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The sources of use knowledge: Towards integrating the dynamics of technology use and design in the articulation of societal challenges

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ABSTRACT

This paper reviews three strands of the innovation literature that have presented innovation as a distributed process that combines knowledge of designers and users: user innovations, Science and Technology Studies (STS), and domestication research. These literatures have explored different aspects of the micro-processes through which use and design knowledge are locally embedded. This paper pulls together insights from the literatures, and identifies an important gap: the connections between the local embedding of use and design knowledge, and the meso dynamics of industrial and technological change. The paper then develops a number of integrating concepts and propositions for a framework to study the co-evolution of use and design in innovation processes. It also demonstrates that this framework is most valuable in researching how societal challenges become articulated over time in processes of technological change and innovation.

1. Introduction

Innovation systems and processes need to be able to respond to changes in their broader socio-economic environment. When technology becomes embedded in society, it both incorporates knowledge about societal issues, while at the same time it shapes the very nature and understanding of such issues [1–4]. This paper revisits this basic insight to take stock of what we know about the underlying processes of aligning technological and socio-economic change. Our vantage point is that policy makers and innovators alike have become increasingly interested in *particular* challenges on the demand side of innovation [5]. Sustainable or eco-innovation is a recent example [6], where technological change is seen as a potential solution to the societal challenge of facilitating transitions towards more sustainable forms of energy production and use. This has a normative dimension: policy makers strive to channel technological change into directions deemed desirable. However, societal challenges also affect innovation processes more immediately, when they open up chances and threats for innovators in general. Demographic aging, for instance, bears a number of threats for social and health-care systems that can be addressed through new technical solutions. At the same time, it also provides a chance for knowledge-intensive economies to define and corner new markets by timely responses to associated changes in consumption patterns [7].

In this paper, we contend that addressing societal issues through technology is inherently linked to ideas and imaginations about technology use: If we want to foster more energy efficient patterns of mobility, what novel forms of using transport technology does this entail? If we want to promote healthy aging, what images of older technology users does this encompass [8]? For policy makers and innovators alike, it is thus important to comprehend the mechanisms through which a broad and often paradoxical understanding of societal challenges is articulated into more concrete ideas of technology users and use in technological change [9–11]. Such comprehension will enable them to address these challenges through informed interventions

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into the *boundary zones* or junctions [12] where knowledge about technology use is embedded with knowledge about technology design. This paper delves deeper into some of the fundamental conceptual issues surrounding such embedding processes.

Technological change and innovation are not one-off instances, but are processes that stretch over different phases, spaces and social worlds [3,13]. Hence, the articulation of societal challenges in innovation has a *diachronic dimension*, where knowledge claims about such challenges evolve together with technology. In this paper, we strive to develop a conceptual framework for empirical research to address the diachronic dimension of the articulation of societal challenges in innovation. For this purpose, we do not present original empirical material, but the results of a comparative literature study of three hitherto just loosely connected literatures, which are pertinent in understanding the use side of innovation: The *user innovation literature* has focused on users as the actual source of innovation [14,15]. Within Science and Technology Studies (STS), the *semiotic tradition* has explored how users and use are constructed and imagined along with technical objects [16,17]. And, finally, *domestication research* has delved deeply into the issues at stake when new technical objects are embedded in the local practices of users [18,19].

Our review demonstrates that the current understanding of the embedding of use and design knowledge in innovation has, thus far, remained partial and fragmented. The literatures stem from dispersed areas of innovation research; they partially focus on different aspects of users and use; they derive their insights from distinct empirical domains, and they follow dissimilar epistemological paths. At the same time, they reveal a considerable degree of overlap in their attempt to come to grips with the embedding of use and design knowledge. We use this to develop a conceptual framework that can be applied to follow empirically the articulation of societal issues in innovation processes over time.

The paper proceeds as follows: Section 2 briefly revisits classic insights from innovation studies about the interactions between the demand and supply side of innovation. Two long-standing challenges are identified, which then guide the exploration of the three literatures—the local embedding of use and design knowledge in technical objects, and the co-evolution of the related knowledge bases in innovation processes. The actual literature review investigates these challenges for each of the literatures separately (Sections *2.1*–*2.3*) and sheds light on some of the methodological and epistemological differences between the literatures (Section *2.4*). Section **3** pulls together the insights from the three literatures into a framework (Sections *3.1*–*3.3*), and Section **4**, finally, outlines how this framework can be used in further empirical research on the articulation of societal challenges in innovation.

2. Reviewing approaches to users and use in innovation

It is among the most basic tenets of innovation research that technology-push or demand-pull models cannot explain technological change adequately. Since its inception in the 1970s, the Neo-Schumpeterian evolutionary tradition of economics has therefore revolved around the idea that innovation is a *process* that responds to supply and demand side factors simultaneously [20–24]. Likewise, early contributions in Science and Technology Studies (STS) have carefully torn down sharp distinctions between technological innovations and their subsequent diffusion. Rather, technological change has been shown to incorporate knowledge from many different social worlds, among them the worlds of manufacturers and users [1,25–31]. While it is not our intention to recapitulate these broad debates, two pivotal issues arise from them that are crucial for the further discussion in this paper.

First, user needs should be treated as something different than demand in its strict economic sense, mostly because user needs refer to a quality and demand refers to a quantity [32–34]. Hence, in innovation processes socially dense relationships and information channels shortcut the market mechanism between the domains of user and producers [34]. Furthermore, notions like *learning by doing* [35] and *learning by using* [36] highlight the use of new technology as an important source of learning about a technology. Rosenberg further distinguished between *disembodied learning*, where experience during use leads to an improved understanding of how a product can be operated, and *embodied learning*, where learning by using leads to actual design modifications—either because users modify a product directly or propose a modification to a manufacturer [36: 124]. This distinction not only marks a difference between two forms of learning. More importantly, we contend, it marks an essential *boundary* in innovation processes where the knowledge generated by users is embedded with the technical knowledge of designers. *As a first dimension, our literature review shall focus on how each of the literatures explains the transgression of this boundary between disembodied and embodied learning.*

Secondly, the early studies have brought to the fore that innovation is a co-evolutionary process in which knowledge about the use of a technology accumulates together with knowledge about its design. Indeed, at the outset of an innovation neither product characteristics are known nor user needs are “out there” to be elicited. Rather, users have to develop their needs and the forms of meeting these needs through experience with evolving product characteristics [4,37]. The links and knowledge flows between the poles of using and designing new technology deserve particular attention, where the knowledge created by local learning is spread among and modified by a wider set of actors [38,39]. Indeed, Lundvall has proposed the notion of interactive learning to capture the essence of innovation, when local accomplishments at different sites gradually feed into a generic knowledge base [34,39]. This is resonated in more recent and fine-grained ideas about innovation as a process of *social learning* that focuses on use–design linkages as important interfaces in innovation processes, where knowledge about design and knowledge about use come together and co-evolve [40–43]. *As a second dimension, our literature review shall focus on how each of the literatures has addressed such processes of cumulative learning about the use and design of new technology*.

In the remainder of this section, we review and pull together the results from the abovementioned literatures along these two dimensions: First, the sources of use knowledge are explored. Where does knowledge about use originate according to the three literatures, and how is it embedded locally with design or technical knowledge? In other words, we give special attention to the fine line between embodied and disembodied learning highlighted by Rosenberg [36]. Secondly, we look at the links between local processes of embedding with the global process of technological change. How, if at all, do the studies discussed explain how knowledge generated locally becomes part of the evolving knowledge base of a technology? As *use knowledge*, we define knowledge about the context and character of use and about the characteristics of users. Use knowledge, therefore, includes both knowledge about users and their needs and preferences, as well as knowledge about the functionality, usability and utility of a product.

To a certain degree, every selection of literatures has to remain arbitrary. Both the specific delineation of the studies included, as well as the bundling of certain studies into a more or less coherent "literature", depends on the potential for gaining new insights. The chosen literatures are to date the only coherent sets of studies that are dedicated explicitly to illuminating the local embedding of use and design knowledge. This, in turn, presumes that they maintain an analytical distinction between using and producing new technology. We have, therefore, excluded from the analysis those bodies of literature that have blurred this distinction.[1] The boundaries between the literatures were established so that they coincide with boundaries between relatively unconnected areas of innovation research. Pulling insights together from these areas thus maximizes the potential to integrate fragmented knowledge into a framework that gains from a wide set of different perspectives.

2.1. The sources of innovation

Eric von Hippel and scholars working in his tradition have shown that users are not just important in innovation but frequently are the actual source of innovation: users often invent, prototype and field-test significant increments in functional utility themselves [53: 212]. Since this original work, the relevance of such *user innovations* has been demonstrated in many empirical studies [15]. In what follows, we explore the underlying conceptual model of user innovations in terms of four propositions that circumscribe broader implications regarding the role of users in innovation processes:

(i) Economic agents can be distinguished according to their *functional relationship* with a technology [14]. If agents manufacture a technology to sell it, they are producers; if agents use a technology to benefit from its functions, they are users. Profit motives of innovators are different depending on the functional relationship they have with the innovation: a producer benefits from selling an innovation while a user profits directly from the enhanced functionality of an innovation [54].

(ii) Based on this distinction, the *source of an innovation* is defined based on the functional relationship between innovator and innovation [14]. Quite often the source of innovation is the user, be it an individual or an organization. User innovations are tailored directly to the particular needs of the innovator who thus profits from increased functionality, rather than from a higher commercial value. Frequently, user innovators are particularly knowledgeable users ahead of market trends, i.e., they are *lead users* [55,56].

(iii) User innovations are often attractive for other users as well. After all, user innovations embody intimate knowledge of the use environment and thus also an elevated functional value. For manufacturers, it is, therefore, attractive to pick up and commercialize user innovations [57,58]. Baldwin et al. [59] have summarized more recent knowledge about *the diffusion and commercialization of user innovations* in a formal model including three steps:

First, a user develops an innovation to obtain its direct use value and, subsequently, refines this innovation by sharing the necessary information with other users [60–62]. Initially, therefore, the user innovation is diffused and refined within a user community. Secondly, some users might be willing to purchase the innovation from one of the original innovators because they are not willing or able to spend the necessary time and effort to reproduce an innovation. Then, some users in the community turn into user–purchasers, while others become user–producers or small-scale manufacturers [63]. Competition between user–innovators increases, which leads to more careful strategies of revealing information *selectively* within the user-community [64–66]. Thirdly, established manufacturers eventually join the process when they perceive a version of the user innovation to be attractive enough for a larger number of customers, i.e., when they see a commercial value in the user innovation. Typically, this happens when the original innovation has stabilized to some degree and manufacturers can mass-produce the user innovation at low variable costs.

Although this model is stylized, it explains two important mechanisms in the diffusion of user innovations. Users often share information so that other users can replicate the original innovation, and large manufacturers pick up commercially attractive versions of a user innovation and produce it for a broader set of customers. Often the spread and evolution of a user innovation involve both mechanisms, although either can also function separately [67].

(iv) On a more general level, the work on user innovations has highlighted that every innovation involves combining use and design knowledge. These types of knowledge are distributed asymmetrically among manufacturers and users and are

[1] This is also the main reason why we have not included the majority of STS studies in the literature review. While STS has obviously produced rich insights into the use of technology, the semiotic tradition has focused explicitly on the interactions between design and use as distinct processes in *innovation*. As Jelsma [44] has pointed out, the semiotic tradition in STS can, in this respect, be positioned between more traditional social constructivists' accounts of technological change [29,45,46], which downplay the capacity of design to structure actions and interactions of human beings [47], and those claims in STS, which blur the analytical differences between the realms of technological design and use altogether [48–52].

"sticky", i.e. they cannot be transferred between users and manufacturers at a reasonable cost [68,69]. This explains why lead users are so important—as knowledgeable users they possess a certain degree of design knowledge, and can thus modify or invent designs based on their intimate, local and sticky knowledge of the use context [70–74]. Hence, real-world innovation processes often progress through a series of iterative steps, where tentative versions of an artifact are transmitted back and forth between user and producer sites.

Early studies on user innovations have focused on traditional industrial goods, such as scientific instruments, process equipment or semiconductors and printed circuit boards [53,54,57,58,75–79]. Since the 1990s, however, empirical studies have abounded that could widen this focus considerably (for reviews see [15,80,81]). These studies have demonstrated the relevance of user innovations for technologies ranging from radical innovation of medical devices [73,82,83], radical service innovations [74], stressed skin panels [84], and library information systems [85] to consumer goods such as sports equipment [64,66,86–90], juvenile products [63], video games [91,92], fashion [93], or French cuisine [94]. Moreover, certain aspects of the user innovation process have received particular attention. Hence, knowledge about the characteristics and roles of lead users has been elaborated in a number of studies [70–73]; communities of users and the (motives for the) spread of knowledge among users and manufacturers have been put under detailed scrutiny [61,64,93,95][2]; user-entrepreneurship, i.e. the commercialization of user innovations by users themselves, has been shown to be an important mechanism in the diffusion and commercialization of user innovation [63,91,110]; manufacturers' activities to tap into the knowledge of users have been explored more systematically [92,111–113]; and, finally, the observed pervasiveness of user innovation has been said to lead to more profound changes towards a democratization of innovation [15,114].

In the user innovation model, the source of use knowledge is straightforward—it is simply the user. However, user innovators are a special kind of users: they also possess a degree of design knowledge necessary to innovate [81], and apply their combined use and design knowledge to a new or modified design. Local embedding is thus explained through the existence of expert users, both willing and able to engage with design on the basis of their use knowledge. The distinction between embodied and disembodied forms of learning, however, is more complicated in the user innovation model. Slaughter's [84] study on stressed-skin panel is illustrative in this regard. She has investigated minor adaptations that were more or less realized spontaneously on construction sites by different construction companies. From these user innovations less than one-third were commercialized by manufacturers, whereas all of them diffused into the repertoire of techniques that construction companies employed regularly to deal with the specificities of particular projects. Apparently, manufacturers refrained from commercializing widely available local knowledge of users, although, as Slaughter could demonstrate, this created a host of inefficiencies in the overall innovation process of stressed skin panels [84: 92].

Slaughter has pointed out a critical element in the user innovation model. When, under which circumstances and in what form do local modifications or inventions of users turn into widely diffused changes of a technology? Both Slaughter's work as well as the more recent studies summarized in Baldwin et al.'s model (see above) indicate that often user innovations result in a particular division of labor between large-scale manufacturers that generalize local knowledge in the form of widely purchasable commodities, and user innovators, that generalize local knowledge in the form of custom designs and changing practices. This leads us back to the very foundations of the user innovation model. As Humphreys and Grayson [115] have recently pointed out, the generation of use value by users is not a phenomenon of great significance. But if users become involved with the generation of exchange value, i.e., value that can be traded beyond the context from which it originally arose, this marks an important shift in the role distribution between producers and users. So far, this fine line between the production of use and exchange value has remained somewhat blurred in the user innovation model, although the emerging literature on user-entrepreneurship demonstrates how users themselves might facilitate the conversion of use into exchange value [63,91].

2.2. Constructing use, configuring users

The user innovation model has provided a rich and multi-faceted picture of innovation processes driven by the knowledge contributions of users. However, as already suggested by von Hippel [68], all innovations incorporate knowledge about use. Hence, manufacturer innovators, although they may not have a clear idea of future users and their needs, also process use knowledge of some kind. This has been emphasized and explored by a stream of empirical studies in STS that have looked specifically at producers of technical objects and how they generate knowledge about future users and use, knowingly or unknowingly. These studies are often referred to as the *semiotic tradition* in STS [116].

The classic study in this tradition is Woolgar's ethnographic investigation in a medium-sized manufacturer of micro-computers [17]. He explored the metaphor of a machine as text, which, as he argues, allows for the distinction between the writing (construction) of a machine and its subsequent reading (use). Just like a text, a machine, by virtue of being written in a

[2] Within this branch of the user innovation literature, open source software development has received particular attention as a mode of innovation. From a user innovation perspective, open source is interesting because the distinction between what have traditionally been called users and manufacturers is especially blurred. Empirical studies addressing various aspects of open source software development have been prolific (for overviews, see the special issues introduced by von Krogh and von Hippel [96,97]). While many studies have focused on knowledge sharing outside the market mechanism [98–100], the user innovation literature, in particular, could demonstrate how open source involves a blend of market-based and open modes of knowledge sharing [101–106]. As such, therefore, open source software development, while obviously a peculiar case of innovation, can be captured by the abstract model above, where knowledge exchange outside the market mechanism is an essential feature in the diffusion of user innovations. Indeed, there have been profound claims that the open source mode is not limited to software development [104,107–109].

particular way, suggests a certain reading. Hence, certain kinds of usage are encouraged by the way a machine is written, while others are rendered difficult or impossible. A machine thus mediates between its writers and readers. The essential point Woolgar derives from this analogy is that a machine, by the way it is designed, assumes some degree of authority about its future users.

For the case investigated—the design process of a specific micro-computer—Woolgar could demonstrate how "the user" was constructed from multiple conceptions of users and uses; use knowledge was socially constructed by designers and then inscribed into the machine, so that certain types of actions are readily available to future users. Indeed, subsequent usability trials were primarily devised to evaluate if the machine, together with its manual, would lead test users to the "correct" use. In Woolgar's case study, the company not only constructed a user, but also dedicated a considerable amount of effort to design the machine to configure real users accordingly. Designers' preconceptions about users and use, Woolgar concludes, become incorporated in technical objects and thus "the evolving machine effectively attempts to *configure* the user" [17: 61].

To capture the influence a technical object exerts on the relationships users can entertain with it, Akrich [16], in another seminal publication, coined the term *script*. Also for Akrich, designers *inscribe* in to a technical object a vision of future users and use. "Thus, like a film script, technical objects define a framework of action together with the actors and the space in which they are supposed to act" [16: 208]. According to Akrich, however, technical objects become real only through the actual users, uses, and networks they describe. Therefore, it is the adjustment between projected and real users that determines the fate of a technical object. Naturally, real users may refuse to subscribe to the script presented to them, and they may try to renegotiate the original script. That is, users may try to subvert the suggestions of designers (de-inscription), and enact their own behavioral programs in relation to the new object [117].

These original works in the semiotic tradition of STS have established that designers construct use knowledge before real use takes place. In other words, designers, while specifying the characteristics of a technical object, create in parallel a script for the future use of the object. As both Woolgar's and Akrich's early studies have emphasized, the use knowledge contained in such scripts is not necessarily based on any explicit consideration of future users and use. Indeed, the "I-methodology", where designers project themselves as future users, is a widespread way to generate knowledge about future use [118]. A number of subsequent studies have elaborated upon this general perspective to draw a more nuanced picture of the sources of use knowledge to which designers may turn in innovation. Hence, studies of consumer electronics could spell out how designers frequently project themselves as future users, implicitly refer to their own preferences and skills as source of use knowledge, or infer such knowledge from stories circulating within their professional networks [119–121]. Furthermore, technical traditions can be powerful carriers of use knowledge as far as they contain vestiges of use knowledge based on earlier experiences from related fields [122]. In this regard, also the notion of *genderscript* has received dedicated attention to explore how technical objects embody, spread, and reinforce existing gender biases [123–130]. All these cases share an emphasis for the practices and imagination of designers as a vital source of use knowledge.

Also following earlier cues by Akrich [118], user representations have received extensive attention in the semiotic tradition of STS. Empirical work has illuminated how managers in a user organization represent end-users in design projects [131], how interest groups and policymakers frame their vested interests as vital representations of use [132–137], or how experts often directly represent users in design processes with generalized forms of alleged user interests and needs [118,138,139]. The latter is, for instance, the case when usability experts contribute to the construction of use knowledge with general principles of ergonomics [140]. In this regard, a number of studies have addressed the often unconscious practices of designers to stick effectively to their own imaginations as a primary source of use knowledge, despite laborious engagements with potential real users [141–145].[3]

Against this background, the semiotic tradition in STS has, above all, spelled out how manufacturers construct use knowledge along with designs by turning to a whole range of different knowledge sources. In this sense, the semiotic tradition does not regard use knowledge and its production as the exclusive domain of users. The original cases described by Woolgar and Akrich are straightforward in this respect—manufacturers are the source of both design knowledge and use knowledge—and offer the converse of von Hippel's model: producers are not only knowledgeable in their domain of design, but they are also knowledgeable about the user. In these cases, disembodied learning is virtually absent, and use knowledge becomes embodied in new designs without the explicit consideration of users and use. Later studies have provided a nuanced picture of different processes from which use knowledge emerges and is incorporated in design. In attending to the fine line between disembodied and embodied learning, these studies have illuminated the intricate interplay of designers, users (with their representatives) and technical objects in embedding use with design knowledge.

In this regard, the literature also runs up against limits as it focuses primarily on the work of designers. Indeed, this has been the very aim of Woolgar: to demonstrate that users are present in innovation, even before trial or real-world use takes place. He has thus established an important distinction between constructed and real users. But the process of actually configuring users reaches further, when artifacts constrain forms of real use and, vice versa, when real users work against these constraints to establish alternative forms of use. In this respect, the semiotic tradition has not gone full circle to capture how designers continue to learn about real use as an impetus for product modifications. In other words, while the semiotic tradition has studied in detail particular episodes of writing and reading technical artifacts, cumulative learning about use and design has not received comparable attention. In explaining the local embedding of use and design knowledge, the semiotic tradition is complementary to

[3] It should be obvious that, at first sight, the semiotic tradition in STS shares interest with the marketing literature and its concern for approaches to tap into the knowledge of users (for overviews see [146,147]. However, the semiotic tradition in STS has explicitly addressed how designers or R&D departments are able to incorporate marketing knowledge, a well-known lacuna in the marketing literature [148].

the user innovation model: Manufacturer innovations incorporate use knowledge before real use. Thus, the semiotic tradition in STS has shown that embodied learning may pre-structure disembodied learning as much as the other way around [149,150].

2.3. Domesticating technology: the sources of innovation extended

In the discussion thus far, one aspect has remained underdeveloped: users not only acquire increased understanding of how to operate a technical object; they create a relevance structure for technical objects as well. Such relevance structures are the background against which the use value of an object is determined. In this regard, *domestication research* has concentrated on the meaning and relevance of things rather than their functionality as a centerpiece of innovation [116,151]. To this end, it has looked at users in their everyday lives to argue that, in the sphere of users, artifacts undergo an intricate process through which their relevance is spelled out, and different forms of use are defined and put into practice [152–155]. This process has been called *domestication* because it is "quite literally a taming of the wild and a cultivating of the tame" [19: 60].

At the core of domestication research is a framework proposed by Silverstone et al. [18] that distinguishes between four elements: appropriation, objectification, incorporation, and conversion.[4] *Appropriation* takes place at the point of purchase, when an individual acquires a commodity. Through appropriation, commodities turn into objects and achieve authenticity and significance as they move from the public into the domestic. Through appropriation, an artifact is introduced into the spatial and temporal patterns of the moral economy of the household. *Objectification*, then, describes the disposition and display of the artifact, through which it becomes part of, contributes to and signifies the esthetic culture of a domestic sphere. Artifacts are not objectified in isolation, but they are linked to and molded according to an "already constructed […] and meaningful spatial environment" [18: 23]. As a complement to this, *incorporation* focuses on the way artifacts are used, and describes how they are incorporated into the routines of daily life. Through incorporation into social practices, artifacts change the temporal patterns of domestic cultures as they become functional in the context of these patterns. Objectification and incorporation together complement clear-cut notions of functionality with meaning, and underscore the constant redefinition and alignment of both functionality and meaning within and between different domestic cultures. Finally, *conversion* constitutes a reverse process of appropriation. While through objectification and incorporation meaning and relevance is established for "potentially alienating commodities" [18: 25], through conversion results of this process are released into the public sphere. It is conversion that safeguards the significance of domestication work in the more immediate environment of the neighborhood, work or peer group, but also as signals "for producers and their allies in the market" [19: 46].

A unique feature of domestication research is that it links insights about consumption, as a wider context of use,[5] to the theory of innovation. Indeed, as Silverstone and Haddon [19: 46] have put it, it is the "design/domestication interface" where "the industrial and social logic of innovation" come together. Empirical studies have emerged from an interest in media, communication and technology [153,162]. Here, they have drawn a diverse and rich picture of domestication focusing on private households [163–165] including those of nuclear families [166], single parents [167], low-income home owners [168] and older adults [169]. Furthermore, professional contexts such as small and medium sized enterprises [170,171], home workers [172,173] or migrant researchers [174] have attracted attention. Domestic environments have thus increasingly been defined in a broad sense including home and work environments as locally bounded social contexts. The particularities of such contexts are not only disrupted by the arrival of a new technology, but also shape the meaning and relevance of the new technology.

For this paper, domestication research offers two possible readings. First, domestication can be interpreted as a specific form of user innovation—individuals (as members of a domestic sphere) actively work towards redefining the nature of an artifact, and traces of these redefinitions accumulate and shape the public meaning of that artifact. Redefinition, however, is defined purely in terms of the practical and symbolic work of users, rather than in terms of design changes. Initially, therefore, domestication describes a local and disembodied form of learning by using. It does not stop here, however. Through conversion the local work of users contributes to the generalization and stabilization of a technology's identity in the public sphere as well. In principle, therefore, domestication describes a collective and cumulative learning process through which disembodied knowledge is diffused.

The approach, however, has tended to explore in detail the objectification and incorporation of artifacts in particular settings more than it has specified mechanisms of conversion across such settings. Consequently, it has difficulties to explain how the results of disembodied learning during domestication become embodied in design changes. In other words, domestication research has not, so far, delivered an understanding of the "design/domestication interface" [19]. It is thus a second reading that seems to be most relevant for the discussion in this paper. In the process of domestication, users may expend quite some effort to realize use, and through this effort use knowledge is created. Therefore, domestication research complements the semiotic tradition in STS by focusing in detail on how users re-write the scripts embodied in technical artifacts. As Haddon [153: 196] puts it: "[…] although technologies come preformed with meanings […], both households and individuals then invest them with their own personal meanings and significance." Domestication research has thus augmented straightforward notions of use, where the criteria of improved or better use are clearly defined. Therefore, it has indeed taken to heart Clark's [4] classic finding that users, while they learn how to operate a new technology, also learn how to evaluate the operation of that technology.

[4] While this framework has undergone slight modifications over time, it has persisted, in different shadings, to be the main framework for empirical studies of domestication [153].

[5] Domestication builds on the particular tradition of studying consumption that has focused on the sign value of things rather than their utility value. Among others, this tradition is marked by the works of Veblen [156], Douglas and Isherwood [157], Baudrillard [158], Bourdieu [159], Miller [160], and McCracken [161].

2.4. Methodological and epistemological differences

The three literatures are embedded in different disciplinary traditions of thought. This implies a number of more fundamental methodological and epistemological differences:

(I) User innovations have been studied from an economic and management perspective, where value, knowledge sharing and incentives are central concepts. Indeed, the very distinction between users and manufacturers is established around the incentives related to either using or trading an innovation [14: 3, 67: 294]. Furthermore, user innovations have been studied through *positivist* lenses primarily, assuming that propositions about the phenomenon can, ultimately, be tested and generalized into a set of "facts". As a consequence, this literature has been highly cumulative, collecting evidence to build on and further develop a well-articulated conceptual core. Methodologically, the user innovation literature has relied mostly on case study research and has used cases to develop a *middle-range theory* [175]: insights from a broad range of empirical studies are integrated into a conceptual understanding of one particular phenomenon—the generation and diffusion of user innovations.[6]

(II) Empirical studies in the semiotic tradition are associated with the post-humanist branch of STS thinking [176]: Semiotic studies are embedded in a *grand theory* about the nature of social structures and their constitution in reciprocal interrelations of human and non-human agents [177,178]. Following an *interpretivist* epistemology, which emphasizes the active involvement of researchers with the interpretation of the meaning actors give to certain occurrences [179], studies in the semiotic tradition of STS typically arrive at a refinement, revision or rejection of earlier conceptual contributions. This literature, too, relies heavily on case studies, and on ethnography, in particular. In between the grand theories of STS and conceptually rich and dense accounts of specific cases, however, it is difficult to identify an integrated and formalized theory of the construction, configuration and scripting of users.[7]

(III) Domestication research, finally, is grounded in cultural and media studies and thus borrows from a tradition of consumption studies influenced by cultural anthropology (see footnote 5 above). This shares elements with STS thinking. Indeed, domestication research also follows an *interpretivist* agenda, although without an explicit reference to a social theory of technology. Instead, domestication research has focused on the symbolic and esthetic dimension of technical objects [19] thus gaining a meticulous understanding of the process by which users link technical objects to the social order of the everyday. Owing to its grounding in cultural anthropology, this literature has been somewhat limited to "thick descriptions" [183], i.e. it has refrained from generalizing findings to either theory or other cases (although Silverstone et al.'s [18] original framework seems to provide conceptual guidance for many empirical studies).

One consequence of these differences stands out: As an effect of their respective epistemological choices, the above literatures operate on different, sometimes overlapping, levels of analysis. Hence, the user innovation literature has used its empirical findings to generate theories and models of innovation processes at the meso-level of industries or technologies. STS and domestication studies, in contrast, have generated an opulent set of "sensitizing concepts" [184] at the micro-level of single companies, projects, artifacts or households, but have only provided limited guidance towards a coherent framework of industrial or technological change. Finally, domestication research, rooted in anthropological studies of consumption, has tended to focus on the meaning created around technological objects, rather than embodied technological change [see 185]. Bridging this difference is not trivial. Indeed, this might explain the scant attention the literatures have hitherto paid to each other. Notwithstanding their different conceptual assumptions, the literatures share an interest in the same phenomenon—the use of technology as an inherent contribution to innovation—and have highlighted different aspects and sites of this phenomenon. In the remainder of this paper, this joint interest is taken as a starting point to develop an integrative framework that presents an overarching understanding of the different mechanisms that have been shown to embed use with design knowledge.

3. Reconciling Insights

In the previous section, three bodies of literature have been discussed that focus on the use and users of innovation. Each of these literatures has been prolific. The review can and should be read as a doorway to them, and it has attempted to bring out the conceptual foundations of each literature. For this reason, we have chosen to discuss seminal contributions in depth, and present each body as a relatively consistent set of empirical studies.[8] In what follows, the results thus gained are pulled together into an integrated framework. In line with the introductory remarks to Section **2**, our framework revolves around the sources of use knowledge (Section 3.1), the boundary zones for embodied learning (Section *3.2*) and the processes of cumulative learning (Section *3.3*). The framework, as we demonstrate in the concluding section, provides the basis further empirical research about the articulation of societal issues in innovation processes.

[6] It has to be noted that we are not aware of any explicit reference to the Mertonian idea of middle-range theory in the user innovation literature.

[7] In STS it continues to be an important dispute whether one should seek formal theory of any degree [180–182]. Within the confines of this paper, the important point is that the user innovation literature differs considerably from the STS literature in terms of theory building.

[8] This is necessarily a simplification. Excellent recent reviews of each of the discussed literatures that focus more on their internal disputes and diversity have been presented in Bogers et al. [80] for user innovations, Oudshoorn and Pinch [186] for approaches to users and use in STS, and Haddon [153] for domestication research.

Table 1
Overview over insights of the three literatures.

Technologies[a]	Use knowledge and local embedding	Cumulative learning
User innovations		
Scientific instruments [53,54,58] Process equipment [57,75,76,79,108] Construction [84] Medical equipment [73,82,83] Services [74] Sports equipment [64,66,86–90,93] Computer aided design [55] Library information systems [85] Open source software [65,89,101,102,105,106,111,202] Juvenile products [63] French cuisine [94] Computer games [91,92,95] Fashion [93]	- Users learn by using (disembodied learning)… - … and incorporate use knowledge thus created in design (embodied learning). - Users possess use and design knowledge. - Users' intimated knowledge of the use environment makes their innovations likely to be attractive for other users as well. - Exchange value of users' designs is contested.	- User-producer interactions in the narrow, literal sense. - Artifacts move back and forth between users and producers, thereby being modified. - Know-how sharing among users. - Use knowledge is the domain of users. => Transition from use to exchange value insufficiently covered.
Science and technology studies (semiotic tradition)		
Personal computers: hard- and software [17,129,145,149] Photoelectric lighting kit [16] Electricity grids [16] Rapid application development [131] Digital cities [126–128,137] Male contraceptives [125] Healthcare technologies [121,122] Consumer electronics [119,120,143] Vaccines [134,135] Shavers [130] Car advertisements [124] Household robots [144] Virtual reality [142]	- Producers construct a user (disembodied learning)… - … and incorporate knowledge thus created in design (embodied learning). - Producers possess use and design knowledge. - More or less elaborate methods to elicit use knowledge enrich product design. - Use value of producers' designs is contested.	- User-producer interactions in a broad sense. - Producers (can) exploit more and more sophisticated sources of use knowledge as an artifact diffuses. - Use knowledge is the domain of producers and users. => Feedback of real use into design processes insufficiently covered.
Domestication research		
… for Single Parents and Nuclear Families [166,167] … for Older Adults [169] … for Low-income Home Owners [168] … for Home Workers [172,173] … in SMEs [170,171] … in Academia [174]	- … and incorporate use knowledge thus created into meaning and relevance of technology (disembodied learning). - Users do not utilize design knowledge.	- Informal and often unintentional knowledge sharing. - Use knowledge is the domain of users. => Embodiment of use knowledge not covered.

[a] This list only includes genuine empirical work and does not include cases reported in overview articles.

Table 1 summarizes the central assumptions and concepts for each literature and is the basis of our discussion. For each literature, it indicates the range of empirical cases, and specifies how the local embedding of use and design knowledge and subsequent cumulative learning is explained. A first obvious point to note is that, in terms of sheer numbers, the user innovation model has had the most extensive empirical coverage. Its analytical scope includes scientific instruments, construction, extreme sports equipment, software, and juvenile products. Studies in the other traditions are fewer in numbers. However, the semiotic tradition of STS includes an equally broad scope, with investigated technologies extending from male contraceptives, shavers and personal computers to health-care technologies and electricity grids. Only domestication research has explicitly concentrated on a specified group of technologies, i.e., media and ICTs, which it has investigated in a wide scope of different use contexts [153,162]. All above literatures, therefore, suggest a degree of universal coverage in the sense that their scope is not confined to a specified set of technologies or settings. In other words, the conceptual boundaries around each literature do not coincide with certain technological domains. While these overlapping claims for universal coverage make it necessary to specify further under which circumstance insights from each literature is relevant, they also underpin that the literatures are ready for an integrative exploration.

3.1. The sources of use knowledge: processes of disembodied learning

Analytically, all literatures deploy insights about what could be called use knowledge. They revolve around the idea that technological change entails new ideas about prospective users, contexts of use, and forms of use to which a technology should be put. Together, the literatures have significantly refined Rosenberg's [36] notion of disembodied learning by using. The user innovation literature is largely in line with classical contributions: users, by using a particular technology, accumulate experience of use and thus obtain a more specific idea of the functions they need. The domestication literature has added to this an understanding that disembodied learning includes the production of a shared sense of meaning, which, in turn, is entangled deeply with the definition of what function is and could be. The semiotic tradition in STS, in contrast, has offered a mirror picture to the classical understanding: manufacturers engage in a range of more or less sophisticated practices to construct a future user (and the respective forms of use). In so doing, also manufacturers generate use knowledge, albeit in ways that can be remarkably unconnected to any actual use environment. Disembodied learning about use can thus take many forms, ranging from users' experience with a technical object to manufacturers' imaginative attempts to configure users and use. For the integrative framework proposed here, this implies to extent earlier readings that describe disembodied learning as a result of *learning by using* to a definition that describes it as resulting from *learning about use*: Disembodied learning cuts across various locales of the innovation process including the R&D labs of manufacturing companies, the sites of intermediaries, and the households of consumers. Hence, not only the sources of innovation can vary greatly [14], but also the sources of use knowledge. The literatures above have provided us with a broad set of possible sources of use knowledge into which innovators can tap[9]:

(i) *Non-representation:* Users are neither involved nor represented; designers refer to their own practices and imaginations or stories circulating within their professional networks to obtain use knowledge.
(ii) *Implicit representation:* There is no conscious representation of users or use, but traces of earlier explicit attempts to represent users inform the construction of users and use. Technical traditions can be a vital source for handing down certain images of prospective use [122].
(iii) *Indirect representation:* Experts may represent users based on their expertise about users and use. This is the case, for instance, when usability experts enrich a design process with basic principles of ergonomics. In such cases, generalized expertise about users and use is a source of use knowledge. Also intermediary groups, such as consumer lobby groups, may speak in the name of real users and thus contribute to creation and articulation of use knowledge [187].
(iv) *Direct representation:* Experts can also mediate directly between producers and real users. In this case, their representation of use is based on an empirical investigation of users and use in the context of a specific innovation project. Different forms of marketing research usually fall into this category.
(v) *Co-creation:* Users can participate directly with designers to co-design an innovation. This is a very interesting source of use knowledge that borders on user innovations in the sense that users are deliberately made co-designers. While some experience exists with co-realization in the development of IT systems [188], true co-creation of innovation is still found to be a rare instance [189].
(vi) *Domestication or learning by using:* When users put a new design into use and thus domesticate it, they create knowledge about its meaning and functions. In particular the domestication literature suggests that this is the most elaborate source of use knowledge. However, it is also the source of use knowledge most detached from actual design modifications.

Design knowledge is a natural counterpart of use knowledge; it implies ideas about how a technology is designed, manufactured and marketed. A central claim that especially underlies the user innovation as well as the STS literature is that design knowledge embodies knowledge about users and use. That is, through disembodied learning ideas and imaginations about

[9] The categories of non-, implicit and indirect representation are a refinement of Akrich's [118: 173–174] earlier denotation of these forms of representation as “implicit techniques”.

		Sources of Innovation: Local embedding by …	
		Users	Producers
Source of Use Knowledge at …	Users	User Innovation *Learning by using*	Domestication Semiotic Tradition Extended: De- and Re-inscription Re-configuring the user *Learning byusing* *User participation* *Direct representation* *Indirect representation*
	Producers	"Customization" -	Semiotic Tradition Narrow: Configuring the user I-methodoloy *Implicit representation* *Non-representation*

Fig. 1. Boundary zones for embodied learning.

users and use abound, but only a selection of these ideas becomes incorporated in technology.[10] In this regard, a key message in the semiotic tradition in STS is that technological designs are not innocent, but that they, by way of incorporating certain selections of use knowledge, deploy certain ideas about users and use. While the other two literatures have not addressed this as their central concern, they seem to share the underlying thread—for instance, when Tyre and von Hippel delve into situated learning in user firms to show how this is structured by its social *and* material setting [75: 72] or when Silverstone and Haddon introduce the idea of *pre-domestication* [19: 49]. It is thus crucial to understand how and why certain bodies of use knowledge become embodied in technology, whereas others are not. This squarely addresses Rosenberg's distinction between embodied and disembodied learning—it is important to understand not only the different sources of use knowledge, but also the mechanisms through which certain knowledge from these sources is embedded with design knowledge. We now turn to the mechanisms that the literatures highlight for such local embedding of use and design knowledge.

3.2. Boundary zones for embodied learning: the local embedding of use and design

Following von Hippel's work on user innovation and the discussion in Section **2**, different mechanisms of embedding use with design knowledge (i.e. embodied learning) can be categorized along two dimensions: the sources of innovation, i.e. the locales where the embedding of use with design knowledge takes place [68], and the sources of use knowledge, i.e. the locales from which the embedded use knowledge originates. Fig. 1 illustrates the two-dimensional space thus spanned using the distinction between users and producers. It maps the discussed literatures as well as the different sources of use knowledge within this space. Broadly, the boxes indicate different types of *boundary zones* between design and use where the fine line between disembodied and embodied learning is crossed. In what follows, we discuss these boundary zones along the lines suggested in Table 1.

Two extremes are shown in the top left and the bottom right box of Fig. 1, where use knowledge stems from the locale where it is also embedded with design knowledge. The original contributions in the user innovation literature and Woolgar's initial paper on the configuration of users [17] have explored these boxes: in user innovations, users draw on their often tacit experience created through *learning by using* to modify a technology. In this case, users possess the necessary design knowledge in order to innovate. Their combined design and use knowledge explains the transgression between disembodied and embodied learning. Woolgar's original case of configuring the user as well as Akrich's notion of the I-methodology describe the mirror image [17,118]: Producers embed use knowledge tacitly assumed through *implicit* or *non-representation* with design knowledge. In this case, producers are innovators that also possess a degree of use knowledge, however tenuous its relation to actual users and use contexts may be. Their combined design and use knowledge explains the transgression between disembodied and embodied learning.

The upper-right box of Fig. 1 represents the case of producer innovations that draw on some form of explicit consideration of users and use. In such cases, producer innovators engage in more or less elaborate methods to tap into the knowledge of users. The use knowledge, therefore, stems from the users, and the locales of generating use knowledge and embedding it with design are not identical. In addition to more traditional forms of marketing research, studies in the semiotic tradition of STS have

[10] To reiterate: this is neither to say that such selections are consciously or even deliberately made (although they may), nor that it is easy to trace which ideas about use become embedded with design [131,190]. The point is that ideas about users and use, in one way or another, become part of design knowledge. This is also a central claim that von Hippel [68] makes (see Section *2.1* above).

explored the deliberate attempts to tap into the knowledge of users as attempts to construct a user. The boundary between disembodied and embodied learning, therefore, is transgressed when certain representations of users are scripted into technology. This tradition has shown that representations of users and use that can be read of designs are often quite distinct and simplified versions of those representations that emerged from the different sources of use knowledge [126,191]. Hence, this literature has underpinned that it is not so much the sources of use knowledge that matter per se, but the merging of the knowledge obtained from these sources with other forms of knowledge and constraints in the design process [131].

The domestication literature, likewise, has claimed that the knowledge produced in domestication influences design at the design–domestication interface [19]. Unfortunately, empirical studies of domestication provide little insight in this regard—neither did they put users' attempts to modify technology center stage [185], nor did they explicitly address domestication processes as a source of inspiration for product design [153]. Rather, they have provided an elaborate idea of the social context of use and the manifold dimensions of disembodied learning beyond simplistic ideas of functionality. The joint message of the upper-right box in Fig. 1, therefore, is that crossing the boundary between disembodied and embodied learning is a process that not only involves the creation of use knowledge, but also the often implicit selection and translation of use knowledge that becomes part of design decisions. The semiotic tradition in STS is the only literature that has addressed this issue at some length, while domestication research provides elaborate cues about how scripted versions of users and use interact with real world contexts of use.

Up to this point, the discussion has focused on single instances of embedding use with design knowledge, and it has downplayed the diachronic dimension of innovation—that the different bodies of use and design knowledge co-evolve over time as an innovation proceeds through different rounds of modifications. Indeed, every new or modified design represents conjectures about its future use. The discussion in this section has explored what the three literatures say about how such conjectures are inscribed in new technology. The remainder of this paper shall focus on what the different literatures say about how such conjectures evolve when new technology moves through the different boundary zones indicated in Fig. 1.

The bottom left box of Fig. 1, seemingly odd at first sight, provides further cues in this regard. Here, we find cases where users embed use with design knowledge, but where producers frame such user innovations as customizations not worth further pursuit. Slaughter's investigation of stressed skin panels has dealt with this situation in more detail, where a continuous stream of user innovations failed to be integrated into generically available design knowledge [84]. In such cases, new designs continue to be informed by the use knowledge of producers. While this box obviously leaves room for further discussion and empirical inquiry, which exceed the scope of this paper, it foreshadows another important aspect—namely, that the results of local embedding have implications beyond the circumstances from which they stem. While the value of a new design or a design modification is by definition clear to the innovator, over time this value has to prove viable across a range of contexts. In other words, the use knowledge embedded in new designs becomes contested when the design moves to different locales in the innovation processes.

Summing up, Fig. 1 has mapped the different forms of locally embedding use with design knowledge that could be identified in the three literatures in a two-dimensional space. It sensitizes future empirical analysis for both the sources of use knowledge and the sources of innovation as crucial, yet distinct variables that characterize single instances of innovation, and analyze such instances as particular combinations of use and design knowledge. The literature has suggested different boundary zones in which these types of knowledge are embedded so that the fine line between Rosenberg's [36] disembodied and embodied learning is crossed. Most pertinently, the semiotic tradition suggests that exploring cases of producer innovation more closely in terms of how deliberately generated use knowledge is embedded with design warrants additional future research.

3.3. Cumulative learning: toward the co-evolution of use and design

Innovations are not limited to discrete instances of knowledge creation. Rather, they emerge, evolve and stabilize when results from such instances are contested, combined and accumulated across different social settings [192]. The literature review in Section **2** has already pointed to an important aspect in this regard: When we conceive of a new design as a specific combination of use and design knowledge, which is the perspective of all three literatures, then we should analyze innovation processes as simultaneous changes in the use and design knowledge embedded in the evolving technology. This section summarizes what each of the literatures suggests about such processes of cumulative learning (see Table 1) and identifies a number of gaps in this regard.

The contestation of the use knowledge embedded in technical objects is the most immediate aspect of cumulative learning that emerges from the literatures. The local embedding of use and design knowledge takes place in specific settings, but the resulting implicit and explicit conjectures about an artifact's future use are contested once an innovation travels to other settings. In this regard, each literature has provided more or less well-elaborated further cues that can be structured along the lines suggested by Humphrey and Grayson [115] (see above): If users innovate, the exchange value of their innovation remains underspecified until manufacturers come into play. In the case of rodeo kayaking, for instance, the use knowledge embedded by highly skilled kayakers proved insufficient as a basis for mass-produced rodeo kayaks. For these, manufacturer modifications were necessary that incorporated more generalized representations of user skills [59]. Similarly, when a new design stems from a producer, its use value is challenged in real use contexts. This was the case, for instance, when the safety device for elderly users investigated by Hyysalo [122] did not fit the real-world infrastructure in which these devices had to operate. Real users did thus not comply with the scripts presented to them.

Both these forms of contestation characterize the movement of use knowledge between the spheres of producers and users. In both cases, such contestation may run up against powerful initial conjectures: the user innovation literature has highlighted that the exchange value of user innovations benefits considerably from the user's intimate knowledge of the use environment (after all, rodeo kayaks invented by users have been put into large-scale production with little further modification). Equally, the use value of a producer innovation can profit considerably from the producer's advanced design knowledge, which allows him or her to conceive of uses outside the imagination of real users [193]. In this sense, the literatures together have highlighted the specific strengths of use knowledge created by users and producers respectively. But how ideas about technology use evolve over time, when an innovation travels through the different boundary depicted in Fig. 1 is only partially covered in each literature:

- The user innovation literature has explored the creation of use knowledge in the domain of users. Analytically, therefore, it has remained relatively close to Lundvall's traditional idea of user–producer interactions: Artifacts move between the spheres of users and producers. Producers pick up the use knowledge already embodied in user innovations [68]. The accumulation of use knowledge has been addressed comprehensively in the sphere of users, where user-invented designs and the underlying knowledge are often freely shared [61,62,67]. The user innovation literature, however, has not provided a comparably dense coverage of how user innovations are turned into commercial products, and in particular how manufacturing firms modify user innovations in order to enhance their exchange value. While the models proposed by Baldwin et al. [59] and Hienerth [66] as well as recent literature on user entrepreneurship [63] are important steps into this direction, they revolve largely around the notion of economic value. We still lack an in-depth understanding of how manufacturers modify user innovations that they deem worth commercializing.
- The semiotic tradition in STS has extended Lundvall's idea of user–producer interactions to include real users as well as the users imagined or constructed by designers. Creating use knowledge, therefore, is a task that involves both producers and users. This literature, then, has sensitized researchers to the interplay between the uses and users imagined by designers and the real world contexts of use. However, the semiotic tradition in STS, probably due to its epistemological foundation in in-depth single case study research, has tended to take a *snapshot view*, where certain episodes of locally embedding use with design knowledge have received more attention than their diachronic counterpart of cumulative learning [40]. Those scarce studies that have followed technology through multiple sites and episodes of embedding use with design knowledge suggest that producers gradually learn to employ more sophisticated means of tapping into use knowledge [43].
- The domestication literature, finally, has almost exclusively focused on the sphere of users. Analytically, this literature has assumed that use knowledge is the domain of users. Cumulative learning takes place through *conversion* when meaning generated in the private sphere of households is (often unintentionally) shared between households, and thus stabilizes into a publicly shared meaning. This literature has thus been extremely helpful in illuminating how consumers and in particular collectives of consumers consummate technology through consumption. Unfortunately, domestication has not gone full-circle to explore how the use knowledge thus created feeds back into design.

Together, the three literatures reveal a rather piecemeal picture of cumulative learning. Especially the transgression of technology between the different locales of producers and users and the associated forms of contestations mark an under-researched area in each of the literatures. This is unfortunate as the sources of innovation as well as the sources of use knowledge are likely to change during the course of an innovation. Given that all literatures have demonstrated universal coverage (see Section 2.4 above)—i.e. the boundary zones in Fig. 1 may be relevant across a broad range of domains—different mechanisms of locally embedding use and design knowledge may subsequently become relevant in innovation processes. For instance, a user innovation, when transferred to the site of a producer, may then incorporate use knowledge from any of the sources depicted in the upper-right box of Fig. 1. Conversely, a new product may initially start in the way described by Woolgar [17], but over time more direct forms of user involvement are likely to emerge, possibly also including design inputs of users.

Finally, this allows us to go beyond what we know from the discussed literatures. In the longer run, innovation processes combine a specific blend of sources of use knowledge when technical objects move within and between the spheres of users and producers. In a diachronic perspective, it therefore becomes questionable whether it makes sense to talk about a user or a manufacturer innovation at all. To the contrary, the synopsis of literatures above suggests that, in the longer run, users and manufacturers contribute to both use and design knowledge. To grasp cumulative learning, we need to be able to follow these contributions over time, as an innovation moves through the boxes of Fig. 1, and explore how certain sequences of sources of use knowledge feed into an evolving technology. In the following concluding section, we suggest an empirical agenda that follows from and makes use of these considerations. This agenda, we contend, is particularly useful in researching how societal challenges become articulated in innovation.

4. Conclusion: toward understanding the articulation of societal challenges

This paper has started with the question of how challenges in the societal environment of innovation become articulated in processes of technological change. To address this question, we have reviewed three bodies of literature that focus on the use and user side of innovation. Most importantly, the review has identified a set of boundary zones in which the use and the design of new technology meet. Fig. 1 has mapped different sources of use knowledge in these zones. Furthermore, the review has revealed the processes identified in the literatures for the creation, selection and embedding of use knowledge during processes of technological design and use. The concepts of use and design knowledge can be employed to bridge the methodological and epistemological differences between the reviewed literatures. They pull together different insights about the local embedding of use and design knowledge. Together the literatures suggest a perspective where innovation proceeds through instances of combining existing knowledge with either new use or new design knowledge, and they flesh out a prolific account of the micro-processes that lead to such new combinations.

However, the literatures fall short in accounting for the diachronic counterpart of these micro-processes—the co-evolution of use and design knowledge in innovation. *The literatures do not provide an explanation of, and empirical insights about, how use knowledge becomes specified and embedded with technology over time, when different sources of use knowledge subsequently become relevant.* This paper therefore connects with the emerging body of studies that try to move beyond a "snapshot view" of innovation and focus on longer-term learning processes in use–design relationships [40,43,194]. Our paper adds to this literature a detailed overview of the different locales and mechanisms described in earlier studies that give form to such use–design relationships. It has transpired from the review above that learning in innovation proceeds in succeeding instances of locally embedding use with design knowledge. That is, it proceeds in specific movements through the boundary zones depicted in Fig. 1.

These insights, finally, present essential cues for further empirical research on the articulation of societal challenges in innovation. *How are specific and probably conflicting understandings of certain societal challenges shaped in technological change and innovation?* Indeed, such challenges have been shown to be powerful repositories of use knowledge: Broad notions such as 'sustainability' or 'demographic aging' are evoked and molded during innovation, and thus loaded with more specific meanings in the technological projects that address them [1–3,9,10]. We posit that the boundary zones in Fig. 1 denote pertinent spaces for such articulation processes when, for instance, designers imagine the role of technology in the life of older persons, or, vice versa, older persons domesticate technology designed to support their "independence" or "health". Hence, following different innovation activities in the context of the EU's recent engagement with innovation for "healthy aging" [5] through the different boundary zones in Fig. 1 is likely to provide a nuanced picture of how this very notion is articulated when it "travels" through different sites of technology design and use.

Hence, we propose that the framework developed in Section **3** should be used to explore heterogeneous sets of innovation activities in the context of the same societal challenge. This challenge, then, constitutes a common setting in which to integrate findings derived from diverse instances of embedding use and design knowledge. The research agenda that follows from this comprises three steps:

(1) In the context of a societal challenge, researchers should select innovation projects that populate the different boundary zones in Fig. 1—i.e. cases that span different time-frames and sites, such as the household of older technology users, the laboratories of technology researchers, or the R&D departments of technology producers. This ensures that the research covers both different phases of innovation, and the whole breadth of sources of use knowledge identified above.
(2) For each of these cases, the sources of use knowledge, and mechanisms of arriving at specific articulations of, for instance, "healthy aging" that prevail from these sources, should be analyzed. This implies to also focus on how the use knowledge already embedded in artifacts plays out when these artifacts enter new settings. The notion of contestation and the related concepts of exchange and use value might prove particularly beneficial in this regard: Tapping into the different forms of contestation, when artifacts move between different boundary zones, is essential to understand the mechanisms through which different articulations of "healthy aging" evolve over time.
(3) Finally, the insights from the different case studies should be integrated into a comprehensive understanding of the articulation of a specific societal challenge, and the mechanisms that account for these articulations. The conceptual framework developed above is crucial in this regard. It allows for structuring detailed case studies along comparable conceptual lines, although the cases may cover different technological domains, different levels of complexity of the relevant technical objects, or different phases and episodes of the innovation process. What our framework adds to previous research is the possibility of *systematically exploring and comparing* the micro-processes highlighted in Section 3.2 above in a specific societal domain. Through selecting cases in a variety of settings but relating to the same societal domain, it becomes possible to connect results generated by different micro-approaches into a *theoretical understanding* of how technology evolution incorporates and shapes specific definitions of broad societal challenges.

From an empirical point of view, the proposed agenda is challenging as it pulls together data from different sites, time frames and levels of analysis. In echoing the above epistemological discussion, this can only be accomplished within an interpretivist framework that abstracts from empirical studies to concepts rather than "facts". Indeed, our agenda implies to "follow" innovation activities through different societal settings and different points in time, and to make sense of these activities within the conceptual framework of societal challenges and their articulation. Data collection for such an endeavor is bound to be at least partially eclectic, because each of the relevant boundary zones is likely to pose specific problems of field access. For instance, researching the domestication of technology by older people might allow for ethnographies at older person's households [see 195], but understanding how company researchers imagine older technology users might have to rely on interviews with key personal [see 144]. Traditional multi-case analysis runs up against limits in this regard, because it encourages researchers to carefully select cases to represent comparable time-frames and levels of analysis [196: 54]. The research we envision, by contrast, connects to those grounded theory inspired approaches that explicitly aim at *theory generation* through bridging case material derived from a broad range of social settings and associated research methods [197–200]. While it is beyond the scope of this paper to elaborate on such approaches in more detail, the concluding proposition that follows from them is to use the concepts developed above as analogies between different empirical settings.[11] This, in turn, allows for elaborating ideas such as use and design knowledge, contestation, or the sources of use knowledge into theories of how specific societal challenges become

[11] For a history and discussion of analogical reasoning as a style of knowing see Kwa [201].

articulated across a broad range of innovation activities. For innovation policy such an understanding of the mechanisms through which societal challenges are articulated is relevant, because it brings out the subtler processes through which innovation not only responses to societal challenges, but also contributes to the way they play out over time.

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