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14 Learning Environments for Invention Pedagogy

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Introduction

Within invention pedagogy, we consider schools to be learning ecosystems composed of the operating culture, collaboration practices and networks, pedagogic practices, digital and non-digital instruments, and learning environments. Further, learning environments can be interpreted to include physical, virtual, and epistemic-social environments (Nardi, 1999; Nonaka & Konno, 1998). One of the aims of invention pedagogy is to create learning environments that provide multifaceted technological (tools) and social (community) resources that enable students to participate in creative practices of inventing and making artifacts in schools. Such environments are usually seen as "makerspaces," distinct from structured, formal learning environments (e.g., Halverson & Sheridan, 2014; Hatch, 2014). Makerspaces (sometimes also referred to as hackerspaces, hackspaces, and fablabs), are creative, do-it-yourself spaces where people can gather to create, invent, and learn. Makerspaces emphasize personally meaningful informal learning and nurture purposeful tinkering and peer-supported inquiry, whereas maker-centered learning in schools tends to be more preplanned, structured, and guided by teachers (Halverson & Sheridan, 2014; Martinez & Stager, 2013; Sheridan et al., 2014). Although many researchers are excited about the educational potential of makerspaces, maker-centered learning often takes place in informal and non-formal contexts, such as museums, libraries, or science centers (Gutwill et al., 2015; Halverson & Sheridan, 2014; Kafai & Peppler, 2011). Our research efforts in invention pedagogy have focused on how learning by making can be integrated into school environments and practices for systematically educating personal and collaborative creativity in formal education.

Finnish schools have had a type of makerspace since the 19th century: craft classrooms. As crafts is a standard school subject in Finland (see Porko-Hudd et al., 2018), each school has dedicated spaces for crafts, usually one classroom for textile crafts and another for technical crafts (Figure 14.1). These typically include basic workplaces and workstations for various craft techniques, such as sewing, seaming, knitting, and printing in the textile classroom and woodwork, metalwork, plastic work, electronics, and machine tools in the technical classroom (Jaatinen & Lindfors, 2019).

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Figure 14.1 Examples of technical and textile craft classrooms.

Photographs: Juha Kokkonen.

In recent years, efforts to expand the craft classrooms with instruments of digital fabrication, such as 3D design and making tools, wearable computing (e-textiles), and educational robotics, have taken place. In addition, some schools have built separate makerspaces or created mobile solutions, such as maker toolboxes or maker vans. Such efforts have been fueled by policies underlining that learning environments should offer "possibilities for creative solutions and the exploration of phenomena from different perspectives" (Finnish National Agency of Education [FNAE], 2016, p. 53) and by research indicating that a holistic makerspace with well-defined areas of working and paths for moving provides students multifaceted opportunities for design and problem-solving (Jaatinen & Lindfors, 2019).

Internationally, research on makerspaces has revealed that there is a wide variety in the composition of makerspaces; the purpose, settings, equipment, users, and management of makerspaces vary considerably (Mersand, 2021). Carefully designed makerspaces have proven to support participants' engagement and innovation (Sheridan et al., 2014) or students' literacy (Nichols & Coleman, 2020), among other things. Further, research indicates that physical re-design of learning environments may facilitate shifts in how, when, and why students engage in learning (Hughes & Morrison, 2020), and that "makerspace design should consider the development of possible encounters between people and things to support unforeseen transformations" (Keune & Peppler, 2019, p. 281). However, both internationally and in Finland, research is still scarce in terms of how to develop well-functioning makerspaces in formal education, considering the essential underlying pedagogical conditions that must be designed, implemented, and addressed to foster students' creative practices of inventing and making.

In this chapter, our aim is to explore the ongoing co-development process of the Innokas FabLearn Lab, a makerspace concept for Finnish schools, through the framework of pedagogical infrastructures, that is, the conditions designed and implemented in an educational setting to support the fundamental learning objectives (Lakkala et al., 2008, 2010; Riikonen et al., 2020). We first provide a background for the co-development of Innokas FabLearn Lab concept. Then, we outline the pedagogical infrastructures, i.e., the (1) epistemological, (2) scaffolding, (3) social, and (4) material-technological infrastructures underpinning the development of the concept. We illustrate the co-development process through a case example, in which a network of technology- and development-oriented teachers co-created a flexible and modifiable concept for designing a multipurposed learning environment. We use direct quotes from their interviews conducted in the fall of 2021. Finally, we provide some conclusions and future directions for the development of environments that support learning through inventing and making.

Co-development of Learning Environments for Invention Pedagogy

Multidisciplinary collaboration by educators, architects, and various experts is needed when designing school learning environments. Educational activities cannot be separated from spaces, and users' active participation in design is important (Daniels et al., 2019; Frelin et al., 2021; Tse et al., 2019). The ownership of design solutions should be shared by the users and supported systemically (Higgins et al., 2005). There is an interrelationship between environments and their users shaping each other through practice and activity (Daniels et al., 2019). A tendency exists to underestimate the effects of physical spaces for learning (Lei, 2010), to give inadequate attention to materiality in learning (Fenwick et al., 2011), and to move into new and more innovative spaces (French et al., 2020). An increased knowledge and understanding of the relationship between architecture and educational practices would help make more informed design decisions and uses of school spaces (Deppeler & Aikens, 2020; Gislason, 2010).

Guiding Principles in the Co-development of Innokas FabLearn Labs

The Innokas Fablearn Lab concept was and still is developed collaboratively in the Innokas Network and is based on the needs and expertise of the members in the network, the Finnish curriculum, and the research on invention pedagogy. The aim is to support inventive activities in Finnish schools, considering their diverse starting points and resources. The Innokas FabLearn Lab is a member of the international FabLearn Lab network (www.fablearn.org/labs/) developed at Columbia University by Paulo Blikstein and his team. FabLearn advocates and supports constructionist, equitable learning experiences for all students. These experiences should be accessible to all students, a force for inclusion and diversity, based on rigorous academic research, and shared globally. Further, FabLearn Labs should include the following principles: activities should be personal, cross-curricular, meaningful, holistic, and process- and product-oriented. The concept and proceeding should be modeled by teachers and developed in each country based on the local curricula, needs, and resources.

The Innokas FabLearn Lab development work is situated in the context of Finnish schools and their curriculum. The work follows the principles of the international network and is carried out as part of the Innokas Network's activities. The development work was originated following the request of several network members when they realized there was a need to develop new facilities or mobile solutions to support invention pedagogy. Pedagogical perspectives guide the communal design of facilities, materials, and tools. The involvement of network actors, user ownership of the design of solutions, and support by systems and behavioral change (Higgins et al., 2005) play a focal role in the development work.

It is essential that the design and co-development of the Innokas FabLearn Labs acknowledge the capabilities and resources of each school to implement learning environment solutions. Adaptivity is considered in the design of space solutions; the culture and identity of the user community, the intended activities, the facilities that are available, and other resources determine the kind of FabLearn Lab model implemented in the school. Some of the network's municipalities design space solutions as part of new schools under construction, some consider how existing facilities could be modified to support invention pedagogy activities, and some design mobile solutions such as tool kits with mobile tools and materials. Innokas FabLearn Labs can thus be separate, purpose-built spaces, combinations of existing spaces, or other material and spatial solutions that support invention pedagogy. The common pedagogical goal of developing learning environment solutions is well described by the following comment by a network member:

> The Innokas FabLearn Lab is a learning environment that stimulates creativity, where technology is utilized, and everyday problems are solved. Working together and leading oneself are highlighted. Central to the FabLearn Lab are problem-based learning, learning by doing, collaborative learning, cross-curricular learning, and entrepreneurship education. School becomes a motivating place for the student as the work connects to real life.
>
> (Teacher 1: Class teacher, deputy director, medium urban school with a separate FabLearn Lab since 2015)

Network- and School-Level Co-development

The community-based development of the Innokas FabLearn Lab is an open process, through which the structure and the grounds of the concept are defined together in the network. The key questions in the beginning of the process are: What basic principles are common to all, and what can be adapted in accordance with the local user community? A team of interested members of the network review and develop common guidelines and practices for the Innokas FabLearn Labs and present them at the biannual network meetings at which the whole community is participating in co-development. The co-development work utilizes the methods of the innovation process (see Chapter 15 of this book). Development work materials can be accessed and commented on openly by all members on a joint online platform.

The practices developed and ideated in the developer group and network meetings are tested in schools and further developed based on the needs of schools across Finland. At the school level, FabLearn Labs are designed with the identity and culture of the user community in mind, including the age structure of the community, the emphasis and history of the school, and local strengths, such as potential business partnerships. At the school level, the design of space solutions is also influenced by the needs of school actors; that is, they are designed, for instance, on a project basis, on a user-basis, or based on learning environment development. It is also important to consider whether only internal or also external users of the school use the space.

The starting point for school-level planning is the user-driven definition of practice. It is important that the users describe the projects they would like to undertake and what tools and facilities would be needed to carry out these projects. The versatility of the space designed for FabLearn Lab activities is often important. The space must be flexible for the different stages of invention pedagogy projects, including brainstorming and making, as well as presenting and sharing. The design considers whether the available space is fixed or mobile, open or closed, a separate space, or a combination of spaces. It is also important to consider the relationship of mobile solutions to other teaching facilities in advance.

At the school level, according to the Innovative School model (see Chapter 16 of this book), a range of actors at the school are involved where possible, including students, teachers, and other staff, principals, and partners, such as parents. Participating in the planning and co-development of activities and facilities strengthens the commitment of the actors and the formation of common practices for the users of the learning environment solutions. Collaborative development work is supported by the openness of the process, and practices can be tried out together in joint workshops for parents and students, for instance:

> I have held a 3D printing school for parents and students, student pairs. It involved training so that I didn't have a FabLab at the time, but there was a printer anyway, and the parents and students were trained in 3D modeling and using these devices, and then they implemented these joint plans at home, after which the parents and students brought them into the school, and they were printed.
>
> (Teacher 2: Craft teacher, big urban school with a FabLearn Lab close to craft classrooms since 2020)

Collaborative planning can also mean involving school networks in the planning process. Especially in the design of a new space, the school staff typically collaborates with the architects and the municipal environment services responsible for the design and implementation of the facilities. External expert support is often needed in the planning of pedagogical activities.

Pedagogical Infrastructures in Learning Environments for Inventing

It is essential in invention pedagogy to provide adequate structural support to facilitate students' learning processes and to unleash their full potential during complex and multifaceted invention projects. From the viewpoint of learning environment design, this requires recognizing the underlying pedagogical conditions that need to be addressed in the environment to enhance the desired type of learning. Within invention pedagogy, we have conceptualized these conditions with the help of a pedagogical infrastructures framework, which was first introduced by Lakkala et al. (2008, 2010) in the field of technology-enhanced knowledge-creation learning. The framework was inspired by Bielaczyc (2006), whose research on computer-supported knowledge building highlighted the role of the appropriate social infrastructure around the technical one, that is, the classroom culture and its established norms and social practices as well as the organization of physical and virtual spaces. Lakkala et al. (2008, 2010) identified interrelated technical, social, epistemic, and cognitive infrastructures that simultaneously affect the educational setting. The infrastructures create the background conditions that mediate the intended social and cultural practices of a learning environment but do not strictly prescribe learning activities (Lakkala et al., 2010).

Within invention pedagogy, distinct from more discursive computer-supported collaborative learning, we have developed a slightly modified version of the pedagogical infrastructures framework (Riikonen et al., 2020). While Bielaczyc (2006), Lakkala et al. (2008, 2010), and also others (e.g., Scardamalia & Bereiter, 2006) have underscored the role of conceptual ideas and tools in the learning process, invention pedagogy also highlights the importance of material artifacts and socio-material intertwining (Orlikowski & Scott, 2008; see also Chapter 6 of this book). Thus, instead of "cognitive" infrastructure, we refer to "scaffolding" infrastructure, which includes not only epistemic but also embodied and tangible support. In addition, we have used a broader concept, "material-technological infrastructure," for outlining both the technological and material conditions of the educational setting—the combined non-digital and digital settings that support the invention process. In this chapter, we use the pedagogical infrastructures framework to describe the pedagogical conditions underlying the collaborative development of learning environments for invention pedagogy. An overview of the modified framework is presented in Table 14.1.

Epistemological Infrastructure: Co-creating Knowledge through Inventing

The epistemological infrastructure refers to the operational practices that encourage teachers and students to share and co-create knowledge (Lakkala et al., 2008, 2010). This requires knowledge to be treated as something that can be shared and jointly developed (Bereiter, 2002; Scardamalia & Bereiter, 2006). Creating new knowledge is seen as a process embedded in shared practices ("knowledge practice") that are enacted (Hakkarainen, 2009). A proper epistemological infrastructure enables knowledge creation in dynamic and innovative processes that involve

Table 14.1 Pedagogical infrastructures in the co-development of learning environments for invention pedagogy

Pedagogical infrastructure	*Definition*	*Essential features of the setting*
Epistemological	**Operational practices** that encourage teachers and students **to co-create and share knowledge** through inventing	**Concept of Innokas FabLearn Labs in a school context** for open and shared innovation processes, spaces for co-creation, cooperation, sharing, and presenting. Various users: versatile tools and activities and ways to use the spaces, with options for short and long-standing projects.
Scaffolding	**Epistemic and embodied scaffolding structures** for promoting teachers' and students' capabilities of engaging in invention processes	**Pedagogical support** for the meaningful use of spaces. Invention pedagogy teaching and learning materials for teachers and students. Training sessions and events for teachers and students. Multiple communication channels for pedagogical discussions.
Social	**Arrangements for organizing** students' and teachers' **collaboration**, social interaction, and shared responsibility	**Physical and social arrangements** of spaces for organizing productive teamwork and interaction. Team-teaching and tutor-student practices for supporting invention pedagogy activities within the spaces. Digital arrangements for coordinating the use of the spaces; fixed settings, mobile solutions, external users.
Material-technological	**Organization of appropriate spaces, materials, and technologies** and support for applying them	**Co-created handbook** for designing versatile spaces, places, projects, equipment, and tools.

Modified from Lakkala et al., 2008; Riikonen et al., 2020.

several participants with various backgrounds and skills and mediating artifacts where knowledge is embedded (Paavola et al., 2002). In invention pedagogy, the epistemological infrastructure enables knowledge creation through long-term, iterative designing and making processes, where students' advancement is visible in their design artifacts, such as sketches, prototypes, and final inventions (Riikonen et al., 2020).

The long-term, iterative, and socio-material nature of the invention process, as well as the various participants and versatile activities, need to be taken into account while developing the learning environments for invention pedagogy. Innokas FabLearn Labs are used both during and outside school lessons, and the users can be students and their teachers or others interested in inventing and making. During lessons, a whole class of students with varying levels of motivation and skills participate in the activities. The environment needs to be designed in a way that supports teamwork, such as the building up of team spirit and the co-creation and sharing of ideas. For other users, the space should allow activities included in self-directed personal projects. Different users and their varying needs for the environment impact on the design and implementation of spaces and activities.

> If you think that there are students or teachers who have acquired the basic skills and already know them well and have a lot of interest and innovation to come here to develop something, something that is their own thing, then it is a completely different thing in a way or if you are teaching a group that comes because of wanting to innovate or because of what you can do in a makerspace, then it is a little different than teaching a regular class.
>
> (Teacher 2)

For all users, the learning environment should enable both short- and long-term invention projects. Long-standing projects require time, which should be considered when designing, storage solutions, for example. Ideas, prototypes, and other artifacts created during invention projects should be visible for everyone visiting the space, allowing the users to be inspired by projects created by others.

> The time needed to work depends on the group of students; if the group of students is not familiar to others, then it is worth spending time on those warm-up tasks, probably 45 minutes is suitable. Then, for this initiating or brainstorming, it easily takes a few hours, maybe even more. It may take up to five hours, and then you start making the artifact; so it depends entirely on that artifact, but it may take 5–10 hours and then the marketing and pitches and sorts; then it depends on how you guide the project, but five hours maybe it could count to that, too.
>
> (Teacher 1)

Various Innokas FabLearn Labs have been established in different parts of Finland. In some cities, the Lab is situated in a school, but other schools and nonschool users can use the space as well (Figure 14.2). In many small schools, the most practical solution is to set up the space in a normal classroom to provide a low threshold for invention pedagogy activities. In addition, mobile solutions, such as maker toolboxes, enable invention projects in educational institutions short of space or resources (Figure 14.3).

Scaffolding Infrastructure: Epistemic and Embodied Support Structures

The scaffolding infrastructure includes the epistemic and embodied support structures that promote students' and teachers' capabilities of engaging in the invention process. These support structures involve both conceptual tools, such as guidelines,

Figure 14.2 FabLearn Lab Vuores.

Photographs: Juha Kokkonen.

Figure 14.3 Mobile solution of FabLearn Lab Lohja.

Photograph: Panu Pitkänen.

models, and templates that support students' planning, monitoring, and reflection of their learning (Lakkala et al., 2008, 2010), as well as material and embodied scaffolding that facilitates students' competencies in designing and making (Riikonen et al., 2020). In invention projects, the scaffolding infrastructure consists of design briefs introducing the open-ended invention challenge and related constraints, guidelines relevant for designing and making, and teachers' and tutors' real-time support. The scaffolding infrastructure is often embedded with some other pedagogical infrastructure, and particularly the distinction between epistemological and scaffolding infrastructures is not clear cut (Lakkala et al., 2008).

The establishment of Innokas FabLearn Labs is scaffolded with training sessions and learning materials based on systematic research and the development of invention pedagogy. The training and materials are created through research-practice partnerships (Coburn & Penuel, 2016), through which cutting-edge research supports the design of accessible pedagogical practices tested in the field.

> Our space is intended for use in basic education in our city. In practice, I am currently offering training here, and when we join the Innokas FabLearn Lab, I will be involved, and we will have other teachers actively involved in Innokas, and training will be organized here as well. The aim is to train the teaching staff and students, especially here at our school.
>
> (Teacher 2)

An essential element of the scaffolding infrastructure is the possibility for interaction and pedagogical discussion through multiple channels. Active members of the Innokas FabLearn Lab community share best practices and good experiences through social media and discussion groups. Real-time support for various challenges and questions in the learning environment design has been especially significant for many teachers.

> We had already given a little thought to starting FabLab activities in the Innokas Network, and this device listing was already done. And then, of course, I started asking others for ideas, and because we have a great network, I got a lot of ideas through it.
>
> (Teacher 2)

Social Infrastructure: Arrangements for Organizing Collaboration

The social infrastructure includes the agreements and organizational structures that enable the participants to collaborate and create common ground. It can include the physical and social settings for advancing students' and teachers' teamwork and social interaction, formulating learning tasks in a way that requires shared responsibility for accomplishing them, and sharing the learning process, as well as its outcomes (Lakkala et al., 2008, 2010; Riikonen et al., 2020). As invention pedagogy relies on multidisciplinary team teaching, it is also essential to create a school culture and practices that support teacher collaboration (Härkki et al., 2021; see also Chapter 11 of this book) and co-planning of invention projects (Aarnio et al., 2021), as well as spaces for them.

The premise of Innokas FabLearn Labs lies in collaborative practices: spaces, tools, and activities are designed to support collaborative making. Projects are planned in a way that requires teamwork, and each team member has an essential role in setting up and achieving the goals of the project. Shared responsibility supports the development of students' socio-emotional skills, such as self-confidence, perseverance, and communication skills (see Chapter 5 of this book).

> I believe that the skills learned in invention projects are exactly the skills you will need in the future: working together, creativity, problem-solving, and self-management, that kind of self-directed work, although it is quite difficult, but when supported, it works really well.
>
> (Teacher 1)

In Innokas FabLearn Labs, collaboration is often very visible and tangible, and limited tool resources guide students to create inventions in teams. In addition, establishing the Lab in a space in which the activities can be seen by people passing by can be inspiring for many students, teachers, and other possible future inventors.

> The space is between the primary and secondary schools, and we were able to open it on both sides to have a wall with a window; from there you can see it on both sides in full swing, and it is used by the whole comprehensive school, and we have discussed that of course because the high school is in the same building, so then they will also be able to take advantage of it as well.
>
> (Teacher 1)

Material-Technological Infrastructure: Organization of Spaces, Materials, and Technologies

The material-technological infrastructure involves the organization of appropriate materials and technologies and support for applying them in a way that facilitates students in the invention process (Riikonen et al., 2020). In invention pedagogy, the material-technological infrastructure is multidimensional. It includes the tools and materials for designing, engineering, programming, and crafting the inventions, as well as technologies for documenting, reflecting on, and sharing the process of creating knowledge through making (Kangas et al., 2022; see also Chapter 8 of this book). Sufficiently rich material and technological resources are crucial for sparking students' creative ideas and for testing the usability of ideas and solutions. Furthermore, diverse equipment, machines, and tools enable students to learn by doing and to adopt a responsible attitude toward making (FNAE, 2016).

While developing learning environments for inventing and making, the material-technological infrastructure is usually the first element addressed. In the development of the Innokas FabLearn Lab concept, members of the community started by creating a list of age-appropriate and pedagogically meaningful tools and materials. The key questions in this work were as follows: What kind of learning do we want to support? What learning paths do we want to enable? How can we implement these? What kinds of projects support students' innovative capabilities? Essential in the material-technological infrastructure was to enable creativity, learning by doing, and student agency, as well as understanding technology as both a tool and an object of learning. Low-tech and high-tech tools are equally important for supporting students' understanding of technologies and their development from mere consumers to active shapers and makers of the technological world.

An essential component of the Innokas FabLearn Lab concept is the handbook, which will bring together the technological tools and materials used in different types of FabLearn Labs and thus support the operation of diverse labs planned in different parts of Finland. The handbook will cover all infrastructures of invention pedagogy in a comprehensive way so that practitioners can get an idea of the dimensions of the Innokas FabLearn Labs and consider these factors in the design, implementation, and organization of learning environment solutions.

The aim is that the handbook provides a pedagogical framework for the design and implementation of a range of FabLearn Lab solutions. The needs-based and regularly updated handbook responds to the needs of those planning the activities and working in the spaces: it provides practical tips for the design and implementation of various collaborative invention projects and the use of tools and technologies. The handbook opens up the invention process and contains tips for carrying out the whole process from the ideation stage to the presentation of the final outputs. It provides support material for teachers to carry out activities with students of different ages, as well as tips for training provided by the Innokas Network to support FabLearn Lab activities. The handbook also contains links to other interesting material related to the topic and, for example, to social media groups.

The needs-based handbook considers that schools also want practical support for the implementation of the Innokas FabLearn Labs and the use of digital solutions: What kind of reservation system is needed for the equal use of shared spaces? Who is responsible for maintaining the space? What are the common rules? How can technology be used to guide students and support teachers, for example, in implementing projects or learning to use tools? How can we enable long-term multidisciplinary projects with limited resources? The regularly updated FabLearn Lab handbook is openly distributed to anyone interested in FabLearn Lab activities.

Conclusions and Future Directions

The aim of the ongoing development of the Innokas FabLearn Lab concept presented in this chapter is to bring together the co-created epistemic, scaffolding, social, and material-technological infrastructures that should be considered in the design and implementation of learning environment solutions. The goal is to support schools and other users in carrying out and further developing invention pedagogy practices and activities. Knowledge of physical, virtual, and epistemic-social learning environments (Nardi, 1999) and the integration of these into functional pedagogical entities in a meaningful way with the possibilities of digital technology are needed to create environments that support students' creative activities and future-oriented learning.

Innokas FabLearn Labs are based on the needs of the users; their culture and identities, as well as the importance of facilities for operations, are considered from the beginning of the planning. Diverse spaces serve both short-term and long-term projects and enable ideation, implementation, sharing, and reflection. In some municipalities, entirely new schools and Innokas FabLearn Labs are planned, while some schools consider renovating existing facilities with solutions that support invention pedagogy. For example, the organization and equipment of classrooms for crafts, arts, or physics are modified for better enabling creative and collaborative activities based on invention pedagogy. In addition, mobile solutions are designed to provide possibilities for schools with limited spaces and resources.

So far, the development of Innokas FabLearn Labs has mainly focused on how learning by inventing and making can be integrated into school environments and practices in formal education. However, attention has also been turned to include other user groups as well. After-school and club activities linked to school, as well as collaboration with parents or local businesses, are natural ways to develop the diverse use of the facilities. Moreover, in the future, more emphasis will be placed on inclusion and diversity, that is, designing learning environments that are accessible to all students. More research is also needed on how the pedagogical infrastructures can be used to inform the design and implementation of learning environments. Furthermore, stronger connections with the international FabLearn network would support the wider sharing of experiences and the international co-development of innovative learning environment solutions.

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