integration of independent knowledge to create something radically new, hence adopting the learning perspective.

5.4. Possible applications to emerging innovation contexts

In view of the insights emerged from our review, we invite researchers to include boundary objects in their study of different emerging innovation contexts. For instance, the information processing, cognitive and learning perspectives of boundary objects in innovation might open new avenues for the study of innovation grand challenges. When faced with wicked problems, such as the Covid-19 pandemic, complexity of the collaboration action is higher than a standard product development setting. Grand challenges call for systemic action involving a high number of collaborating actors. When this is the case, boundary objects must prove their effectiveness at different levels. For example, boundary objects need to facilitate cognitive integration and joint frame development, to foster the elaboration of common purposes in so called "mission oriented" innovation initiatives that involve actors from heterogeneous social worlds (Reale, 2021). Also, the suggested perspectives on boundary objects can help to shed light on the critical role and possible failures of organizational knowledge integration mechanisms that are designed to support grand challenge-related initiatives (Bertello et al., 2021).

Another example of a pressingly relevant context is the management of innovation in light of the transformation of work. Digitalization introduces new or radically improved tools for collaboration and design, and this has profound effects on the nature of innovation work, with an impact on task content, collaboration patterns, decision-making authority, organizational set-ups and boundaries (Marion and Fixson, 2021). Technological change is also changing the nature of collaborative work in a further direction. Through the diffusion of Artificial Intelligence, collaboration will increasingly take place between humans and robotic actors (Arslan et al., 2022), with unknown implications on the cognitive and learning dynamics. Our suggested perspectives of boundary objects can help to navigate into the complex issues triggered by these transformations.

6. Conclusions

This article provides an extensive appraisal of the scholarship about boundary objects. The comprehensive review of existing academic contributions organizes the literature across three themes: information processing, cognitive, and learning perspective on knowledge integration within boundary spanning. The articles have been identified employing several means: systematic search on established databases, secondary search-engines, and citations search. The analysis of these papers shows that boundary objects is a multi-faceted construct that reflects the nature of knowledge boundaries. This is fundamental to enhance the current understanding of the concept and to lay the groundwork for future theoretical development.

From a practical perspective, boundary objects are an integral part of organizational life. Acknowledging their role may be a source of competitive advantage and continuous organizational improvement. The three themes encourage innovation managers to constantly question how the role of boundary objects change throughout the innovation process and how boundary objects can be leveraged to support the process effectively. The review can be used as a decision-making tool to design and to select boundary objects that best cater to current and emergent knowledge boundary spanning objectives in the innovation process.

6.1. Delimitations of the study

Some boundaries to this review should be noted. First, we have not reviewed articles that study boundary objects implicitly. We acknowledge the fact that existing innovation scholarship has sometimes used the word "artifact" or named an object specifically, while describing material elements, which could be described as boundary objects. However, we wanted to portray the applications of the term "boundary object" by established authors in the field of innovation, rather than imposing our own interpretation of how the term should be applied.

Moreover, in line with existing innovation literature we adopted an instrumentalist approach. We focused on articles that talk about boundary objects and their role to enable knowledge integration, which is their primary application. Existing literature on boundary objects' effectiveness stresses knowledge integration as a primary reason for employing boundary objects (Carlile, 2002; Hsiao et al., 2012; Swan et al., 2007). However, several contributions show that boundary objects support practices, which do not necessarily involve knowledge work. For instance, Kaplan et al. (2017) discuss the use of boundary objects to overcome political boundaries in interdisciplinary research, and Swan et al. (2007) show how boundary objects facilitate the creation of a common identity through symbolic representations in the context of biomedical innovation. This suggests that boundary objects' effectiveness in supporting knowledge integration is enhanced by their ability to span ancillary boundaries of different nature. However, this review does not cover articles that focus solely on other properties of boundary objects, such as their symbolic and political valence.

Data availability

No data was used for the research described in the article.

Appendix

Title	Authors	Source Title	Publication Year	Context	Boundary object
See what I mean? Analogical objects for knowledge mediation in early phases of cross-industry innovation	Lyng, Hilda B.; Brun, Eric C.	INTERNATIONAL JOURNAL OF INNOVATION AND TECHNOLOGY MANAGEMENT	2022	Cross-industry collaborations	Analogies

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Title	Authors	Source Title	Publication Year	Context	Boundary object
The role of digital artifacts in early stages of distributed innovation processes	Becker, Markus C.; Rullani, Francesco; Zirpoli, Francesco	RESEARCH POLICY	2021	Distributed innovation in open-source software	Digital artifacts
Exploring ideas generation through a shared artifact: The case of GasTec	Pattinson, Steven; Lassalle Paul, P.; Heinonen, Jerna; Scott, Jonathan M.; Preece, David	INTERNATIONAL JOURNAL OF ENTREPRENEURSHIP AND INNOVATION	2022	Idea generation	Imagineering wall
Innovation, the public and the third space: understanding the role of boundary objects in open laboratory work	Hu, Mengwei; Fritzsche, Albrecht	TECHNOLOGY ANALYSIS and STRATEGIC MANAGEMENT	2021	Open laboratories	Workspace items
Alone but together: flow experience and its impact on creative output in LEGO (R) SERIOUS PLAY (R)	Zenk, Lukas; Primus, Dirk J.; Sonnenburg, Stephan	EUROPEAN JOURNAL OF INNOVATION MANAGEMENT	2021	Co-creative workshops	LEGO Serious Play
Evolving a Value Chain to an Open Innovation Ecosystem: Cognitive Engagement of Stakeholders in Customizing Medical Implants	Randhawa, Krithika; West, Joel; Skellern, Katrina; Josserand, Emmanuel	CALIFORNIA MANAGEMENT REVIEW	2021	Product development	3D printing tech for orthopedic medical implants
Multiplex boundary work in innovation projects: the role of collaborative spaces for cross-functional and open innovation	Ungureanu, Paula; Cochis, Carlotta; Bertolotti, Fabiola; Mattarelli, Elisa; Scapolan, Anna Chiara	EUROPEAN JOURNAL OF INNOVATION MANAGEMENT	2021	Collaborative space	Space
Supporting innovation processes using material artifacts: Comparing the use of LEGO bricks and moderation cards as boundary objects	Zenk, Lukas; Hynek, Nicole; Krawinkler, Stephanie A.; Peschl, Markus F.; Schreder, Guenther	CREATIVITY AND INNOVATION MANAGEMENT	2021	Creative workshop	Lego
From People to Objects: The digital transformation of fields	Alaimo, Cristina	ORGANIZATION STUDIES	2021	Expert fields	Data objects
Market bifurcations in board sports: How consumers shape markets through boundary work	Diaz Ruiz, Carlos; Makkar, Marian	JOURNAL OF BUSINESS RESEARCH	2021	User Innovation	Board
Opportunities as artifacts and entrepreneurship as design	Berglund, Henrik; Bousfiha, Marouane; Mansoori, Yashar	ACADEMY OF MANAGEMENT REVIEW	2020	Opportunity discovery	Business model representations
Integrating design into organizations: The coevolution of design capabilities	Bjorklund, Tua; Maula, Hanna; Soule, Sarah A.; Maula, Jesse	CALIFORNIA MANAGEMENT REVIEW	2020	Product Design	Visualizations and prototypes
Unpacking the notion of prototype archetypes in the early phase of an innovation process	BenMahmoud-Jouini, Sihem; Midler, Christophe	CREATIVITY AND INNOVATION MANAGEMENT	2020	Ideation (Early innovation phase)	Prototypes
Leveraging innovation spaces to foster collaborative innovation	Caccamo, Marta	CREATIVITY AND INNOVATION MANAGEMENT	2020	Ideation (Early innovation phase)	Materials (post-its, cardboard, paper, etc.), Workspace (movable whiteboards, online bog, Facebook, etc.), and Artifacts (Persona, 3D prototype, video, etc.)
Multiplex boundary work in innovation projects: The role of collaborative spaces for cross-functional and open innovation	Ungureanu, Paula; Cochis, Carlotta; Bertolotti, Fabiola; Mattarelli, Elisa; Scapolan, Anna Chiara	EUROPEAN JOURNAL OF INNOVATION MANAGEMENT	2020	Collaborative community development	Space and digital channels
Boundaries, roles and identities in an online organization	Bange, Saara; Jarventie-Thesleff, Rita; Tienari, Janna	JOURNAL OF MANAGEMENT INQUIRY	2020	Online collaborative communities	Roles
Team design thinking, product innovativeness, and the moderating role of problem unfamiliarity	Nagaraj, Varun; Berente, Nicholas; Lyytinen, Kalle; Gaskin, James	JOURNAL OF PRODUCT INNOVATION MANAGEMENT	2020	New Product Development - Prototyping phase	Prototypes
Mapping, analyzing and designing innovation ecosystems: The ecosystem pie model	Talmar, Madis; Walrave, Bob; Podoynitsyna, Ksenia S.; Holmstrom, Jan; Romme, A. Georges L.	LONG RANGE PLANNING	2020	Ecosystem innovation	Ecosystem pie model

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Title	Authors	Source Title	Publication Year	Context	Boundary object
Those who control the code control the rules: How different perspectives of privacy are being written into the code of blockchain systems	Renwick, Robin; Gleasure, Rob	JOURNAL OF INFORMATION TECHNOLOGY	2020	Technological shift	Code
Boundary objects and the technical culture divide: Successful practices for voluntary innovation teams crossing scientific and professional fields	Kertcher, Zack; Coslor, Erica	JOURNAL OF MANAGEMENT INQUIRY	2020	Technological shift	Grid computing
Large-scale innovative projects as temporary trading zones: Toward an interlanguage theory	Lenfle, Sylvain; Soderlund, Jonas	ORGANIZATION STUDIES	2019	Project management	Linguistic representations, project management tools, material representations
Matter battles: Cognitive representations, boundary objects, and the failure of collaboration in two smart cities	Zuzul, Tiona White	ACADEMY OF MANAGEMENT JOURNAL	2019	Ideation (Early innovation phase)	Contracts, projects master plans and financial plans (cognitive representations)
The role of plans in the formation of a new innovation practice: An innovation object perspective	Fosstenlokken, Siw M.	INTERNATIONAL JOURNAL OF INNOVATION MANAGEMENT	2019	Organisational innovation	Plans
The transformative power of knowledge sharing in settings of poverty and social inequality	Qureshi, Israr; Sutter, Christopher; Bhatt, Babita	ORGANIZATION STUDIES	2018	Collaborative community development	Video screening events
Aligning and Reconciling: Building project capabilities for digital delivery	Lobo, Sunila; Whyte, Jennifer	RESEARCH POLICY	2017	Digital delivery of complex engineering project	Integrated software
Mapping the road to future projects: Roadmapping as a balancing and transformation process	Bengtsson, Marie; Lindkvist, Lars	PROJECT MANAGEMENT JOURNAL	2017	Ideation (Early innovation phase)	Timeline
The practice of scenario planning: An analysis of inter- and intra-organizational strategizing	Bowman, Gary	BRITISH JOURNAL OF MANAGEMENT	2016	Cross-organizational collaboration in the public sector	Stories in scenario planning
Content as community regulator: The recursive relationship between consumption and contribution in open collaboration communities	Kane, Gerald C.; Ransbotham, Sam	ORGANIZATION SCIENCE	2016	Collaborative community development	Content
Beyond 'the Eye' of the Beholder: Scent innovation through analogical reconfiguration	Islam, Gazi; Endrissat, Nada; Noppeney, Claus	ORGANIZATION STUDIES	2016	Ideation (Early innovation phase)	Parfume
The anthropophagic organization: How innovations transcend the temporary in a project-based organization	Prado, Patricia; Sapsed, Jonathan	ORGANIZATION STUDIES	2016	Redeploy of innovations on different projects	Innovation database
Visual organizing: Balancing coordination and creative freedom via mood boards	Endrissat, Nada; Islam, Gazi; Noppeney, Claus	JOURNAL OF BUSINESS RESEARCH	2016	New product development early stage in parfume making	Mood boards
Roles and identity work in at-home ethnography	Jarventie-Thesleff, Rita; Logemann, Minna; Piekkari, Rebecca; Tienari, Janne	JOURNAL OF ORGANIZATIONAL ETHNOGRAPHY	2016	Transition between corporate world and academia	Roles
Social enterprise emergence from social movement activism: The fairphone case	Akemu, Ona; Whiteman, Gail; Kennedy, Steve	JOURNAL OF MANAGEMENT STUDIES	2016	New venture creation	Phone
The innovation journey and the skipper of the raft: About the role of narratives in innovation project leadership	Enninga, Tanja; van der Lugt, Remko	PROJECT MANAGEMENT JOURNAL	2016	Project management'leadership in an innovation project	Narratives
Boundary emergence in inter-organizational innovation. The influence of strategizing, identification and sensemaking	Smith, Pernille	EUROPEAN JOURNAL OF INNOVATION MANAGEMENT	2016	Interorganization RandD team	Prototypes

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Title	Authors	Source Title	Publication Year	Context	Boundary object
Bridging knowledge boundaries: The use of boundary objects in virtual innovation communities	Marheineke, Marc; Habicht, Hagen; Moeslein, Kathrin M.	R & D MANAGEMENT	2016	Virtual innovation community	Virtual board
Making incremental innovation tradable in industrial service settings	Geiger, Susi; Finch, John	JOURNAL OF BUSINESS RESEARCH	2016	Co-development of innovative services in the chemical industry	Objects, agreements, measures, protocols, and review processes
Developing a relational view of the organizing role of objects: A study of the innovation process in computer games	Scarbrough, Harry; Panourgias, Nikiforos S.; Nandhakumar, Joe	ORGANIZATION STUDIES	2015	Game development	Concept book, Design documents (game design, technical design, art design), Milestone schedule
Understanding and classifying the role of design demonstrators in scientific exploration	Moultrie, James	TECHNOVATION	2015	Translation of scientific work to the market	Design demonstrators
Innovation Roadmapping: Building Concepts from Practitioners' Insights	Simonse, Lianne W. L.; Hultink, Erik Jan; Buijs, Jan A.	JOURNAL OF PRODUCT INNOVATION MANAGEMENT	2015	Non-empirical	Innovation roadmaps
The emergence of boundary clusters in inter-organizational innovation	Rehm, Sven-Volker; Goel, Lakshmi	INFORMATION AND ORGANIZATION	2015	Cross-organizational collaboration, cluster emergence	Information systems
Drawing on the map: An exploration of strategic sensemaking/giving practices using visual representations	Garreau, Lionel; Mouricou, Philippe; Grimand, Amaury	BRITISH JOURNAL OF MANAGEMENT	2015	Strategic sense-making in the development of concepts for new shopping malls	Photographs, drawings, and sketches
Contextualizing entrepreneurial innovation: A narrative perspective	Garud, Raghu; Gehman Joel; Giuliani Antonio Paco	RESEARCH POLICY	2014	Research on entrepreneurial innovation	Narratives
Interstitial spaces: Microinteraction settings and the genesis of new practices between institutional fields	Furnari, Santi	ACADEMY OF MANAGEMENT REVIEW	2014	Informal/non-institutionalized get together (interstitial spaces)	Symbols (words, labels, and other symbolic representations, such as objects, artifacts, visual icons, and gestures)
Managing the repertoire: Stories, metaphors, prototypes, and concept coherence in product innovation	Seidel, Victor P.; O'Mahony, Siobhan	ORGANIZATION SCIENCE	2014	New product development early stage	Stories, metaphors, prototypes, concepts
Managing projects with distributed and embedded knowledge through interactions	Bosch-Sijtsema, Petra M.; Henriksson, Lars-Henrik	INTERNATIONAL JOURNAL OF PROJECT MANAGEMENT	2014	Design meetings in construction, oil, and gas industry	3D drawings, sketches, BIM
Justification and Interlaced Knowledge at ATLAS, CERN	Tuertscher, Philipp; Garud, Raghu; Kumaraswamy, Arun	ORGANIZATION SCIENCE	2014	New Product Development - Prototyping phase (Development of the ATLAS detector at CERN and integration of its subsystems)	Templates for presentations, conventions for presenting physics results using plots, elaborate frameworks for producing Monte Carlo simulations as well as the results created by such simulations, and PERT/CPM charts reporting progress.
A knowledge sharing framework for black, grey and white box supplier configurations in new product development	Le Dain, Marie Anne; Merminod, Valery	TECHNOVATION	2014	New Product Development (Co-development between customers and suppliers)	Documents stored in IT systems with versioning control
The periphery on stage: The intra-organizational dynamics in online communities of creation	Rullani, Francesco; Haefliger, Stefan	RESEARCH POLICY	2013	Online collaborative communities	Code and virtual discussions around open source
Boundary objects, zones of indeterminacy, and the formation of Irish and Jewish transnational socio-financial networks	Lainer-Vos, Dan	ORGANIZATION STUDIES	2013	Innovation in Finance - Israeli and Irish governements trying to fundraise in US	Quasi-philantropic bonds
Digital boundary objects as negotiation facilitators: Spanning boundaries in virtual engineering project networks	Alin, Pauli; Iorio, Josh; Taylor, John E.	PROJECT MANAGEMENT JOURNAL	2013	New product development early stage (ideation of a hypothetical building)	Objects in a 3-D virtual space (e.g. team wall and Simvision)
From knowing It to getting It: Envisioning practices in computer games development	Nandhakumar, Joe; Panourgias, Nikiforos S.; Scarbrough, Harry	INFORMATION SYSTEMS RESEARCH	2013	Computer games development	Vision
Visualizing an information technology project: The role of powerpoint presentations over time	Yakura, Elaine K.	INFORMATION AND ORGANIZATION	2013	Development of IT systems	Powerpoint

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Title	Authors	Source Title	Publication Year	Context	Boundary object
Managing metadata: Networks of practice, technological frames, and metadata work in a digital library	Khoo, Michael; Hall, Catherine	INFORMATION AND ORGANIZATION	2013	Creation of metadata for a digital library	Community of practice
Understanding the dynamics of learning across social worlds: A case study from implementing IS in the Ethiopian public health care system	Mengiste, Shegaw Anagaw; Aanestad, Margunn	INFORMATION AND ORGANIZATION	2013	Information System development	Information systems
Understanding the role of objects in cross-disciplinary collaboration	Nicolini, Davide; Mengis, Jeanne; Swan, Jacky	ORGANIZATION SCIENCE	2012	Cross-disciplinary work in a scientific project for the development of a bioreactor	Bioreactor prototype
Organizing thoughts and connecting brains: Material practices and the transition from individual to group-level prospective sensemaking	Stigliani, Ileana; Ravasi, Davide	ACADEMY OF MANAGEMENT JOURNAL	2012	Collective sensemaking in a design project	Boards and user rooms, thumbnails, sketches, frameworks, slides, project rooms
Resolving conflict in problem-solving: Systems of artifacts in the development of new routines	Cacciatori, Eugenia	JOURNAL OF MANAGEMENT STUDIES	2012	Development of a new bidding routine	Excel worksbooks, bidding procedures, technical drawings
Accidental innovation: Supporting valuable unpredictability in the creative process	Austin, Robert D.; Devin, Lee; Sullivan, Erin E.	ORGANIZATION SCIENCE	2012	Accidental innovation	Technologies and characteristics of technologies
Cogitate, articulate, communicate: The psychosocial reality of technology roadmapping and roadmaps	Kerr, Clive; Phaal, Robert; Probert, David	R & D MANAGEMENT	2012	New Technology Development	Roadmaps
Transferring technology from university to rural industry within a developing economy context: The case for nurturing communities of practice	Theodorakopolous, Nicholas; Sanchez-Preciado, Deycy Janeth; Bennett, David	TECHNOVATION	2012	Techology transfer from academia to communities	Agenda, goals, action plans and technology diffusion assessment frameworks
Exploring negotiation through boundary objects in global design project networks	Di Marco, Melissa K.; Alin, Pauli; Taylor, John E.	PROJECT MANAGEMENT JOURNAL	2012	Global design project networks	3D model
Construction of meaning in socio-technical networks: Artifacts as mediators between routine and crisis conditions	Holzer, Jacqueline	CREATIVITY AND INNOVATION MANAGEMENT	2012	Standard innovation process	Stage gate process and the designed prototype (solenoid)
IT alignment and the boundaries of the IT function	Valorinta, Mikko	JOURNAL OF INFORMATION TECHNOLOGY	2011	IT outsourcing and collaboration between business and IT	Enterprise architecture, plans, roadmaps, mock ups, and user interfaces
Boundary object use in cross-cultural software development teams	Barrett, Michael; Oborn, Eivor	HUMAN RELATIONS	2010	Crosscultural software development	Project space, specifications, timelines
Finding a place in history: Symbolic and social networks in creative careers and collective memory	Jones, Candace	JOURNAL OF ORGANIZATIONAL BEHAVIOR	2010	Creative careers	Buildings, books, designs
The process of embedding new information technology artifacts into innovative design practices	Baxter, Ryan J.; Berente, Nicholas	INFORMATION AND ORGANIZATION	2010	Architectural innovation in the work of F.Gehry	3D CAD Technology
What do business models do? Innovation devices in technology entrepreneurship	Doganova, Liliana; Eyquem-Renault, Marie	RESEARCH POLICY	2009	Market exploration	Business models
Knowledge practices in design: The role of visual representations as 'epistemic objects'	Ewenstein, Boris; Whyte, Jennifer	ORGANIZATION STUDIES	2009	Architectural design project	Visual representations
The role of narratives in sustaining organizational innovation	Bartel, Caroline A.; Garud, Raghu	ORGANIZATION SCIENCE	2009	Innovation	Narratives
Ensuring project success through collective competence and creative conflict in public-private partnerships-A case study of Bygga Villa, a Swedish triple helix e-government initiative	Ruuska, Inkeri; Teigland, Robin	INTERNATIONAL JOURNAL OF PROJECT MANAGEMENT	2009	Development of an innovative internet portal in a public private partnership	Sketches
Role of boundary objects in negotiations of project contracts	Koskinen, Kaj U.; Makinen, Seppo	INTERNATIONAL JOURNAL OF PROJECT MANAGEMENT	2009	Project contract negotiations for technological delivery	Project contract and relationships between client and customer

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Title	Authors	Source Title	Publication Year	Context	Boundary object
Knowledge sharing ambidexterity in long-term interorganizational relationships	Im, Ghiyoung; Rai, Arun	MANAGEMENT SCIENCE	2008	Interorganizational exploring and exploitative knowledge sharing	Information systems
Research and technology commercialization	Markman, Gideon D.; Siegel, Donald S.; Wright, Mike	JOURNAL OF MANAGEMENT STUDIES	2008	Collaboration between academia and industry to commercialize research - non empirical - intro to a special issue	Non-empirical
Memory objects in project environments: Storing, retrieving and adapting learning in project-based firms	Cacciatori, Eugenia	RESEARCH POLICY	2008	Developmment of a new bidding routine	Sketches, drawings, generic representations of process, diivision design requirement manuals, excel workbook, engineering systems etc.
Integrating functional knowledge and embedding learning in new product launches: How project forms helped EMI Music	Ordanini, Andrea; Rubera, Gaia; Sala, Mario	LONG RANGE PLANNING	2008	Product launch	Project forms
Technological agglomeration and the emergence of clusters and networks in nanotechnology	Robinson, Douglas K. R.; Rip, Arie; Mangematin, Vincent	RESEARCH POLICY	2007	Collaboration across technology clusters to advance in nano-technology	Technogical platforms
Wakes of innovation in project networks: The case of digital 3-D representations in architecture, engineering, and construction	Boland, Richard J., Jr.; Lyytinen, Kalle; Yoo, Youngjin	ORGANIZATION SCIENCE	2007	Architectural innovation in the work of F.Gehry	Digital 3-D representations
Leveraging standard electronic business interfaces to enable adaptive supply chain partnerships	Malhotra, Arvind; Gosain, Sanjay; El Sawy, Omar A.	INFORMATION SYSTEMS RESEARCH	2007	Innovation challenges	Posts
The object of knowledge: The role of objects in biomedical innovation	Swan, Jacky; Bresnen, Mike; Newell, Sue; Robertson, Maxine	HUMAN RELATIONS	2007	Collaboration in biomedical innovation	Shared databases, Patients' questionnaire and booklet, flowcharts, information pack
In case of fire, please use the elevator: Simulation technology and organization in fire engineering	Dodgson, Mark; Gann, David M.; Salter, Ammon	ORGANIZATION SCIENCE	2007	Collaborative innovation in fire control and management	Simulation technologies
Integrating scientific with indigenous knowledge: Constructing knowledge alliances for land management in India	Puri, Satish K.	MIS QUARTERLY	2007	Development of information systems	Land management application (IS)
Life in the trading zone: Structuring coordination across boundaries in postbureaucratic organizations	Kellogg, Katherine C.; Orlikowski, Wanda J.; Yates, JoAnne	ORGANIZATION SCIENCE	2006	Development of innovative services	
Collaborating on multiparty information systems development projects: A collective reflection-in-action view	Levina, Natalia	INFORMATION SYSTEMS RESEARCH	2005	Multi-party collaboration for the development of Web based applications	Information systems
Models in action: How management models are interpreted in new product development	Engwall, Mats; Kling, Ragnas; Werr, Andreas	R & D MANAGEMENT	2005	New product development early stage and project management	Management models
Postcards from the edge: Local communities, global programs and boundary objects	Sapsed, Jonathan; Salter, Ammon	ORGANIZATION STUDIES	2004	Global product development in an IT program	Project management tools such as timelines, reporting tools and modular roadmaps
Knowing in practice: Enacting a collective capability in distributed organizing	Orlikowski, Wanda J.	ORGANIZATION SCIENCE	2002	Global new product development	Project plans, documents, schedules, technical specifications, etc.

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