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Tying Knots: Participatory Infrastructuring at Work

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Corresponding Author:	Susanne Bødker Aarhus Universitet Aarhus N, DENMARK
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Aarhus Universitet
Corresponding Author's Secondary Institution:	
First Author:	Susanne Bødker
First Author Secondary Information:	
Order of Authors:	Susanne Bødker
	Christian Dindler
	Ole Sejer Iversen
Order of Authors Secondary Information:	

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Susanne Bødker, Christian Dindler, Ole Sejer Iversen
Aarhus University
Center for Participatory IT
Aabogade 34, 8200 Aarhus N, Denmark
bodker@cs.au.dk
tel. +45 87156148
fax +45 87154113

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Abstract

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To illustrate and discuss the process of participatory infrastructuring we use a case study from an educational context. This particular project contains a diverse set of design activities at many organizational levels revolving around technology, decision-making, competence-building, commitment and policy-making. The project highlights these complexities, and our discussions lead to a vocabulary for participatory infrastructuring that focuses on knotworking, rather than structure, and on both horizontal and vertical reach and sustainability. This vocabulary is grounded in the meeting of the literature on infrastructuring, participatory design, and activity theory, and leads to a revised understanding of, for example, learning and conflicts in participatory infrastructuring.

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1 Introduction

The starting point for this paper is that while this was not true of the original infrastructuring literature (Star and Ruhleder, 1996; Bowker and Star, 2002), more recent literature often portrays participatory approaches to infrastructuring as primarily horizontal and local processes. Star and Ruhleder (1996) originally talked about an infrastructure as occurring when the tension between the local and the global is resolved and local practices are afforded by a larger-scale technology. It becomes transparent as local variations are folded into organizational changes. Karasti (2014) describes infrastructures as interrelated technical, social, and organizational arrangements involving hardware and software technologies, standards, procedures, and practices. However, infrastructures are not without tensions and conflicts as Star (1999) states: ‘One person’s infrastructure is another’s topic, or difficulty’ (p. 380).

As noted from these writings, infrastructures span (but do not unite) many levels of use and development, many levels of organizational practices, and the potential for tensions among many perspectives, and many temporal scales, in contrast to the work of e.g. Monteiro et al. (2013).

In the literature, the concept of participatory infrastructuring is featured several times (Binder et al., 2011; Clement et al., 2012; DiSalvo et al., 2013; Capaccioli et al., 2016), yet it is mentioned in passing, rather

than defined. Karasti (2014) more gracefully discusses infrastructuring and participatory design (PD), yet her work lacks a uniting and defining concept, that we think participatory infrastructuring could potentially become. With our background in PD, we find the horizontal and local focuses surprising, and slightly disturbing. In this paper, we frame our inquiry into the area of infrastructuring with the concept of participatory infrastructuring. By participatory infrastructuring we refer to infrastructuring activities that engage users in processes of design and use. We suggest that these activities are crucial for PD efforts to succeed and should be considered PD activities. Participatory infrastructuring activities may, however, be different from what we usually conceive of as core PD activities and in order to understand participatory infrastructuring at work, we need to extend our understanding of what constitutes PD activities. To define, illustrate and discuss the process of participatory infrastructuring we introduce concepts that we believe can serve as useful theoretical ground, and present a case study from an educational context. We report a case from a project with a diverse set of design activities on many organizational levels revolving around technology, decision-making, competence-building, commitment, and policy-making, and illustrate our suggested approach to participatory infrastructuring.

1.1 Towards a concept of participatory infrastructuring

Several CSCW, innovation, and organization researchers have pointed out that design and innovation do not simply happen in singular projects at singular points in time. The complexities that emerge when design and innovation happens across artifacts, people and organizational levels has been discussed at length. Heiskanen et al. (2010) point out the importance of time in communities where users take part in innovation, and Kensing and Blomberg (1998) discuss the relationships and collaboration with and among users at different organizational levels, referencing Gärtner and Wagner (1996) and their conceptualization of different arenas of participation. Infrastructuring provides a useful frame for understanding and addressing projects in which technology is developed over time, arenas, and communities of users and practices (Star and Ruhleder, 1996; Bowker and Star, 2002), and in which various groups of users participate in various stages and at various times. Infrastructures, and in particular, information infrastructures are discussed by Pollock and Williams (2010), Monteiro et al. (2013), and Hanseth et al. (1996). What they call information infrastructures are characterized by openness with respect to the number and types of users and interconnections of dynamically evolving ecosystems that are shaped by an installed base of existing systems and practices. In the edited volume by Voss et al. (2009), many contributions study user-designer collaboration as processes of co-realization over time. In this book, Büscher et al. (2009) focus on the relationships between specific user participation and general technology development. This two-layer strategy is known also from Grønbæk et al. (1997) and can be seen as one attempt to extend PD methods to technology development beyond each specific user project.

In the infrastructuring literature, we have found two bodies of work that are particularly relevant for our current inquiry into participatory infrastructuring. First, in their development of the relationship between infrastructuring and PD, via Dewey's notion of publics, Le Dantec and DiSalvo (2013) bring together the infrastructuring and PD literature to discuss the attachments between objects and their diverse publics. They base their work on Ehn's (2008) idea that infrastructuring through design supplements PD's focus on design-for-use, centered on useful systems, with a focus on design-for-future-use, structured to create fertile ground to sustain a community of participants. In their approach, infrastructuring is the work

of creating resources that, both socially and technically, enable adoption and appropriation beyond the initial design. Le Dantec and DiSalvo (2013) state that 'infrastructuring is a particular mode or practice of PD that develops and provides sociomaterial resources and experiences' (p. 247). In their work on participation and democratizing innovation, Björgvinsson et al. (2010) discuss infrastructure as central to innovation, as the latter demands extensive collaboration over time and among many stakeholders. This leads them to address design as continuous co-creation in the 'collective interweaving of people, objects and processes' (ibid. p. 44). These processes may include participants who were not present during the initial design, and as such their processes are concerned with PD that involves possible users beyond the immediate ones. However, the main focus seems to be on how the designer may facilitate an engaging co-design meeting between particular people and socio-material resources to somehow set these people free (a worthy cause indeed), rather than on addressing the wider organizational, political, and technological contexts in which the participation happens. Such contributions, along with e.g. how Clement et al. (2012) focus on challenging the perceptions of identity and privacy by hooking up to existing identity management infrastructure in the civic space, are certainly useful. Although we appreciate the possibilities of enriching democracy through infrastructuring, at the same time it does look as though in many instances the designers or researchers choose to work with communities of users that *do good* things, almost as a researcher or designer catharsis, as discussed by Bødker (2015a).

Second, Pipek and Wulf (2009) use the term 'infrastructuring' to describe how information systems may be seen increasingly as systems of systems that emerge and evolve over a long time, with multiple and expanding numbers of users and uses. Pipek and Wulf (ibid) address the timing and layering of infrastructures in their approach to understanding infrastructuring processes. However, in their discussions of points of infrastructuring, it seems that these points occur after design, when technology is appropriated and tailored for use. In their view, design and implementation happen in parallel; existing users are already engaged, and similar to Le Dantec and Di Salvo (2013), work should be done simultaneously to address the immediate use and the longer-term sustainability of the system. However, in their writings, it is not evident how the infrastructuring processes involve users beyond the 'points of infrastructuring', and hence how users may be involved in the longer-term and future-directed design processes. Nonetheless, we pick up from Pipek and Wulf (2009) their concerns for the complexities and intricacies of infrastructures, which also voices a concern for socio-technical organization and users working in organizations rather than people being brought together in more ad-hoc manners (such as publics).

Returning to the understanding of infrastructure provided by Star and Ruhleder (1996) and Star (1999), we believe that two aspects in particular need to be re-accentuated and further developed, in order to develop our understanding of participatory infrastructuring. First, in the literature relating to PD and infrastructuring we find that focus is often on front stage design activities such as workshops or cooperative prototyping, where designers, researchers, participants, and stakeholders come together to work on the object of design (e.g. Leong and Robertson, 2016; Kanstrup et al., 2014; Light and Akama 2014). While these are indeed both necessary and important, we suggest that we also need to turn our attention to how infrastructuring is actually achieved in large and complicated settings that stretch beyond front stage activities of PD. Second, we find that much attention is paid to the local and horizontal aspects of participatory processes such as the methods and micro-dynamics of participatory work during PD workshops or other activities (e.g. Bossavit and Parsons, 2016; Makhaeva et al., 2016). As much as

we recognize the importance of these activity-oriented contributions, we do see the need to expand the understanding of PD work beyond the micro-dynamics of PD interventions, towards a focus on the sometimes fuzzy and chaotic processes that emerges before, between and after these interventions.

Consequently, we suggest that in order to shed light on the practice of participatory infrastructuring, we need to expand our view of design activities in three dimensions. First, we see a need to re-accentuate and develop our understanding of how participatory processes play out vertically in different political and practical arenas. Second, we see a need to focusing on the back stage of design, the messy and less photogenic activities that occur before, between and after the participatory workshops. And third, we see a need to provide an account of participatory processes that articulates their reach, the way they tie into existing networks and systems across organizations, and how agency and initiatives become dispersed within these networks.

To make the case for re-accentuating and developing the above-mentioned three dimensions, this paper is structured as follows. First, we offer a conceptual understanding of how participatory infrastructuring is practised, by synthesizing recent work that addresses the messy and multifaceted process that unfolds on the back stage of PD between workshops and meetings. We argue that these activities are crucial in terms of understanding the process of infrastructuring, yet remain underdeveloped in the literature. In particular, we draw on concepts of knotworking and networking (Engeström et al., 1999), relational agency (Edwards, 2012; Dindler and Iversen, 2014), and sustainability (Iversen and Dindler, 2014; Kyng, 2015). Second, we explore how these processes play out in a case study in which PD work was conducted at several hierarchical levels of political authority. The case study adds to the discourse and vocabulary of the back stage of participatory infrastructuring by demonstrating how PD work takes on different forms as it moves through levels of power. In the concluding part of this paper, we discuss how this view of the back stage of PD challenges traditional concepts of mutual learning and stakeholders as the cornerstones of PD.

In the context of this special issues, this paper addresses the practice of infrastructuring 'in the wild' and provides a language with which to describe activities, constellations and kinds of expertise that are crucial to participatory infrastructuring. We use Star et al.'s (Star and Ruhleder, 1996; Star and Bowker, 2002; Star 1999) original work on boundaries and infrastructures and activity theory concepts such as relational agency in PD (Edwards 2012; Dindler and Iversen 2014), and the concepts of knotworking and networking (e.g. Engeström et al., 1999), to show participatory infrastructuring possibilities. In combining these theoretical elements we seek inspiration in Star (1997) who illustrates how symbolic interactionism, and activity theory 'afford' each other, politically, aesthetically and scientifically (see also Bødker, 1999):

'I believe that jointly activity theory, interactionism, and information-systems research have some important insights to offer scholarship and development. We know that, in spite of the failure of rationalism, the world does not fall apart. We've begun to understand that the absence of a monolithic voice does not mean chaos or babble, but pluralism, and that requiring translation' (Star, 1997 p. 313).

2 Conceptual grounding

In the two sections discussing our conceptual grounding, we explore theoretical work that we believe serves as a basis for understanding (1) how participatory processes play out vertically in different arenas, (2) the back stage design activities that unfold between workshops and (3) the reach of participatory processes as they tie into existing networks.

2.1 Knotworking, networking, and relational agency

From the outset, PD has been committed to facilitating the meeting of different stakeholders (Greenbaum and Kyng, 1991), and the PD literature is rich in methods and tools for accomplishing this task (Robertson and Simonsen, 2013). Workshops, meetings, and cooperative prototyping sessions provide venues for mutual learning, and are often considered to be the drivers of PD processes. However, these are only the front stage of PD. Behind these activities are preparations, negotiations, and political work that fundamentally shapes the set-up and outcomes of the entire process. These may be thought of as the back stage of PD. Our thinking is inspired by Star (1999), Bowers (1994), and Edwards and Grinter (2001), and borrows from Goffman's idea of front stage and back stage (Goffman, 1959). This is done with two purposes: First, to address the messy, conflict-prone unfolding of activities in PD generally, and in participatory infrastructuring, in contrast to the romantic show of feel-good participatory activities that we often see in the literature. The front stage is the pretty image of success, whereas the back stage is the often hidden chaos of conflict and turmoil, which Bowers (1994) discusses in the case of procurement and Star (2002) addresses as: 'In some instances, this means going back stage, in Erving Goffman's terms, and recovering the mess obscured by the boring sameness of the information represented. It is often in such back stage work that important requirements are discovered' (p. 120).
Secondly, the concept of back stage orients us to the activities and the processes that tie together particular design activities, such as workshops and meetings, together. These activities specifically target issues such as the alignment of actors and decision-makers, and the underlying development of the technological platforms used, the latter being parallel to the processes described by Obendorf et al. (2009) and Kyng (1995).

These back stage processes accentuate the need to look at design processes over time, beyond the specific PD activities in which users and designers collaborate, similar to some of the cases discussed by Heiskanen et al. (2010). The concept of infrastructuring helps us look at the activities around and beyond that. For example, Karasti et al. (2010) present a case of e-science research, specific projects, and an overall longer-term development of shared data definitions (metadata) to understand the role of time and long-term activities in infrastructuring. They describe the collaborative development of metadata in scientific classification, discussing this process as two-level, occurring in two separate time-scales: the individual project, and the meta-development that they relate to infrastructuring. They discuss tensions between the two levels, and differences and relationships between the developments on the two different time scales. The back stage work of participatory infrastructuring, as in the case they present, is not primarily about direct PD. It may involve conflict and negotiation, straightforward technical development, strategic discussions of and among designers, and it may involve strategic engagement with participants and stakeholders at other organizational and political levels, to mention a few elements to which we will

return. To shed light on these back stage activities we begin by considering relationships among participants in the process.

The significance of personal and professional relationships in design has been addressed from several perspectives in the literature. The tools and techniques documented in the literature reflect careful consideration of how the meeting between different stakeholders is arranged (Muller 2007). The significance of relationships and networks within communities, in terms of sustaining the results that emerge from the effort, has also been explored (Merkel et al., 2005; Carroll and Rosson, 2007; Iversen and Dindler, 2014). More recently, the questions of how to facilitate the emergence of more or less stable networks and relationships has emerged as a topic, through studies of the practice of facilitation (Light and Akama, 2012) and designers' relational expertise (Dindler and Iversen, 2014). Here, we pick up the latter thread of research, which focuses on the nature of the relationships and networks that emerge in participatory projects, and the designer's agency in this process.

To describe the kinds of relationships that emerge through design and the dynamics that characterize them, we draw on Engeström's work (2007). In particular, we note a spectrum of temporary and unstable 'knotworks' and more stable, enduring networks, which we both see as elements of infrastructuring. The term 'knotworks' is derived from Engeström's (ibid.) characterization of social production as a form of production where traditional notions of centers of control and mechanisms of coordination do not hold. He uses the term mycorrhizae (borrowed from the realm of fungi) to characterize the locus of agency in social production, and argues that work in social production is organized in knotworks in the form of fluid assemblies that are less rigid than networks. According to Engeström (2006), mycorrhizae 'are made up of heterogeneous participants working symbiotically, thriving on mutually beneficial or also explorative partnerships with plants and other organisms' (p. 1788). The concept of knotworks indicates the fluid, yet momentarily stable, constellations that emerge among participants with different backgrounds, perspectives, and agendas as they come together in matters of common concern. Engeström emphasizes the symbiotic nature of these constellations; the relationship is mutually beneficial, but the participants' objectives and agendas are not necessarily identical. Engeström argues that these knotworks do not have a stable center of control. We use the concept of symbiotic agreement to refer to the mutually beneficial relationships that emerge among heterogeneous actors. These relationships are far from always formally constituted, fully visible, or permanent, but form the textures from which activities can emerge and grow.

In contrast to the fluid and temporary nature of knotworks, are more stable and enduring networks of people. The significance of these networks is well-acknowledged by Carroll and Rosson (2007), for example. Some networks, as we know them, are indeed developed through PD processes (Bossen et al., 2010), but stakeholders also bring networks into the process from the beginning, and others may be brought on-board along the way. Not only does the designer step into an existing network of working relationships (Suchman, 2002). All participants are cast into working relationships that are defined by the networks of individuals and groups. In any event, the networks may be vital in several respects. They connect the project with arenas outside the project (Gärtner and Wagner, 1996), and provide an infrastructure for disseminating results and ideas beyond the project. In terms of politics, these networks are also significant in terms of understanding how certain stakeholders in a project may gain leverage or positions of power.

For our understanding of participatory infrastructuring this means that design processes in this space need to address the fluid and temporary knotworks, and perhaps even create such, and identify and navigate more permanent networks spanning various user communities. Initiative for activities in these various 'knots' must be addressed analytically as well as when acting constructively in them, as user or as designer.

To characterize the agency involved in establishing and maintaining the knotworks and networks of design, we consider the concept of relational agency (Edwards, 2012). According to Edwards (ibid.), relational agency describes how professionals produce enriched understandings and actions in collaboratory processes by aligning their own responses to problems with those offered by other professionals. Relational agency is a capacity that emerges as people work together to expand their understanding and opportunities for action in relation to the situation at hand. It involves working with others to expand the object of activity by recognizing the resources and understandings that others bring to the situation, and aligning one's own responses to the newly enhanced interpretation with the response made by others, as they act on the expanded object. Whereas knotworks and networks describe the constellations that emerge through infrastructuring, relational agency describes the stakeholders' capacity to engage in these processes. Although it may be argued that designers should be experts in terms of facilitating relationships (Light and Akama, 2012; Dindler and Iversen, 2014), relational agency is exerted by all stakeholders. In extension of Engeström (2007), the concept of relational agency adds a focus on the coming and going of human actors who meet, not only around the socio-material constellation, but also around defining and changing the motivation for their joint activities, and their opportunities for action in the knotworks and networks that we suggest offer a better picture of infrastructuring across single activities. Participatory infrastructuring needs to address the ability of groups of participants (users, designers or other stakeholders) to engage in the shaping and re-shaping of the motivation of the joint activities.

2.2 Sustainability, empowerment and time

Networks and knotworks provide a way to discuss the back stage activities and also parts of an infrastructure in which ideas, technologies, and organizational arrangements are developed and appropriated. However, to understand the significance of these constellations beyond their immediate settings, it is necessary to look at how processes and outcomes are extended over time. Karasti et al. (2010) indicate the need to consider long-term perspectives on infrastructuring and collaborative development, and this is also true for PD: some activities do not centre around the immediate technology or work process at hand, but on creating the conditions that will allow outcomes to be sustainable over time. By sustainable we mean how insights and processes, as well as design results, may be activated on a longer time scale. When, for example, Pape and Thoresen (1987) talk about empowering, they specifically consider how a design project may support individuals and groups of participants in making better-informed design choices later on, independent of the previous specific project. From an infrastructuring perspective, sustainability may then also imply the development of technological components, or methodological elements that may be activated in later activities or knotworks (or projects in the terms of Karasti et al., 2010). In our case study, we provide examples of these practices and how the ideas of knotworks, networks, and sustainability may work in concert, to understand participatory infrastructuring.

In some respects, the question of how PD is extended over time is inherent to the core concept of mutual learning which is tightly coupled to reflection, empowerment, and–largely–to sustainability. Simonsen and Robertson (2012) identify mutual learning as the central component of their understanding of PD as investigating, understanding, reflecting upon, establishing, developing, and supporting mutual learning among multiple participants, in a collective reflection-in-action (ibid p. 2). Mutual learning is a way of finding common ground among participating designers and users. It concerns ways of working in the process (Kensing and Greenbaum, 2013), building trust among participants (Bratteteig et al., 2013), and sharing power within the project (Bratteteig and Wagner, 2012). As pointed out by Bødker et al. (2004), only when a design team has a fundamental knowledge of existing practices is it possible to arrive at a sustainable design. However, the idea of mutual learning does seem primarily suited for discussing what goes on during a design process, and less so for addressing long-term developments.

Pape and Thoresen (1987) presents the concept of empowerment which is picked up by Bødker 81996), who suggests that PD work is not only about project achievements, but also about putting an organization in a position where experiences may be used beyond the project's end. A similar idea is found in the MUST method (Kensing et al., 1998), where sustainability is a grounding principle for ensuring that new IT systems fit preferred work practices, and in Carroll et al.'s (2000) discussion of their long-term PD project. In this latter project, Carroll et al. (2000) note how teachers changed their role from practitioner-informant to analyst, designer, and coach for their colleagues. Their work raises questions, such as how organizations develop self-sustaining learning processes, and the important task of establishing and reinforcing social networks within communities (Carroll and Rosson, 2007; Merkel et al., 2005). The significance of these networks in terms of sustainability has also been explored by Bossen et al. (2010) in their retrospective look at a large PD project. Dindler and Iversen (2014) further develop the discourse on sustainability in PD by suggesting four ideal-typical forms in which PD initiatives are sustained: maintaining, scaling, replicating, and evolving. These forms describe different ways in which achievements from a single project may be carried on and developed. Most recently, Kyng (2015) contributed to the understanding of sustainability by demonstrating how permanent structures (e.g. organizations) may be used to maintain democratic control and ensure sustainability.

In terms of developing a concept of participatory infrastructuring, the foregoing conceptual work points towards the extension of activities over time, towards the ways in which methods and design activities reach back to participants' previous practices and experiences, and forward towards their future (Bødker and Christiansen, 1997). It points towards technologies to be designed for later appropriation and further development (Monteiro et al., 2013), and not least towards how groups and individuals may be empowered to sustain their participation in later projects (see also Pipek and Kahler, 2006; Kaptelinin and Bannon, 2012). Because of this complexity, we are critical of the oversimplified view of technology, that we find in much of the newest writing, as things that can be configured and built together (Bødker, 2015b). Accordingly, we need to be concerned, not only for the relational agency and reflection in these processes, but also for the extension of practices, design methods, and outcomes over time. In what we see as a continuation of Star and Ruhleder's (1996) original work, and that of Monteiro et al. (2013), we return to a more classical understanding of technology that also involves organizational practices and the organization of work, in order to move beyond the engagement of participatory designers in specific activities with specific users. As mentioned earlier, Star and Ruhleder (1996) speak of local practices

being supported by larger-scale technology, which they regard as including networked computer operating systems, local IT-support, and procedures for sharing the shared material on which researchers, in their case, work.

In continuation of this, and our activity theoretical basis, technology exists as a duality that on the one hand captures and 'freezes' certain practices, and on the other hand offers its users new possibilities for action. Mathiassen (1981) and Engeström (1987), with his well-known triangles, point out how these tensions unfold. Moreover, these authors point out that the technology of concern covers the materials that are turned into outcomes, the means and methods for the delegation and division of work and collaboration, and the tools used in the processes.

Accordingly, with regard to participatory infrastructuring, this calls for a greater focus on the methods of infrastructuring, not only in the direct meeting of a group of designers and users, but also for the development of the technological platforms upon which infrastructuring builds, and with which it co-exists, and on the experiences and practices of the people involved, beyond a single knotwork or network.

Obendorf et al. (2009) present a case in which they worked for an extended period of time on the development of an online learning system, first at a university, later on expanding the scope, in terms of both user communities and technological platform. In their intercontextual PD, they set up processes activating both users and designers beyond the specific design case, and discuss how participatory activities make sense across the particular communities, in what they term communities of interest (ibid., see also Fischer, 2001). These processes aim to sustain the development of the overall platform through leveled participatory activities that happen over time, and in interaction with the many different competencies of the many participating groups and individuals. Kyng (2015) provides a useful supplement to this intercontextual focus when he discusses the activities needed to set up and facilitate sustainable PD processes in open-source health care. He offers many examples that illustrate how infrastructuring activities are important at many different levels and across groups of stakeholders and users in many different configurations, to truly make such processes sustainable. We draw inspiration from them, and call for participatory infrastructuring to be considered as more than a string of meetings between designers and users where they configure and build together. Instead, we suggest addressing the longitudinal network of activities in which people and technologies, in the widest sense of the term, are brought together and changed.

3 Case study: Fablab@school.dk

To illustrate and discuss the process of participatory infrastructuring and the conceptual understanding outlined in the previous sections, we now turn to a case study from an educational context. This particular project contains a very diverse set of design activities at many organizational levels evolving around technology, decision-making, competence-building, commitment, and policy making. The project is concerned with the development of a hybrid learning space, 'Fablab@school', for Danish primary and secondary education, introducing digital fabrication technologies and design thinking as parts of the curriculum.

3.1 Project motivation: Fablab@school.dk

In 2014, The Danish Ministry of Education launched a new reform of the standards for the Danish public school (primary and lower secondary school). This initiative included a stronger focus on competencies related to '21st century skills' (Ananiadou and Claro, 2009). This new educational reform emphasized the use of digital technology in all subject areas, and a new craft and design programme replaced woodwork and needlework, to support the innovative and entrepreneurial competences of future generations. In response to this increased focus on ICT in education, the Child-Computer Interaction Group (CCIG) at Aarhus University, together with the three Danish municipalities, initiated a three-year project, Fablab@school.dk, with the primary objective of developing and sustaining digital fabrication and design thinking as parts of lower secondary teaching. The aim was to develop an educational environment that encouraged teachers, students, and schools to integrate new digital fabrication technologies (3D printers, laser cutters, etc.) and digital construction kits (Arduino, Makey-Makey, LillyPads, etc.) into the process of solving real-world problems as part of the educational training. Fablab@school.dk was launched in early 2014 and ends by the end of 2017. The Fablab@school.dk project is collaborating with the global Fablab@school initiative coordinated by Stanford University, and funded for three years by the Danish Industry Foundation. The Fablab@school.dk project is led by managing directors of the three municipalities together with the managing researcher at CCIG. Quarterly steering committee meetings with municipalities and researchers are the backbone of the project management. A full time staff member from one of the municipalities assists the steering committee and coordinates the project on a day-to-day basis.

In 2014, 14 schools were engaged in the process of integrating digital fabrication and design thinking into their teaching. In 2015, the number of participating schools increased to 28, and in 2016 a total of 38 schools have implement digital fabrication and design thinking as part of their lower secondary curriculum. An estimated of 2000 students and 150 teachers have already been involved in the project, either by directly taking part, or by integrating elements of the project findings in their teaching. During the first two years, 10 schools have established a digital fabrication laboratory on campus in which students have access to digital fabrication tools and construction kits. Moreover, each of the three municipalities have established a central fabrication laboratory with digital equipment and an trained staff (2-3 per unit) to assist teachers and students in fabrication processes (www.fablabatschool.dk).

3.2 The Danish school system

The Danish educational system is divided vertically in six levels of authority (see table 1). At the top level is the Danish Parliament. Here, politicians handle legislation relating to schools, and launch educational initiatives to be handled by the national agencies. The Educational Agencies present legislation in executive orders that include the overall educational goals. The executive orders are adopted by the Municipalities, which set the financial frameworks, local goals, and ultimately, supervise and assess the local schools. At the school level, the school board adopts principles for the school activities set by the municipality, and approves the school budget. The school manager (headmaster) is responsible for the operation of each school, and makes concrete decisions regarding the school's individual students. Finally, teachers teach the students. Education in Denmark, and in the Nordic countries in general, is

characterized by freedom concerning the choice of method: generally speaking, the teacher decides how the students are taught and which methods (digitally or other) are used to support instruction and learning.

In order to sustain a new digital fabrication initiative, such as Fablab@school.dk in a decentralized organizational structure, focusing on PD activities on a teacher-student level is insufficient. Many of the decisions that may ultimately bring new digital fabrication technologies and a concern for design thinking into the classrooms are made elsewhere in the organization. For example, the school managers are solely responsible for the teachers' time resources, whereas the municipality is responsible for the budget. However, it is entirely up to the national agency to decide which types of technology that may be purchased to support teaching activities. Consequently, it is obvious that a successful project also needs to work vertically, and integrate all levels of stakeholders to develop and sustain a new initiative, if this initiative, for example, involves integrating teacher resources with resources for procuring new digital equipment.

To illustrate how we work with PD activities, and to explain the complex and highly decentralized infrastructure of the Danish educational system, table 1 lists the core PD activities of the Fablab@school.dk project in relation to the levels of authority at which they were directed. Table 1 illustrates the levels of authority in the Danish educational system, and how these authorities were approached through a variety of project activities in the Fablab@school.dk project. This activity list diverges in several ways from the majority of PD research projects. First, the list of stakeholders differs significantly from activity to activity, not just horizontally, but also vertically. In some cases, school teachers and students were engaged as end-users, and in other activities, politicians and officials were engaged as stakeholders. In contrast to most conventional PD, we worked with the entire vertical scale of authority (Table 1), to give the project the best opportunity to succeed. Second, some of the core activities in the Fablab@school (listed as project activities in Table 1) might be considered outside the scope of participatory practices found in the literature. In our case, sitting on panels of experts, being invited as keynote speaker, ding survey studies of current literature, and doing steering committee work were vital parts of the work, albeit seemingly less participatory than conventional PD activities, such as field studies, user workshops, or collaborative prototyping. Nevertheless, we see these back stage activities as being just as important as the front stage activities usually reported in PD research and PD practice.

Insert Table 1 approximately here

4 Infrastructuring activities

In the following section we look in greater depth at examples of the many Fablab@school.dk activities, in order to analyze and discuss the space for participatory infrastructuring activities. In particular, we highlight how four selected activities demonstrate our work with knotworks, networks and symbiotic agreements vertically, across the levels of authority.

4.1 Creating knotworks to sustain the project

In early 2014, three workshops were initiated by our research group to identify and enroll project participants to address the idea of digital fabrication and design thinking in primary and secondary education. Each of the three workshops was conducted in close collaboration with the three municipalities. Here, we focus on the first workshop, to illustrate how participatory infrastructuring was supported by conventional PD workshops.

The first workshop (five hours) was held in a public innovation space, and included more than 75 participants from headmasters and teachers, to researchers and representatives from the municipality. The purpose was to establish a shared understanding of a sustainable Fablab@school initiative that cut across various levels of authority, interests and competencies in the municipalities. The Fablab project had been established at the level of the municipalities involved, and needed to be extended into the various school contexts in order to have impact, making the roles of teachers and headmasters particularly important. The workshop agenda was to create a shared vision for each municipality, to be refined and developed over the upcoming three years. To initiate this, the workshop attempted to set an agenda through a series of staged activities. It began with images from the expensive but now abandoned Olympic City of Athens 2004 to iconically represent the overall agenda. The images were used to articulate the main concern for the Fablab@school.dk startup: How do the municipalities sustain a Fablab@school.dk initiative beyond the initial fascination with digital fabrication in education for the years to come? And how do we secure a return on the investment in in digital fabrication equipment, laboratory facilities and upgrading of teachers skills in order to educate coming generations?

The project aimed to extend discussions of physical Fablab equipment, and engage in more complex negotiations of the various hybrid spaces and structures. The new learning spaces were not merely to be 'Fablabs' implemented at schools as a one-size-fits-all. They were extended and dynamic spaces in which various teachers, pupils, materials and technologies could come together to create new ways of learning over time. The presentation was followed by three different inspirational talks by researchers and practitioners, on different lab spaces and explorative learning. The talks ranged from a virtual tour of a digital fabrication lab at a university, to a boarding school teacher sharing experiences of exploratory science teaching using various technologies in project based assignments. Finally, two researchers from Bremen University shared their experiences of initiating Fablabs in academic and community contexts.

The second part of the workshop was conducted as a two-hour design game (Brandt, 2006; Iversen and Buur, 2002) in which each municipality worked to envision their Fablab@school initiative based on various motivations, visions, and resources. A design game format was chosen to accommodate the collaboration among people with various competencies and interests. A 5×2 metre paper tablecloth acted as the game board. First, the groups (A, B and C) developed an illustration to conceptualize their relationship to the existing school infrastructure in each municipality. In group A, the participants gathered around the two ends of the game board envisioning how a Fablab initiative would develop in their local schools. Despite the workshop intentions, emphasis was on the physical setup of a laboratory facility. The five teachers used their memories of the lectures to draw a blueprint of a digital fabrication laboratory with storage units, and a stage for pitching new ideas. One teacher who had recently visited Stanford University imagined that the school would implement features from the Stanford lab: wall-

mounted whiteboards on all available surfaces, a dedicated workstation with workshop tools, and so on. Over the first 20 minutes the group basically reinvented the Stanford fabrication laboratory. At the other end of the table, a shared vision of innovation and fabrication took form between a school and a public innovation space. This group shared a vision of schools and public innovation spaces in which busses would be the backbone of the physical infrastructure. To this group, the network rather than the physical set-up was central to a shared vision for digital fabrication. As one teacher argued, teaching children to innovate demands an entirely new setup that stretches beyond the physical and contextual boundaries of current education. Their drawing envisioned a network of schools, public institutions, and local industry in which knowledge and processes of innovation developed among variously positioned stakeholders, with a shared concern for building a community around innovation and entrepreneurship. The conversations between the two groups touched on issues such as whether Fablab@school was a local school initiative or a shared concern among the various schools; whether it was necessary to invest in expensive fabrication technologies for all schools or as a collective resource; and, how transfer of knowledge could be achieved across the network. The result of the discussions was a joining of forces, creating constructive ways of knowledge production and sharing for all participants. In this way their work evolved around actors and organizations, departing from the current organization of their local schools.

The second round of the design game targeted the network of people with the different competences that were essential to sustaining the Fablab@school initiative. The three groups were given pictures of a variety of Lego figures with different occupations, ages, and expressions as props, naming different roles and organizational structures for the future initiative. Actors, stakeholders, existing knowledge networks in the municipalities and at national and international levels, were discussed and positioned as a second 'layer' on the game board drawings. Group B made one big drawing of a shared public fabrication laboratory as a central facility for the schools. When discussing the actors and stakeholders, the group quickly settled on the idea that a Fablab@school manager would be the best way to ensure knowledge transfer and technical expertise. One teacher stated that if this lab manager was capable of both introducing new technologies to the visiting pupils and establishing a technology-enhanced learning space, then the teacher's role would be that of a teaching assistants who gradually developed a repertoire of digital fabrication programmes. Eventually, this idea gave birth to the idea of apprenticeship learning. The group wanted to avoid having the central fabrication lab becoming merely a container for the latest fabrication technologies. Instead, it would be the hub for developing teaching competencies in digital fabrication as Fablab pioneers (their term for a selection of engaged teachers) would participate in peer-to-peer learning, facilitated and coordinated by a the lab manager.

The final round of the design game was concerned with the technological equipment of the fabrication facilities. Based on the resources available in the municipalities and the need to 'get a head start' on the new initiatives, various technologies were discussed using an inventory provided by the facilitators. For some participants the list played a different role than forming the basis for critical discussions about technological needs and strategies. Group C was generally very excited about the Fablab initiative and quickly drew a network infrastructure in which a municipal Centre for Learning was the central hub for all Fablab@school initiatives. This organizational structure was already underway, and the workshop consolidated this, while adding new ideas. When prioritizing the digital fabrication equipment, the group coordinator impulsively stated that the task was straightforward: 'C wants to buy and implement all

digital fabrication items listed on the comprehensive inventory. We want it all'. However, this prompted a discussion about sharing resources among the municipality's 47 schools. The concept of four digital fabrication trucks equipped with the latest digital fabrication devices to accommodate for lack of equipment at all schools emerged in the discussion. The group wanted to share resources, to invest in a team of experts from engineering, the arts, and educational research to advise and teach pupils and teachers at the local schools. 'To think with new technologies is not as expensive as the technologies,' as was stated on the game board, became a reminder of the shift from a technology-based to a knowledge-based digital fabrication initiative that focus on human resources rather than technologies. Each of the 47 schools would be provided with a digital fabrication kit – a suitcase – with a set of Makey Makeys, Spheros, Lilypads, Arduino boards, and so on to initiate local fabrication instruction when the four Fablab@school trucks were unavailable.

At the end of the workshop, the three municipalities presented their different visions. Three very different strategies for Fablab@school.dk were developed, from the mobile laboratories of group C, to the collaborative industry-school-public makerspace facility of group A, to the more conventional central physical laboratory of group B, with pioneers from chosen schools to create a larger network. The groups challenged one another's concepts, which drew even more attention to the fact that one strategy does not fit all. The ideas created by each municipality were not completely new, but the workshop was a way to develop dialogues about existing and possible plans among various authorities and interests. In this way the workshop developed unique but contextualized visions of the Fablab@school initiative that fitted the specific environments.

The workshop is a classical front stage activity that we know from PD. However, it illustrates how the participants focused on infrastructuring in terms of connecting to existing knowledge structures and experiences, and the physical and digital infrastructures, bridging educational facilities and various technologies. Despite the focus on equipping the Fablabs with technology and tools, there was an emphasis on facilitation of knotworking and forming new personal and political relationships–what we call symbiotic agreements–among participants: educators, school managers, experts and researchers. Ideally, the symbiotic agreement reached during the three iterations would support and sustain the Fablab@school.dk project beyond the project period, by preparing the organization for the new initiatives. Here, new knotworks formed in each of the municipalities (and among them) were important instruments for securing an essential organizational support for the new initiative, once it launched. The three municipalities chose different visions and different trajectories for the project acknowledging their different set-ups, different approaches and different values, within the framework of a shared goal: to establish Fablab@school.dk and educate students for a digital future.

4.2 Engaging a wider set of stakeholders

In January 2014, one of the authors of this paper was invited to a public hearing on 21st century skills, with a special emphasis on ICT. The hearing was held by one of the schools participating in the Fablab@school.dk project, and initiated by the headmaster and the school board. It was to engage students and their parents in the reorganization of the school to a strong focus on digital fabrication and design thinking. Almost 600 parents, students and local politicians signed up for the evening event to discuss and participate in envisioning a new teaching practice involving digital technology.

Three short lectures by the headmaster, the director of the Confederation of Danish Industry, and the author of this paper opened the hearing. The talks were followed by roundtable discussions among the audience facilitated by a teacher and a 9th grader at each table. During the discussions, the teacher and students uploaded statements and summaries from the roundtables to social media. The statements were projected on large displays on the walls and used as input for a panel discussion and closing remarks from the municipality, the Confederation of Danish Industry, and from researchers. In general, the hearing provided the school with the chance to legitimately focus on digital fabrication and design thinking. Several questions arose in the hearing: while parents had a positive attitude to new learning skills such as ICT, real-world problem-solving and self-assessment, they were very concerned that these new learning goals would overshadow academic fundamentals such as writing, reading, and mathematics. This dilemma was discussed among the representatives of industry, school management and research, and gradually a sense of a shared vision for future learners arose among the parents and students.

The foregoing illustrates how the reach of an initiative expands beyond single projects and activities involving teachers and schools, beyond workshops and project participants to also include a public hearing with parents, national stakeholders, and other interested parties. In this case, the hearing reached out into the political landscape, both through the involvement of the national stakeholders and because it addresses parents and others mainly as voters. The reach of participatory infrastructuring is expanded by activating the networks of various stakeholders. In this particular event, the schools themself took the initiative to organize the event, and both the Fablab@school project and the researchers became means for the school to explain to their network of parents, students and politicians why they wanted to move in a certain direction. At the same time, becoming involved with the hearing was a way for the researchers and the project at large to access networks of important actors in the political landscape. Reaching beyond the scope of a PD project and into existing organizations is an important, and arguably underdeveloped, subfield of PD. Nevertheless, these kinds of unconventional back stage PD activities are essential to participatory infrastructuring and thus for the sustainability of PD initiatives such as Fablab@school.dk.

4.3 Policymaking

Two years into the Fablab@school.dk project, the National Agency for ICT and Learning (NAIL) commissioned the research group to conduct a survey on 21st century learning skills in Scandinavia. As illustrated in Table 1, the National Agency for ICT and Learning plays an important part in the Danish educational system as they set out the directives and guidelines for the national curriculum with a special concern for ICT. From a Fablab@school.dk perspective, this task was not straightforward, since while digital fabrication is arguable a tool to 21st century learning skills, there is more to be considered. Twenty-first century skills refer to the skills and competences that young people need to have to become effective workers and citizens in the knowledge society of the 21st Century (Ananiadou and Claro, 2009). As NAIL was willing to engage in a dialogue about 21st century learning skills as part of the work, we took on the responsibility, as, from a project perspective, this task provided us with a chance to discuss digital fabrication and design thinking with NAIL.

A survey was conducted as a review of national curricula in Denmark, Finland, Sweden and Norway. In addition to the survey, a questionnaire was sent to the four national agencies to compare their national

strategies for the implementation of 21st century learning skills in national curricula. The study automatically involved the heads of the national agencies of Scandinavia in a discussion of international and national initiatives related to ICT in primary and secondary schools, which also related to digital fabrication.

The survey was presented at an international conference in which 800 participants from 21 countries participated. The survey study was presented and students and teachers from Fablab@school.dk presented their work with 3D printers and laser cutters live on stage. NAIL had not previously been exposed to digital fabrication in education, but at this event, NAIL was suddenly involved in disseminating project results to an international audience. Video recordings were used to promote the NAIL nationally and internationally, and NAIL management was complimented for its vision for incorporating digital fabrication technologies into education.

The survey study initiated by the National Agency gave rise to a chain of events at other levels of authority within the Danish educational system. The Local Government Denmark (LGDK) representing all Danish municipalities came to know of the survey, and identified it as a good way to introduce a '21st century learning skills' agenda to their members. They wanted to inform the policy makers at a municipal level of a new agenda that would eventually influence local policy making and to prepare them for budget negotiations with the Parliament (and NAIL) to seek a larger budget for these activities. As a result of these concerns, Fablab@school.dk was invited to address the LGDK summit, with its more than 1800 participants representing 98 municipalities. Based on the talk and the 21st century learning skills survey, several municipalities expressed a desire to reconsider their local strategies for ICT to support 21st century learning skills. Moreover, the head of the LGDK brought the research findings to the policy making process of identifying new educational pathways and new budget needs that were negotiated with Parliament.

A survey study is not usually seen as part of the Fablab@school initiative. However, this case illustrates how such activities may be an important part of participatory infrastructuring. In this case, the survey study opened new doors to the political level of education, and enrolled the national agency as an active stakeholder in the project. The survey created the opportunity for Fablab@school.dk activities to become legitimate school activities, owing to their connections to 21st century learning skills. The case exemplifies two important aspects of participatory infrastructuring. First, relational work does not include activities on a horizontal level only. It also includes activity on a vertical scale– in this case, on the various levels of authority (Table 1). Policy-making on various levels including invisible or less participative work such as surveys, meetings, phone calls, or delivering keynote speeches, may be important back stage work related to participatory infrastructuring. This needs to be considered and dealt with in the back stage activities of projects such at Fablab@school.dk. Second, PD needs to go beyond being driven by a range of participatory events in which participants learn from each other, to reach a better understanding how participants become empowered to act across projects, over horizontal and vertical scales.

4.4 Sustaining the project

By conducting observational studies, workshops and interviews, the Fablab@school.dk researchers identified the main challenges to the introduction of digital fabrication at primary and secondary school. Most significant was the teachers' lack of professional knowledge related to digital fabrication and design thinking (Smith et al., 2016), since these topics are not part of their basic or in-service teacher training.

When teachers incorporate digital fabrication, they experience a lack of control and authority in the classroom (Smith et al., 2016). We also found that teachers lack knowledge of digital technology as well as design processes. They lacked basic training in facilitating explorative and design-oriented processes. The Fablab@school.dk steering committee identified teachers' lack of professional competence as the greatest challenge for the entire project. As stated in the theoretical part of this paper, participatory infrastructuring is not only a concern when designing technology, but for creating the structures, networks and agreements that are crucial to creating sustainable outcomes. To meet this challenge in the Fablab@school.dk project, we designed an educational programme based on literature from digital fabrication and DIY, Human-Computer Interaction, Design Thinking and Computer Supported Cooperative Learning.

The teachers and municipalities were invited to co-design the educational programme. The curriculum was selected to meet the challenges experienced by the teachers, and to provide them with a language and a toolbox for overcoming the impediments described above. Also, the exams and teaching are specifically designed to be incorporated into the teachers' existing practice. Lectures and exercises were held at local fabrication labs at schools, and the teachers worked in groups to provide a safe zone for discussing and exchanging experiences. All course exercises were assignments that the teacher was to try out with his/her students and exams provided documentation (video presentation and a teacher guide) of a concrete teaching course that involved elements of digital fabrication and design thinking.

The shortage of teachers with sufficient background knowledge of digital fabrication and design thinking threatened the Fablab@school.dk project outcome. Therefore, it was necessary to launch an educational programme for schoolteachers, Fablab managers, and municipality experts, as part of the research project, to ensure the sustainability of the project results, and by extension, the sustainability of the infrastructuring. We needed to move beyond empowering participants for future projects, and reach out to a larger group of teachers (i.e. horizontally) and empower them at all levels of their engagement with digital fabrication. The educational programme was accredited as a master module, to ensure that the teachers would be able to show a visible outcome and a personal gain from participating (a university diploma). The programme also provided us with resources for discussing the transformation of practices, by introducing digital fabrication and design thinking to the end-users. As teachers have very little available time in their everyday work, the hours spent away from teaching, in the masters programme, gave them the time they needed to establish the new initiatives within their existing practices, and discuss how the Fablab@school initiative could be disseminated among their colleagues at their schools.

4.5 Summing up

Our case study demonstrates that participatory infrastructuring goes beyond a horizontal string of activities with the same or overlapping sets of actors. The front stage activities are still part of the picture, as they (as well-described in much literature) activate groups of people in order to understand and design for particular elements in the knotwork while helping people make the normally invisible infrastructures visible (Ruhleder and Star, 1996). But there is so much more going on in the embedding of infrastructures in other social and technical infrastructures, and in wrestling with the installed base and limitations of that base (ibid.). Enrolling actors and making them meet across communities is one such thing; addressing how particular people and groups of people may participate over time, and sustain their learning across activities, is another. The activities that we have described activate many levels of the formal political and organizational hierarchy of the school system, and some of these are in certain ways meta-activities that sustain the actual infrastructuring, and enroll actors in ways that make them allies of the greater project.

The definition of participatory infrastructuring has been reconsidered, emphasizing the PD activities that occur across knotworks and networks: Participatory infrastructuring addresses the fluid and temporary knotworks, and perhaps even creates such structures, and identifies and navigates more permanent networks that span across various user communities. Participatory infrastructuring addresses initiatives for activities and asks questions that go beyond the here and now activity. It addresses the ability of groups of participants–whether users, designers or other stakeholders–to engage in shaping and changing the motivation of the joint activities. The methods of participatory infrastructuring are not only concerned with the direct meeting of a group of designers and users, but also with the development of the technological platforms upon which infrastructuring builds, and with which it co-exists, and with the experiences and practices of the involved people beyond the singular knotwork or network. With this understanding, we call for a focus on the longitudinal network of activities, where people and technologies are brought together and changed. We suggest addressing the front stage and back stage activities and the reach of these across activities and time.

5 Discussion

While Pipek and Wulf (2009) oppose a clear separation of design and use at the methodological level, they consider the points of infrastructuring as happening when design meets use, as in when solutions are appropriated by users. Accordingly, they talk about layers in a way that is rather different from ours, namely as time slices of the infrastructuring process. These time slices first address general matters and background (including general technology and organization), then specific, method-driven design where technology and organization meet, and finally, after the point of infrastructuring, appropriation in use. Although this is certainly an interesting and relevant model for how design and use meet in infrastructuring, in this paper we have focused on design activities that connect with the technological (technical, methodological and organizational) infrastructures at various times and with various actors, across the political and organizational structures of the organization as a whole.

What emerges from the examples presented above is an account of participatory infrastructuring in which activities and agency are dispersed both horizontally among the many actors engaged in the process, and vertically through the layers of political authority. This account aims to exemplify and demonstrate the

need for the theoretical position synthesized in the first part of this paper: a theoretical account that highlights the relational work that unfolds in participatory infrastructuring processes. Moreover, the theoretical perspective offered, and the examples, taken together, prompt critical reflection on some of the principles and ideas that are central to PD. We selected three in particular: mutual learning, the object of design, and the reach of participatory projects.

The concept of mutual learning is generally considered a cornerstone and defining trait of PD (Simonsen and Robertson, 2013), and a point of reference for participatory work. Yet in the case presented above, the concept of mutual learning does little to account for the ways in which various organizations and people came together at various stages of the project in more or less stable constellations (knotworks and networks). Although the concept of mutual learning is open to interpretation, it often seems to be associated with a process occurring between designers (technology specialists) and users who are considered experts in their particular practices and faced with the challenge of co-developing new knowledge about technology and practice (e.g. Bratteteig et al., 2012). This idea of mutual learning as knowledge generation between two groups of people is also found in Ehn's (1988) conceptualization of design as the creation of design language games in which both users and designers can participate, and Muller's (2007) conception of a hybrid or 'third space' where designers and users come together. These accounts draw our attention to places, situations and events where things are co-developed, and arguably they reflect a view of 'being in it together'. In the case discussed above, this is only part of the story. The other part of the story relates to the many ways in which people, groups and organizations work on a shared object of activity but from very different perspectives, asynchronously, and not necessarily 'in it together'. This is particularly evident as we traverse the vertical levels of political authority. We find that the concept of symbiotic agreements more adequately describes the strategic nature of these relationships and how people work on a shared object of activity but from different perspectives and with different outcomes in mind. Moreover, from our perspective, this concept does not carry with it the associations of designers and users engaging in front stage activities with the noble aim of learning from each other and developing shared knowledge. This does not dismiss the usefulness of looking at parts of design as a process of learning and development. Instead, it accentuates the complex nature of participatory infrastructuring.

Looking at the design activities as they unfold at various levels of political authority points at the fact that the object of design and what are considered valid arguments is not constant throughout a process. Each of the various levels of power in the Danish school system abides by different rationalities; a well thought-out plan for the design of a physical Fablab that combines technology and educational goals may be important at the level of the individual schools, but these are not necessarily needed to gain the support of national agencies. Yet if projects such as Fablab@school.dk are to achieve lasting, sustainable results, it is necessary to engage these levels of authority. Although good educational ideas might bubble up through the levels of authority over time, and good political ambitions might trickle down, there is no guarantee of this. We suggest that in order to ensure the sustainability of initiatives, designers need to engage with the several levels of authority and doing so involves engaging with the discourse and workings of these institutions. This means that sustaining participatory infrastructuring is not only a matter of how the design is appropriated in use (as described by Pipek and Wulf, 2009), it is as much a matter of making the actors at various organizational and political levels (including the teachers at the

schools) also able to act in future design projects and activities, which parallels Pape and Thoresen's (1987) discussions on empowering.

Adopting the perspective on participatory infrastructuring suggested by the relational concepts of knotworking, networking, and relational agency provides a view of the design process in which agency is dispersed among people and organizations. In the case study, this may be most clearly exemplified by the circumstances of Fablab@school.dk project researchers being invited to a public event on 21st century skills, hosted by another organization. This demonstrates how agency is dispersed, and how the ideas expand and find new places in which to grow far from their starting point. Thus, we may think of participatory infrastructuring in terms of its reach – not only do people and organizations step into a project, as people connect to the project, it extends across organizations and networks. The way this is achieved through the establishment of knotworks and networks is at the core of our relational perspective on participatory prototyping. Although designers and researchers may have special roles in a project, agency is dispersed among actors and organizations that thrive on mutually beneficial relationships.
In terms of what might be considered the vertical reach of the Fablab@school.dk project – how well it extends into levels of power above or below it – it is interesting to note that in our case, vertical reach appears to present very different challenges, when compared to horizontal reach. We understand horizontal reach as the ability of a project to connect similar communities of practice. For example, teachers at one school connect to groups of teachers at another school. This horizontal reach is similar to the community of interest that Obendorf et al. (2009) mention when they discuss how to organize intercontextual design processes: deliberate design attempts to make users and designers meet across specific project and organizational boundaries, to develop the greater infrastructuring project, and support learning across projects and units.

The many back stage processes that enroll and empower actors and support the processes that go into realizing projects such as Fablab@school.dk (see somewhat similar trajectories in Kyng, 2015), point towards the question of the role of participation, and with/for whom? We have seen many participants, some of whom may ultimately be actual future users of the Fablab technologies in the school settings. Yet many will not, either because they participate in other capacities, for examples as parents or bureaucrats, or because ultimately the technology as such may not reach them, because their class, school or municipality may not become users. Thus, participatory infrastructuring re-introduces an important, yet often forgotten discussion from PD: the selection and representativity of users in design (see e.g. Bødker and Grønbæk, 1991). We will not discuss this further here, but only point out, in extension of our initial criticism of current participatory infrastructuring perspectives, that these projects often address a one-to-one mapping between project participants and users. The focus is on designing directly for and with the involved users, a focus that we have previously, and in the current projects, found too limited for PD.

Based on our case study and theoretical synthesis, we propose an understanding of participatory infrastructuring as particularly concerned with stimulating the emergence of new knotworks through participatory activities in which participants actively engage in defining the infrastructures to be, and then sustain the networks of people and technologies that embrace the new artefact(s). These participatory infrastructuring activities often encompass back stage activities such as meetings, phone calls, knowledge dissemination, matchmaking, and networking at various vertical levels of authority. We have presented our participatory infrastructuring activities in the Fablab@school.dk project to illustrate how multifaceted

activities involving a broad range of authorities succeeded in introducing digital fabrication technologies to the Danish school system, and sustaining this endeavor.

6 Conclusion and outlook

The work in this paper offers a view of participatory processes as they play out in the messy and complex interplay among people, organizations, and levels of political authority. We offer a vocabulary for articulating the makeup and dynamics of these processes, by synthesizing recent work on participatory processes inspired by Star and Ruhleder's understanding of infrastructuring (Star and Ruhleder, 1996). Together, the concepts of knotworks, relational agency, and symbiotic agreements bring into focus activities and processes in which participants are not only engaged in designing technology, but in creating the structures, networks, and agreements that are crucial to creating sustainable outcomes. These concepts challenge traditional PD concepts such as mutual learning, and prompt reflection on what may be considered the object of design.

Through our case study, we have provided a view of how participatory infrastructuring may unfold based on our framework of understanding; first, how participatory processes play out vertically in different political and practical arenas; second, on the back stage of design; the sometimes messy activities that go on before, between and after the participatory workshops. Our examples illustrated how survey studies, participating in public hearings and other activities, that are rather loosely connection to conventional PD, were integrated into the project and were essential for the sustainability and progress of the project. The third element is reach; how participatory processes tie into existing networks across organizations and how agency and initiatives become dispersed within knotworks and networks. In our case, the vertical reach is illustrated by the six levels of authority of the Danish educational system, and the horizontal reach covers the many parents, students, teachers, industry representatives, and policy makers that took part in PD activities throughout the project.

This paper contributes to the discourse on infrastructuring by offering a vocabulary for understanding participatory infrastructuring, and to PD by suggesting the broadening of focus beyond the methods and micro-dynamics of participatory work.

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Table and table caption

Level	Authority	Project activities
Parliament	Adopts legislation regarding the schools	Participation in the 2017 Nordic Horizon Project Panel of Experts (http://www.nmc.org/nmc-horizon/)
National Agencies	Lays down legislations as executive orders, including the overall educational goals	Survey of 21st Century Skills. Advisory board participation. Participatory workshops with national agencies. Multiple keynote speeches on the importance of digital competences.
Municipalities	Adopts the financial framework, sets local goals, supervises the schools, and follows up on results.	Keynote speech on the digital divide/digital competence. Steering committee partnership. Joint applications (EU regional funds).
School Committee	Adopts principles for the activities of the school and approves the school budget.	Fablab tryouts. Lectures on the importance of digital competences.
School management	Responsible for the operation of each school, makes concrete decisions for the school and regarding individual pupils.	Dissemination at a school level. Counseling to establish Fablabs. Lectures on the importance of digital competences.
Teacher	Education is characterized by freedom of the choice of method.	Observation studies. Interventions/experiments. Course on digital fabrication. 3-day workshop (120 participants). Hands-on workshops. Visit to Stanford University.
Students	Education in Denmark is compulsory for children below the age of 15 or 16.	3 x 8 weeks digital fabrication workshops. Interviews. Observation studies.

Table 1: The Danish school system and its seven levels of authority. Fablab@school.dk activities are listed at different levels to indicate the vertical and horizontal extent and reach of participatory infrastructuring. Several PD activities engaged representatives from more than one level. The activities are listed according to the highest level of authority engaged in the activity.