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17 Conclusions

The Cornerstones and Future Directions of Invention Pedagogy

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The Four Cornerstones of Invention Pedagogy

In this book, we introduced invention pedagogy, a Finnish research-based approach to maker education, in which students and teachers engage in nonlinear, multidisciplinary, creative technology-enhanced design and making processes in formal educational settings. In the book, the pedagogical approach has been explored from three perspectives: learning by inventing, facilitation of the invention process, and co-development of inventive school culture. Invention projects are emergent and socio-material in nature and focus on knowledge-creating learning through sustained and iterative generation of shared epistemic objects. Facilitation of this kind of learning is based on careful and dynamic orchestration of the invention process as well as on teachers' transformative agency. The focal features of invention pedagogy can also be used for the school-level development of inventive culture—that is, reconsidering the infrastructures and practices of the school in a way that enables and supports the inventive activities of the entire school community.

The invention projects presented in this book vary in their contents and implementation; however, they all share certain key elements, which we introduced at the very beginning. Such invention projects (1) require and develop an inclusive innovator mindset, (2) are based on multifaceted real-world phenomena, (3) call for co-creation of knowledge and artifacts, and (4) use technology-enriched tools and materials. These key elements have been identified as being central to students' knowledge-creating learning (Paavola & Hakkarainen, 2021) and the facilitation of such learning. At the same time, they are also important in the school-level development of inventive culture, which provides the necessary backbone for established-yet-emergent inventive practices throughout the school (Korhonen & Lavonen, 2017). Thus, the four key elements of invention *projects* also form the cornerstones of invention *pedagogy*, each functioning in conjunction with the others and cutting across the various levels of the pedagogy. The intertwined and cross-level nature of the four cornerstones is illustrated in Figure 17.1, which depicts the cornerstones at the levels of learning by inventing (inner circle), facilitation of the invention process (middle circle), and co-development of an inventive school culture (outer circle).

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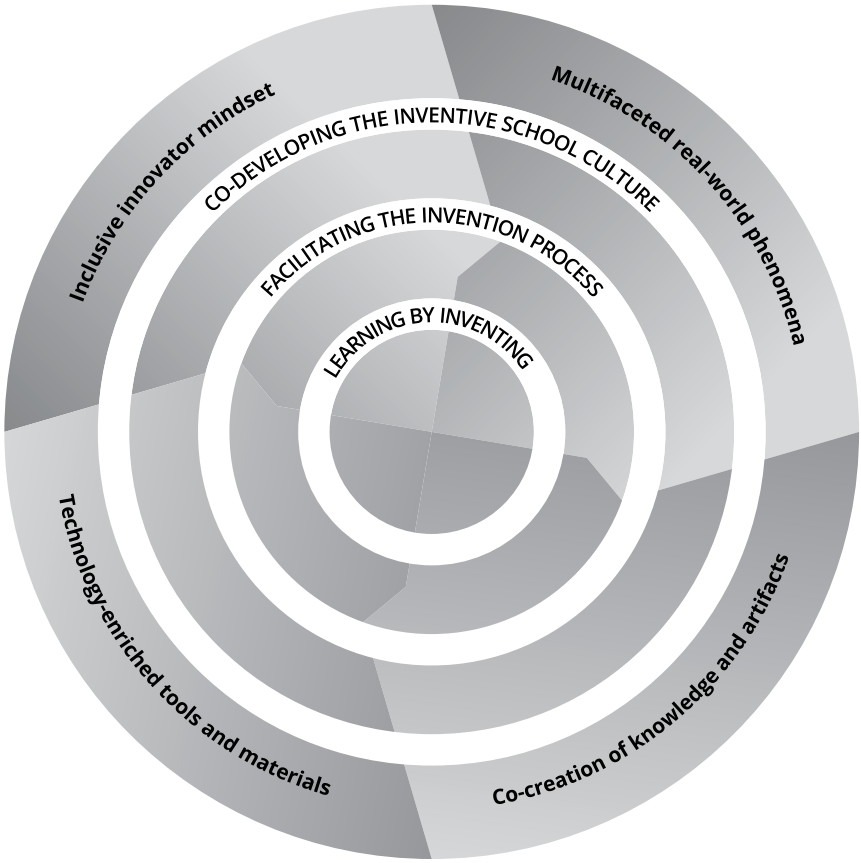

Figure 17.1 The four cornerstones of invention pedagogy across the levels of learning by inventing, the facilitation of the invention process, and the co-development of inventive school culture.

Inclusive Innovator Mindset

Invention pedagogy requires and develops a certain type of mindset in students, teachers, and the other actors in schools. From the perspective of learning, an inclusive innovator mindset is needed from the students for them to be able to create innovative solutions to open-ended challenges; work with others who may have varying perspectives, competencies, and backgrounds; and see themselves as active creators of the future world. Such a mindset has mainly been studied in relation to students (e.g., Chu et al., 2015), but recent research has highlighted that teachers' development of this mindset is essential to the successful implementation of creative learning activities (Jones, 2021). Facilitation of an invention process requires tolerance of the partly unpredictable and ambiguous nature of nonlinear learning, courage to create and test new ways of teaching and learning, and trust in every student's creative potential.

At the school level, an inclusive innovator mindset considers all school infrastructures, practices, and resources as something that can be improved. Thus, in invention pedagogy, mindset is not considered to be something that exists only inside an individual's mind; instead, it emerges and develops through social relationships mediated by the material–technological environment and regulated through cultural traditions. In that sense, it is related to the "makerspace mindset" (Thestrup, 2018), which complements and extends the maker mindset by underlining the culture of the makerspace and acknowledging the opportunities and challenges associated with working with others (Culpepper & Gauntlett, 2020). In invention pedagogy, which is situated in formal education, such a mindset is committed to the continuous and joint development of a school culture that promotes inventive activities.

Multifaceted Real-World Phenomena

In invention pedagogy, the starting point for learning is multifaceted real-world phenomena that are approached through students' own questions, co-creations, and solutions. Therefore, learning objectives or activities cannot be fully determined beforehand, as the goals, contents, and methods of an invention project evolve as the questions and solutions become more defined. New knowledge and skills are applied to the phenomenon, questions, or solutions at hand; thus, they have immediate utility value that is evident in the learning situation. This kind of learning supports students in gaining comprehensive understanding and deeper knowledge of the phenomenon under study (Silander et al., 2022). Although invention pedagogy is situated in formal education and binds to curriculum objectives, its emphasis is on developing students' and teachers' capabilities to navigate in undetermined contexts and utilize the affordances of those contexts rather than focusing only on reaching predetermined goals.

However, invention projects are not characterized as unconstrained exploration (see Sawyer, 2021); rather, they are carefully guided through facilitation that constantly seeks a balance between openness and structure. Facilitating an invention process means giving students the freedom to construct their own ideas and expertise within the boundaries of carefully formulated tasks and with appropriate constraints and materials (Sawyer, 2018; Seitamaa-Hakkarainen, 2022). The underlying phenomenon is formulated, and the invention process is structured in a way that enables student-centered creative pursuits but is not too overwhelming for the students. Teachers provide purposeful structures and address students' emergent needs in parallel (Beghetto et al., 2015; Sawyer, 2021), providing opportunities for all students to flourish and learn. Dealing with multifaceted real-world phenomena also extends beyond individual projects and classrooms to school-level development. Reconsidering and recreating school structures and practices is a similar process of navigating in the unknown; the developers of an innovative school culture determine questions and create innovative solutions related to school-level phenomena.

Co-creation of Knowledge and Artifacts

Inventing something new is a complex and multifaceted process that may go in directions that are unfamiliar to both students and teachers. This is likely to be very challenging and requires collaboration of several people with varying competencies and expertise and systematic joint efforts for externalizing ideas and constructing various types of intangible and tangible artifacts (e.g., Paavola et al., 2004). Whether students are creating inventions in teams, teachers and tutors are collaborating in the facilitation of an invention project, or actors are participating in school-level development work, all participants need to be committed to the shared goals, activities, and division of labor that supports the collaborative achievement of those goals.

Invention pedagogy follows and extends the line of research conducted in the fields of arts and design education (e.g., Davis, 2008; Hetland et al., 2013; Sawyer, 2018) and STEAM (science, technology, engineering, arts, mathematics) education (e.g., Daugherty, 2013; Sousa & Pilecki, 2018), suggesting that creative approaches to education have their own learning heuristic. In art and design, as well as in invention projects, experience-based practices are used for problem-solving, investigation, discovery, and learning. Such practices include envisioning mentally what cannot be directly observed or imagining possible next steps, expressing ideas or personal meanings, exploring playfully without a prestructured plan, and embracing mistakes as learning opportunities. This kind of learning relies on co-construction of epistemic objects that guide and direct the process (Knorr Cetina, 2001; Ewenstein & Whyte, 2009). An epistemic object in an invention project can be described as a cluster of concepts that gradually unfolds through questions and ideas generated by the team members (Mehto et al., 2020); similarly, the development of school-level inventive culture leans on the questions and ideas raised in the community. Experience-based practices enable participants to engage in, persist in, and commit to a project. Furthermore, they promote empathic intelligence (Arnold, 2005), that is, a sustained system of psychological, cognitive, affective, social, and ethical functioning, which enhances participants' connectivity, emotional engagement, and ability to relate to others. Emphatic intelligence is becoming increasingly crucial as the ethnic, cultural, and linguistic diversity in classrooms, communities, and workplaces continues to grow. Furthermore, it enhances academic and labor market prospects, as jobs that require empathic intelligence are less likely to be replaced by technology (see Organisation for Economic Co-operation and Development [OECD], 2019).

Technology-Enriched Tools and Materials

Working with and around various high- and low-tech tools is at the heart of invention pedagogy; technologies are regarded as both objects and tools of learning, depending on the context. The focus of learning is on how to use technologies for creative and academic purposes, for developing students' and teachers' invention competencies, and for narrowing down the "creative participation gap"

(Jenkins et al., 2009). In invention projects, technological tools provide students with the means to externalize and experiment with their ideas, to transform their initially vague ideas into more clearly articulated solutions and artifacts (Kangas et al., 2022; Riikonen et al., 2020). Various technological activities related to designing, engineering, programming, crafting, and documenting both constrain and enable students' inventive activities; furthermore, they provide diverse access points for students to become interested in and inspired by the possibilities provided by technologies. Learning to use technologies for creative purposes follows "the developmental trajectory of creativity," which Glâvenau (2013) describes as "first becoming able to observe and make use of affordances in the surrounding environment and then mastering this use and altering affordances, adapting what already exists and creating new artifacts with new affordances" (p. 76).

Such a trajectory concerns not only students but also teachers facilitating the invention process and all other actors participating in the development of an inventive school culture. Creative use of technologies changes the underlying social and cultural systems in schools. For example, teachers and principals innovate new ways of using technology in organizing school practices and interaction with partners, such as parents and networks. Invention pedagogy underlines teachers' transformative agency (i.e., the proactive pursuit of pedagogical and professional innovations). Teachers' professional development and continuous learning are fostered through appropriating and creating novel technological practices together with colleagues and students and the joint development of an inventive school culture (Korhonen et al., 2014).

Research–Practice Partnerships Supporting the Continuous Development of Invention Pedagogy

The classroom- and school-level invention pedagogy principles portrayed in this book have required both researchers and practitioners to build a joint understanding of the various methods of co-development and to commit to improving teaching and learning in partnership with each other. This development is done not only from the point of view of developing invention pedagogy practices but also of developing research–practice partnership (RPP) processes. In accordance with characterizations of RPPs (Coburn & Penuel, 2016), our collaboration with teachers and schools has been built over several years and through multiple projects, and it has involved co-creation among researchers and practitioners. It has focused on a variety of problems related to practice, the joint testing of solutions for improving teaching and learning and achieving systemic change at the school and municipality levels. We have worked on several invention pedagogy initiatives, from single-classroom cases to school-level development, bringing these developments into discussion and decision-making also at the municipality level.

As researchers in collaboration with school practitioners, we have found RPPs to be a promising path through which we can develop novel ways of working. Simultaneously, we recognize that we must further learn from and study RPPs to realize their full potential. By reflecting on Henrick et al.'s (2017) dimensions of RPP effectiveness, we recognize that we have found routines for collaborating that work

well in the Finnish educational context. We have also learned the meaning of shared expertise, through which the viewpoints and competencies of each partner are valued. Additionally, research results have been reflected on with practitioners in a way that suits the needs of everyday school practice (e.g., mode of presentation, scheduling in accordance with school timetables, and presenting key findings in a clear manner). Finally, the dissemination and sharing of the results has been organized on the school partnership level as well as on a broader, national or international level.

Despite having identified well-functioning ways for organizing and realizing RPPs, we recognize several issues pointed out by Henrick et al. (2017) that can be further developed. The comprehensive use of RPPs as a mechanism for educational improvement is still a relatively new phenomenon in Finland. Through our research and development work with schools, we have found that collaboration could be strengthened through a more balanced negotiation of goals and strategies relating to both practice and research on all levels. Furthermore, it is essential to study RPP processes, organizations, and interactions as a whole to gain a holistic understanding of the circumstances and interconnections through which the co-development of invention pedagogy is realized. This would support practitioners and researchers in recognizing RPPs as a strategy for continuous professional learning through collaboration that can lead to sustainable ways of teaching and learning 21st-century competencies.

Our book depicts invention pedagogy practices in RPPs in the Finnish K–12 educational context. At the classroom level, the aims of invention pedagogy are similar to those of global maker education. The Finnish approach to maker education is unique in that it is situated in the formal education context and developed holistically, in addition to the classroom, school, and municipal levels. It strives to use RPPs to build a multilevel process in which the complexities and related aspects of teaching and learning are considered. This means that all actors, teachers, principals, and administrators are guided toward understanding the goals and cornerstones of invention pedagogy, enabling them to support initiatives for development and implementation. The Finnish classroom- and school-level invention pedagogy approaches presented in this book have been developed for over 20 years and have made an impact on how invention pedagogy is manifested in schools and classrooms. In the future, more effort will be needed to build municipal-level partnerships to solidify these educational practices further and provide equal opportunities for students across Finland to participate in inventing and being empowered through innovation.

Another aspect of our work that should be explored further is the research and development in invention pedagogy through global partnerships—making connections, sharing classroom practices across countries, and deepening the understanding of our practices in the global context. These initiatives could include multinational teacher and student partnerships in developing teaching practices to educate global citizens and innovators of the future. This could include developing competencies that reach beyond inventing and extend to working together with participants from other backgrounds and nationalities. These endeavors can build on and draw from established local and global networks, such as the Fablearn network, the European Schoolnet, Nation of Makers, and Innokas Network. We

suggest that when developing these practices on a global level, the principles of RPP processes should be taken into consideration in the development and research of global inventive maker initiatives.

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