Sustainability and Scalability of CSCL Innovations

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Abstract CSCL innovations involve dynamic changes taking place at multiple levels within the complex educational ecosystem. Scaling of CSCL innovations needs to pay simultaneous attention to changes along several dimensions, including depth of change, sustainability, spread, and shifts of ownership, as well as evolution of the innovation over time. General models for scaling innovations do not take account of the role that technology may play. This chapter examines the sustainability and scalability of CSCL innovations including the role of technology in fostering sustainable and scalable innovation. We review a range of CSCL innovations that span in- and out-of-school settings to synthesize technology-enabled strategies that address scalability challenges at the classroom and education ecosystem levels. A set of design principles is identified to guide future research and practice to transform education through CSCL innovations.

Keywords Sustainability · Scalability · Scaling CSCL innovations · Design principles for scalability · Architecture for learning · Innovation network · Multilevel aligned learning

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1 Definitions and Scope

Since the inception of computer-supported collaborative learning (CSCL), researchers have been making efforts to transform education toward a new learning paradigm featuring students' collaborative knowledge building (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989). Over the past three decades, the field has gained rich conceptual and empirical insights in the sociocultural and cognitive processes of collaborative learning as well as the conditions and designs to scaffold such processes, including that of technology support. A number of CSCL platforms underpinned by innovative, socially grounded pedagogies have been developed, such as Knowledge Forum (Scardamalia & Bereiter, 2014), Web-based Inquiry Science Environment (WISE) (Linn, Clark, & Slotta, 2003), the Virtual Math Teams (VMT) (Stahl, 2006), Quest Atlantis (Barab et al., 2007), and Scratch (Resnick et al., 2009). Collaborative learning is further gaining attention in system-level education reforms that seek to enhance student engagement and develop twenty-first-century competencies, such as the initiatives in Singapore (Looi, 2013), Hong Kong (Hong Kong Education Bureau, 2015), and Europe (Kampylis, Law, & Punie, 2013). However, despite the progress, how to sustain and scale CSCL innovations in broad educational settings for transformative impacts remains a grand challenge (Chan, 2011; Fishman, Marx, Blumenfeld, Krajcik, & Soloway, 2004; Kolodner et al., 2003; Penuel, 2019; Wise & Schwarz, 2017). This chapter is devoted to understanding the sustainability and scalability of CSCL innovations as interconnected challenges. Sustainability refers to the likelihood for an innovation to be continued over extended periods of time, and scalability refers to the probability that an innovation can be deepened and/or spread beyond the original sphere of adoption. While these two concepts appear to be different, they are in fact closely connected and interdependent (Clarke & Dede, 2009; Coburn, 2003).

Efforts for learning innovation and improvement need to be embedded in the multiple contexts in which students learn, teachers teach, and leaders manage school systems (McLaughlin & Talbert, 1993). In addition to valuing student-centered, collaborative, open-ended inquiry as its educational paradigm, CSCL embraces a vision of learning innovations as dynamic and adaptive to cultural, historical, and social changes and contexts, with technology playing an important role. General scalability research does not give special consideration to the role that technology may play in innovation implementation. However, in CSCL research, technology plays an important, interdependent, and coevolving role in supporting the changing educational goals and practices in formal and informal learning contexts.

In this chapter, we synthesize the conceptualizations of sustainability and scalability developed in CSCL and other learning innovations, review how different CSCL programs approach sustainability and scalability, and distill these into a set of design principles and strategies in order to guide future efforts. We draw on current literature to identify issues and strategies that are relevant to researchers as well as policymakers, school leaders, and practitioners who share the concern for making CSCL a pedagogy of choice for education reform. We also examine the scalability of CSCL in terms of the technology used, the interdependence between technology and learning practices, and the facilitating role that the technology may play in fostering scalability. Throughout this chapter, we focus on CSCL in K-16 in- and out-of-school learning settings, though there are also broader applications for CSCL in professional and adult learning.

2 History and Development: Sustainability, Scalability, and DBIR

Educational efforts to institute system-wide changes in curriculum and pedagogy in response to wider social, economic, and political changes first became prominent in the 1960s (Cremin, 1961; Cuban, 1984, 1990; Elmore & Associates, 1990; Elmore & McLaughlin, 1988). Earlier models of change were underpinned by the assumption that innovations go through a stage of prototyping and refinement before scaling, which was considered essentially as a process of diffusion through replication (Rogers, 1962). After decades of research that shows educational innovations to be challenging and seldom sustainable, Coburn (2003) challenged the static model of scaling and put forward a four-dimensional dynamic model of scale. At the core of this model is the idea that expanding the adoption of an innovation in order to achieve lasting change involves not only spread, but deepening changes in three additional dimensions: depth, sustainability, and shift of ownership. Spread refers to the adoption and enactment of a learning innovation in a greater number of classrooms (or other learning settings), including its activity structures, materials, as well as the underlying beliefs, norms, and principles. The depth of an innovation is gauged based on the consequential change enabled, which goes beyond surface structures or procedures to a focus on changes in teachers' beliefs, norms of social interaction, and the underlying learning principles adopted in their professional practices. Sustainability highlights the need to implement the innovation over time for lasting change. In addition, scaling requires a shift of ownership of the innovation and reform from "external" agents to internal stakeholders (districts, schools, teachers, learners), who take on the responsibility of building the capacity to sustain, deepen, and spread principled changes themselves. Building on the above conceptualization, Clarke and Dede (2009) added a further, important dimension—evolution—highlighting emergence as a hallmark of innovations that demonstrate scalability.

According to the dynamic model of innovation as advanced by Coburn (2003) and Clarke and Dede (2009), sustainability and scalability are two interrelated design challenges for learning innovations. As noted above, sustainability refers to the continual implementation and refinement of a learning program over time in its original or subsequent specific setting(s) despite the changing conditions and demands (Clarke & Dede, 2009; Coburn, 2003). Scalability places more emphasis on the spread and growth of the learning innovation in broader contexts and conditions beyond its original setting(s). However, from a design perspective, it is important that these be considered *together* rather than separately. Spread does not simply refer to the wider adoption of activity structures or materials, but importantly through within-unit spreading in order to bring about internalization of norms and principles (Coburn, 2003). Classrooms are nested within schools, districts, and broader educational ecologies forming complex systems (Lemke & Sabelli, 2008). The beliefs and practices of teachers within as well as outside of a teacher's own school or district will also have an impact on the teacher's motivation and persistence in sustaining the innovation practice. Thus, the long-term sustainability of an innovation also depends on its scalability.

Sustainability is fundamental to scaling: "The distribution and adoption of an innovation are only significant if its use can be sustained in original and even subsequent schools" (Coburn, 2003, p. 6). However, sustainability does not imply a simple static continuation of the innovation in its original form. It is inevitable that any educational innovation involves changing the composition and characteristics of the educational ecology: the learning goals and processes, roles of the teacher, the learner, and the institution (Law, Yuen, & Fox, 2011). What is to be sustained are not the surface features of an innovation, but the learning outcome goals and design principles. International comparative studies of technology-enabled learning innovations show that the five dimensions of scalability interact and are interdependent (Kampylis et al., 2013). Studies have also shown that innovations that started with scale as a network of schools demonstrated greater resilience and sustainability over time (Law, Kankaanranta, & Chow, 2005). Since sustainability is subsumed under scalability as one of its five dimensions, we will use the term scalability as the overarching concept. The term sustainability will only be used if we refer only to this specific dimension.

Sometimes, pedagogical innovations that emerge without central agency may successfully scale, given the appropriate technology platform and connectivity support. An example of this is eTwinning, a European-wide initiative to connect teachers from different countries in an effort to develop students' multicultural awareness through online collaboration (Kampylis & Punie, 2013). eTwinning provides secure online spaces and tools for virtual meetings and collaboration to facilitate cross-border student interactions and projects. It has experienced phenomenal growth with a total of almost 800,000 registered teachers in 2020.

For pedagogical innovations to be scalable, they need to be guided by design principles pertaining to two levels of theory: a theory of learning and a theory of change/implementation that form a coherent alignment. The former underpins the design of the innovation at the classroom level to realize the learning experiences that would bring about the desired learning outcomes. In CSCL, knowledge building (Scardamalia & Bereiter, 2014) and knowledge integration (Linn et al., 2003) belong to this type of theory. The latter addresses the ontological tensions created between the new practices and the existing educational ecology. Productive CSCL practices require transforming the classroom into a collaborative community of inquiry with students taking on high-level agency. Such classroom practices represent a new culture of learning that runs against traditional frameworks of curriculum, assessment, and management. Therefore, to facilitate educational change with CSCL principles, programs, and tools, researchers need to consider how people learn in CSCL contexts as well as to understand factors and conditions that enable or inhibit the educational transformation necessary toward the innovation vision (McKenney, 2018).

Implementation research in the learning sciences, including CSCL, values the authenticity of the research context. Thus, strictly controlled experimental designs are not preferred. Instead, research–practice partnerships (RPP, Coburn & Penuel, 2016), which are long-term collaborations between researchers and practitioners (e.g., teachers, leaders, school districts) to codesign and improve educational innovations are popular models of implementation. Design-based research (DBR, also referred to as design experiments) has been developed as a method to test theory-informed interventions in authentic settings through iterative cycles of design, testing, and improvement in partnership with teachers (Collins, Joseph, & Bielaczyc, 2004). The goals encompass improving both theory (the design principles) and practice. More recently, a specific type of design-based research method—design-based implementation research (DBIR)—has emerged in recognition of the need for researchers and practitioners to work together on design issues not only at the classroom level but also on those institutional and other contextual factors (Fishman, Penuel, Allen, Cheng, & Sabelli, 2013) necessary for the educational interventions to be effective, sustainable, and scalable. The participatory nature of DBR/DBIR favors "open-ended social innovations" that not only scale externally designed products (tools, programs) but also the processes and methods by which new learning practices are codesigned in specific contexts (Booker & Goldman, 2016).

3 State of the Art: Design Strategies for Scaling CSCL Innovations

Taking the stance that sustainability is one dimension of scaling educational innovations, this section provides an overview of the research to scale CSCL in schools as well as in out-of-school settings. CSCL is typically organized around open-ended, inquiry-oriented tasks, where the learning process is collaborative and dynamic, and the outcome is generative and often socially shared. For CSCL practices to be scaled, simple dissemination of externally designed tools and activities to more settings would not be adequate as it risks turning classroom reforms into surface changes and losing the ethos of the deep principles (Brown & Campione, 1996). For new learning approaches to contribute to true educational transformations, they need to be embedded in locally cultivated knowledge practices (Hakkarainen, 2009), which are new social practices developed in specific contexts to channel and sustain students' productive inquiry and collaborative interactions for idea advancement. Given the intent of CSCL to bring about transformative classroom changes, gaps and misalignments are expected to emerge between the new learning culture and the existing systems of practices. Thus, researchers need to work with practitioners and other stakeholders to critically reflect on how the existing educational practices are enacted and sustained by epistemic beliefs, social and power relations, resources, and time–space coupling. Such reflection informs co-envisioning of possible futures to create new relations and conditions that nurture transformed forms of learning practices and to examine how learning evolves in the new context (Bang & Vossoughi, 2016; Cole, 2007; Zhang, 2010).

CSCL innovations differ in terms of their specific theoretical underpinnings, design principles, the CSCL technologies they use, as well as the specific learning contexts they serve. These determine the types of inquiry and collaboration at the core of the innovation, the roles of the learner, the teacher (or informal learning educator), as well as the roles played by the selected technology in scaffolding collaborative learning. As a result, different CSCL innovations face different challenges in scaling and involve different mechanisms to support scalability.

The mechanisms to sustain and scale CSCL innovations need to address the two levels of challenges—classroom and school-cum-broader-education-ecosystem levels—in a coherent manner. The first (classroom) level challenge requires the creation of a systematic and robust learning model with support systems that can effectively engage the learners and teachers (i.e., educators) in sustained, collaborative learning practices in the classroom or other learning settings. The second-level challenge requires the creation of supportive contexts and infrastructures beyond the learner–educator interaction level to sustain and grow the innovation, overcome barriers, and build new alignment with the changing conditions and demands of the educational institutions and systems. We synthesize below the design strategies adopted by various CSCL programs at these two nested levels as well as the challenging issues encountered.

3.1 Design of Sustainable CSCL Models and Technologies to Scaffold Productive Learning Interactions

Design for sustainable CSCL needs to provide a transparent model in terms of how the CSCL practices are organized and implemented in light of the educational goals and principles. In this section, we identify four common features of CSCL environments that have been adopted to support a sustainable learning model, from its initial uptake to the continual adaption, improvement, and reinvention of the learning practices in changing contexts.

3.1.1 Principle-Based Collaboration Environments to Guide CSCL Practice

CSCL innovations value a principle-based approach that turns the core learning principles and associated indicators into shared classroom norms and ideals to guide classroom interactions (Brown & Campione, 1996; Engle & Conant, 2002; Scardamalia, 2002). Many collaborative and inquiry-based programs also specify activity cycles and guidelines that inform how principles are to be implemented in practice (Kolodner et al., 2003). Core principles of CSCL are further made transparent through the design of collaborative environments. For example, the WISE program translates the four guiding principles of knowledge integration into a set of design patterns that are incorporated in a library of inquiry projects, which are open to teachers' adaptation (Linn, 2006; Slotta, 2004). Similarly, the Scratch program is guided by four principles to develop creative thinkers: projects for making, passion, peers, and playful experimentation (Resnick, 2017). Knowledge building adopts a principle-based approach to enabling knowledge-creating practices in classrooms, guided by a set of 12 principles (Scardamalia, 2002; Scardamalia & Bereiter, 2014). The principles are made transparent through Knowledge Forum, which provides a collective knowledge space for each knowledge-building community, uses a set of online discourse scaffolds to guide collaborative knowledge building, and uses analytic tools to track students' personal and collaborative progress and provide ongoing feedback (Chen & Zhang, 2016; Scardamalia & Bereiter, 2014). Boundary-crossing designs further extend student interaction to higher social levels across different communities, forming a larger social context for knowledge building. Students can share major insights and challenges with broader knowledge builders for mutual learning and continual build-on, including building on the ideas from previous school years (Yuan & Zhang, 2019; Zhang & Chen, 2019). Long-term studies of classroom innovations guided by knowledge-building principles (Scardamalia, 2002) using Knowledge Forum document how teachers work with the core principles to design and improve classroom practices (Zhang, Hong, Scardamalia, Toe, & Morley, 2011). Core principles such as epistemic agency, collective responsibility, and knowledge-building discourse serve to guide student participation and focus teachers' pedagogical thinking, planning, experimentation, and reflection on/in practice, leading to continual improvement of knowledge-building processes and outcomes.

3.1.2 Discourse Scaffolds and Collaboration Scripts to Inform Students' Engagement

To inform and enhance students' learning interactions, researchers have designed different scaffolding supports offered by the teacher or distributed in the technology environments, which form a synergy (Tabak, 2004). As a specific type of scaffolding, structured collaboration scripts are designed to help create routines and structures that lessen the effort needed to sustain high-quality learning practices over time. These scripts are often embedded in a collaboration platform to specify and sequence various learning tasks and activity procedures and distribute different roles among students to guide their discourse and social interactions (Kirschner & Erkens, 2013; Kollar, Fischer, & Slotta, 2007). The teacher engages in classroom orchestration to integrate and adapt multiple scripts of learning activities in order to cope with many constraints, including the expectations of the curriculum and assessment, time, and space. Research on classroom orchestration highlights the need to make the educational workflow usable, visible, and tangible. This empowers the teacher to not only select a set of predetermined scripts but also to coordinate the different activities in a coherent way in their evolving classroom context (Dillenbourg, 2013).

3.1.3 Reflective Supports for Student-Directed Regulation and Structuration of Collaborative Learning Practices

Sustainable CSCL environments foster students' capacity to direct and reflect on their personal and collaborative knowledge processes for continual improvement. Researchers have tested various strategies to support student metacognition and socially shared regulation of collaborative learning (Winne, Hadwin, & Perry, 2013). These include using group awareness tools, adaptive agents, and visualization and feedback tools to support the ongoing monitoring and optimization of individual and collective processes (Järvelä et al., 2016). In addition to the externally designed reflective support, recent research further highlights the use of student-generated, emergent structures to shape their evolving inquiry and discourse beyond the original framing and boundaries. This process is framed as "reflective structuration" (Zhang et al., 2018), which refers to the reflective processes by which members of a community co-construct shared inquiry structures (i.e., collective goals, directions, processes) over time to channel their personal and collaborative actions. Reflective online supports, such as Idea Thread Mapper, allow students and their teacher to co-organize/reorganize their inquiry directions and groups over time based on emergent needs, enhancing student-driven collaborative processes and knowledge outcomes (Zhang et al., 2018).

The above-reviewed discourse scaffolds and reflective supports work together to create a synergy between the external, distributed scaffolding support, and student-directed generative efforts. An emerging line of research focuses on creating learning analytics to support teacher scaffolding and student reflection in CSCL settings (Wise, Knight, & Shum, this volume). These include designing teacher dashboard tools to monitor student participation and collaboration and inform teacher orchestration; analytics to detect emerging directions, progress, and gaps; and intelligent feedback tools to enhance students' reflective awareness and intentional engagement (Chen & Zhang, 2016; Wise, 2019; Wise, Knight, & Buckingham Shum, this volume).

3.1.4 Discipline-Specific CSCL Programs and Resources to Support Curriculum and Assessment Innovation

While many CSCL models and learning supports are applicable across curricula, CSCL practices need to be refined within the context of a specific discipline(s) and created in a way that induces and shares high-quality practices. One type of CSCL innovation focuses on supporting learning of disciplinary knowledge and skills in specific curriculum areas, such as WISE and Virtual Math Teams. WISE (Linn et al., 2003) provides a library of inquiry projects that teachers can adopt directly or customize to meet their specific classroom settings. Virtual Math Teams (VMT) supports collaborative learning of mathematics and mathematical discourse through the provision of software, curriculum, pedagogy, and research methods (Stahl, 2009). The software environment provides an integrated collaborative learning environment comprising a number of chat tools and thread features, including a shared whiteboard for constructing drawings related to a mathematical problem.

Collectively, the above four features of CSCL environments are culminations of research efforts that provide a robust foundation for the field to develop sustainable designs of CSCL: with core CSCL principles translated into classroom norms, with adaptive supports embedded in the multilevel collaborative environment and enriched by discipline-specific resources, serving to enhance student agency for continually advancing their joint inquiry practices in specific disciplinary/interdisciplinary contexts. Given that these design features are often investigated and adopted in different research contexts by different teams independently, there have not been explicit efforts to seek conceptual coherence or practical alignment in implementation across these features. The ongoing debate between scripted and non-scripted collaborative learning (Bereiter et al., 2017) also highlights the need for further research to address the tensions between prescriptive guidance structures and student agency in classroom practices, and between fidelity and adaptability in CSCL implementation. Such research will guide further advances in the development of coherent ongoing support for CSCL classroom practices as dynamic social systems.

3.2 Design of Supportive Architectures for Learning to Foster Scalability

CSCL innovations introduce changes in educational goals, roles, and practices, and require different priorities in terms of technology infrastructure, support services, and organizational routines for them to become scalable. Addressing the challenge of scalability is a key design focus in DBIR efforts, which are generally organized as research–practice partnerships (RPP), involving stakeholders at multiple levels of the education system (Coburn & Penuel, 2016). RPP projects connecting multiple schools in similar innovation initiatives, such as the Knowledge Building International (KBIP) (Laferrière et al., 2015), to function as innovation networks. It has been found that even when all five dimensions of scalability can be demonstrated in an innovation network, there can still be individual schools that stop engaging in the innovation and leave the network. Thus, successful scaling at the innovation network level may not imply scalability at the school level. Scaling pedagogical innovations is a multilevel challenge (Davis, 2017), requiring changes and aligned learning at teacher, school, community, and system levels. Such aligned learning needs to be facilitated through an appropriate architecture for learning (Stein & Coburn, 2008), which is broadly described as the organizational structure, interaction mechanisms (e.g., established routines described in Spillane, Parise, & Sherer, 2011), artifacts, and technology that are available to facilitate sharing and communication of ideas. The architecture for learning plays an important role in facilitating decision-making that progressively consolidate contextual changes favorable to the innovation at different levels of the education system. Below we highlight the key architectures for learning that support multilevel connected learning across teacher, school, and network levels in DBIR contexts.

3.2.1 Teacher Learning and Innovation Through Codesign

Teacher codesign of learning environments and learning experiences has become a widely adopted model for teacher learning (Mor, Ferguson, & Wasson, 2015). This is also a commonly adopted model for teacher learning in CSCL, as CSCL innovations are characterized by a focus on collaborative inquiry. As technology plays a central role in CSCL, codesign for CSCL implementation generally involves teachers using the related technology not only in their learning design work but also in their own professional reflection, sharing, and discourse. This form of teacher learning has the advantage of fostering shared vision and meanings of classroom change as well as ownership over the innovation, which engender intentional efforts for continual improvements (Teo, 2017; Zhang et al., 2011).

CSCL practices also require new designs of learning assessment. Through design-based research, van Aalst and Chan (2007) worked closely with teachers to codesign student-directed assessment for knowledge building using e-portfolios and other technology support. At the same time, new learning analytics have been designed to assess students' collaborative knowledge building and generate automated feedback (Chen & Zhang, 2016; Resendes, Scardamalia, Bereiter, Chen, & Halewood, 2015). The Knowledge Building Community Project in Singapore involves teachers in codesigning new formal and informal assessments using a set of analytics tools, including designing new report cards to keep track of student progress in content knowledge and in a set of twenty-first-century competencies (Teo, 2017).

3.2.2 Network Models of Professional Learning and Collaboration

Whereas codesign provides experiential professional learning opportunities that are directly connected to teachers' day-to-day professional practice, research in CSCL highlights the importance of creating collaborative, professional learning communities, and knowledge-building networks in which teachers engage in open, professional inquiry, and collaborate to support continual innovation and improvement (Chan, 2011; Goldman, 2005; Teo, 2017; Zhang et al., 2011). In such communities, teachers talk about their classroom stories; reflect on progress, problems, and challenges; share learning designs, classroom actions, observations, and reflections; work together to address difficulties and coinvent better curriculum/pedagogical designs and support materials, and share how students think in the disciplinary areas as reflected through students' ongoing work. Such professional inquiry and collaboration may extend beyond local schools through distributed networks (Chan, 2011; Hong, Scardamalia, & Zhang, 2010; Laferrière et al., 2015). For the professional communities and networks to sustain, it is critical to develop and support cohorts of "change leaders," who engage with their colleagues in reflective inquiry into their teaching and learning and nurture an innovative culture that can sustain and spread (Goldman, 2005).

3.2.3 School–UNiversity–Government (SUNG) Partnerships to Scaffold Multilevel Aligned Learning

Educational systems are complex systems comprising hierarchically nested levels—students, teachers, classrooms, schools, districts, systems—that are interdependent (Davis, 2017). In such a complex system, the learning outcomes at a higher level become the conditions for learning at a lower level (Law, Niederhauser, Christensen, & Shear, 2016). School–UNiversity–Government (SUNG) partnerships (Laferrière et al., 2015) are a form of RPPs that can play an important role in providing shared vision and agency for advancing and scaling multilevel, research-based innovations. Beyond providing peer learning opportunities to teachers, SUNG partnerships can scaffold and mediate top-down and bottom-up initiatives to foster aligned changes across levels. The evolution of roles that takes place (Laferrière et al., ibid) as the tensions in the innovation network shifts in parallel with the increasing scale of the network echo the need for infrastructuring as argued by Penuel (2019).

Even when different measures of scale are progressing in an innovation network, there is still fragility (Laferrière et al., 2015) as agency needs to be exercised at all levels of the complex educational system within which the innovation is embedded. In-depth studies of school-level change conducted within three SUNG networks show great diversities in development over time. Despite similar system-level conditions and network-level support, agency and appropriate architectures for learning at the school level have been shown to be critical for sustainability and scalability of CSCL innovations (Law et al., 2018).

3.2.4 Design and Implementation of Sustainable Out-of-School Practices and Communities

Out-of-school settings can be highly productive spaces to cultivate our understanding of CSCL at scale. This is, in part, because out of school spaces are non-compulsory and thus reveal very early on in iterative technology design cycles what is of interest to learners and the conditions to which individuals will continue to engage with minimal institutional support. For this reason, many researchers have sought to design and deploy CSCL technologies in out-of-school spaces before bringing them into K–16 settings (e.g., Fields & Kafai, 2009; Greenhow, Gibbins, & Menzer, 2015).

Such was the case in the design and scaling of the online computer platform, Scratch (scratch.mit.edu). Scratch was initially designed for use in the international Computer Clubhouse Network (Kafai, Peppler, & Chapman, 2009). The early testing of this technology took place at a select number of Computer Clubhouse sites until it became the most popular technology in these spaces (Peppler & Kafai, 2009). Following this version of the design and testing, the platform was rolled out to the whole Clubhouse network and was made generally available to the public through the scratch.mit.edu website (Resnick et al., 2009). As teachers and parents saw the platform being widely used in the out-of-school hours, they looked for opportunities to bring it into the school day, creating a community of practice to share and support computer programming that spanned school and recreational hours. The platform's scalability can be attributed to the fact that teachers and parents could see the educational value of the tool, while the core mechanics of the platform made it inviting for youth to deepen their practices beyond the school day (Maloney, Peppler, Kafai, Resnick, & Rusk, 2008).

The broader field of serious games has pursued similar strategies, seeking out games with core mechanics that work well in out-of-school settings in order to teach core disciplinary content and other types of soft skills to youth (Salen & Zimmerman, 2004). This is similar to the work done by researchers looking into Wikipedia (Forte & Bruckman, 2006) and Fanzine work (Lewis, Black, & Tomlinson, 2009) to investigate general principles to engage young people in self-selected engagement in high-quality learning practices. Researchers in these areas seek out how these principles can be leveraged to reimagine how CSCL experiences can bridge school and informal learning environments.

While well-designed CSCL environments have been successful in engaging young people in out-of-school learning, it is important not to lose sight of the ecological perspectives surrounding in-person and online communities, and how to design and support these broader initiatives at a community and citywide infrastructure. As typical out-of-school environments lack a natural infrastructure to scale these innovations, new infrastructure—in the form of technologies hosted online, formalized curriculum, models, professional development and training, etc.—needs to be designed to support the spread of CSCL innovations in both the short- and long term. Another key difference between in-school and out-of-school CSCL innovations is that, when the innovation applies to out-of-school learning, participants are likely to be more diverse in age, prior experiences, and background, which provides opportunities for studying how CSCL innovations impact lifewide and lifelong learning. How databases are merged, how learning environments are connected, and researchers learn and report on this data are all considerations that factor into designing an out-of-school CSCL technology in order for the various actors in a learning ecosystem to access what they need from the innovation.

In recent years, there have been concerted efforts to look at sustainable and scalable models for these types of infrastructures. One example is the Hive Learning Networks (Hive NYC, 2019). Hives is an umbrella model for youth-serving afterschool programs comprised of various youth-serving nonprofit organizations (i.e., museums, libraries, advocacy groups, clubs, community centers, etc.) that are colocated and organized around the shared purpose of developing an urban network that connects youth with organizations and learning environments aligned with their passions.

While it is encouraging that these learning infrastructures are forming, the field needs new technologies to facilitate collaboration between providers and offer visibility into the student learning process. One example is the City of Learning (chicagocityoflearning.org) project (Barron, Gomez, Martin, & Pinkard, 2014; Digital Youth Network, 2019), which sought to create a shared infrastructure for highlighting all the learning happening across Chicago and connecting in- and out-of-school learning environments.

4 The Future: Conclusions and Next Directions

Addressing the challenges of sustainability and scalability is critical to the field of CSCL for it to achieve its dream of educational transformation. The concept of scaling is multifaceted: It involves sustaining an innovation over time, deepening the innovation for transformative changes, while spreading and adapting the innovation to a broad spectrum of learner populations and conditions. The process of scaling CSCL requires a complex system approach to educational and cultural changes; instead of simply thinking about how to bring pre-developed tools and practices to more school and classroom settings, researchers need to partner with educational practitioners, policy makers, and institutional partners to evolve aligned systemic changes at different levels of the education ecosystem. The core learning principles of CSCL can be used to inform shared vision building and guide continual refinement of learning design in specific contexts to address multiple demands and constraints.

4.1 Design Principles for Scalable CSCL Innovations

Drawing upon lessons learned from the work in CSCL and other related fields, we summarize eight emerging design principles to inform future work in this area. The first four principles pertain to the nexus between CSCL learning theories, pedagogical models, and technology. These principles address design issues at the classroom level and are specific to CSCL. The last four principles pertain to building a supportive architecture for aligned learning across multiple levels of the education ecosystem. These principles draw also on general educational innovation research beyond CSCL, and their applications are not limited to CSCL.

1. *Maximize the principle-based scaffolding potential of the CSCL technology in designing learning interactions and activities*. Robust CSCL models are inextricably connected to the collaboration environment developed by the researchers concerned. The former underpins the design of the latter, and the latter plays a crucial role in supporting the envisioned CSCL interactions. Teachers, researchers as well as school leaders, and policy makers need to recognize the

importance of this principle and facilitate its realization within the context of their role and capacity in the innovation.

2. *Integrate learning design scaffolds into the CSCL environment to support teacher learning and codesign*. Whereas CSCL technology features offer scaffolding for the collaborative interactions of learners, there is not much attention given to the design/provision of technology scaffolds that would help teachers in the design of principle-based learning activities appropriate for the targeted students and learning outcomes. More attention to the design of technology features and functions that support teachers in their design and codesign of CSCL tasks and interactions would provide valuable support to teacher learning.
3. *Make learning at multiple levels visible through learning analytics and visualization tools*. If multilevel aligned learning is important for scalable CSCL innovations, there need to be multilevel collaboration environments with rich artifacts and interaction mechanisms to scaffold multilevel interaction and aligned learning (Zhang & Chen, 2019). An important research challenge is to design data-based tools to provide feedback to different stakeholders, so that they can visualize and understand the progress regarding the achievement of core learning outcomes and the extent to which the learning interactions follow the principle-based CSCL model at the different levels. These tools and the analysis results generated can become boundary objects for sharing of ideas and negotiation in the refinement of routines and other aspects of the practice.
4. *Build mechanisms to support the coevolution of CSCL technology alongside changing CSCL practices as the innovation progresses*. Innovation implementation is not a simple replication process but involves dynamic changes as the nexus between research and practice progresses. Using the sociological theory of technology adoption as sociotechnical systems (Geels, 2005), Law and Liang (2019) identified sociotechnical coevolution (i.e., the intentional iterative redesign of the digital learning environment) to prioritize and promote more desirable pedagogical practices as a feature of scalable e-learning innovations.
5. *Promote ownership and agency across levels*. Shift of ownership is one of the dimensions for scalability of educational innovations. Long-term sustainability and scalability can only be achieved through deep changes at the level of the educational ecosystem. Ownership and agency for the CSCL innovation need to be shared among teachers, school, and district leaders. Stakeholders at different levels need to share the vision of the innovation and take responsibility for and pride in its success.
6. *Develop organizational structures and routines to support collaborative codesign of curriculum and assessment that align with the CSCL goals*. The adoption of new learning technologies and innovative pedagogies inevitably generate tension with existing practices which can only be resolved through the development of new organizational structures and routines. Changing organizational infrastructures requires decision-making at the institutional level on a continuing basis as the innovation progresses. For decision-making to be responsive, timely, and efficacious, there needs to be multilevel participation and joint ownership for change across levels.

7. *Leverage the power of networks to scaffold multilevel aligned learning throughout the educational ecosystem*. Collaborative inquiry and professional dialogues lead to the creation and accumulation of principled practical knowledge about what works, how, and why (Bereiter, 2014; Means & Penuel, 2005). Network-based collaborative inquiry provides a context and supports for forming shared agendas of change and indicators/benchmarks of successful implementation, and for building human capacity and nurturing change leaders through multiple professional learning communities centered around authentic problems in everyday practices.
8. *Create a nexus of practice (Hui, Schatzki, & Shove, 2016) that connects children and youth with technology and existing social culture to scale out-of-school CSCL innovations*. Maker activities using well-designed technology platforms are popular forms of out-of-school CSCL activities that attract large numbers of children and youth around the globe. Unlike school-based contexts where there are ready infrastructures that can be leveraged to mediate and scaffold, the principle-based learning activities, external funding support to set up youth-focused community infrastructures, such as the Hive Learning Network, have shown to be very valuable in scaling these out-of-school creative learning activities.

Given that challenges and effective strategies at the architecture for learning level are largely independent of the specific CSCL models and technologies involved, there are theoretically greater possibilities of as well as potentially greater benefits from cross-network collaboration of CSCL-related RPPs across a wider theoretical and technological spectrum. In addition to enriching the literature on scalability of educational innovation, such collaborations will also provide opportunities for exploring theoretical questions regarding CSCL, such as how collaborative learning interactions operate across the different social levels and timescales and what types of learning supports are desirable at the different levels.

4.2 Implications for Policy

Design principles are advice to guide different aspects in the design of CSCL environments and implementations. They are not intended to be prescriptive, but rather to inspire design work for more efficacious solutions. Hence these are directly relevant to people working in RPPs that focus their work on CSCL. On the other hand, the scalability of educational innovations is also greatly dependent on appropriate policy-level support. There are some policy implications derived from the above design principles, which are mentioned below.

1. *Provide funding and policy-level support for different forms of SUNG partnership to steer the two connected levels of principle-based design for DBR and DBIR*. Prescribed criteria for funding support, monitoring, and evaluation can be designed to align with the above design principles to enhance scalability.

2. *Promote cross-network communication and sharing of artifacts, technological tools, and resources*. Different RPPs may be guided by different learning theories and design principles and use different CSCL technologies. It does not mean that these practices and tools are necessarily incompatible. There may also be benefits from learning from other RPP networks about strategies and practices that promote (or hamper) scalability. Policies that promote the creation of usable and shareable knowledge and artifacts across RPP networks would be valuable.
3. *Provide funding and policy support for urban out-of-school CSCL hubs for children and youth*. To serve as effective infrastructure for scalability of these informal learning activities, these hubs should not be standalone organizations but should connect with relevant community groups, institutions, and infrastructure so as to create a nexus of practice for the children and youth participating in these activities.

As elaborated throughout this chapter, the scalability of CSCL innovations can only be achieved through systemic aligned strategies at multiple levels. Appropriate policy support at the system level is crucial for CSCL innovations to contribute to sustainable and scalable educational transformations.

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Further Readings

Chan, C. K. K. (2011). Bridging research and practice: Implementing and sustaining knowledge building in Hong Kong classrooms. *International Journal of Computer-Supported Collaborative Learning, 6*(2), 147–186. This is a case study of scaling and sustaining Knowledge Building in Hong Kong classrooms. The analysis documents efforts and changes at different levels, including educational policies reform, the knowledge-building teacher network, and knowledge building design and practice in classrooms.

Clarke, J., & Dede, C. (2009). Design for scalability: A case study of the river city curriculum. *Journal of Science Education and Technology, 18*, 353–365. This article builds on Coburn's (2003) framework to examine the multiple dimensions of scale: depth, sustainability, spread, shift in ownership, and introduces "evolution" as an additional dimension. This framework is applied to guide the scalability design of the River City project.

Coburn, C. E., Russell, J. L., Kaufman, J. H., & Stein, M. K. (2012). Supporting sustainability: Teachers' advice networks and ambitious instructional reform. *American Journal of Education, 119*(1), 137–182. This study uses qualitative social network analysis and qualitative comparative analysis to study the relationship between sustainability and teachers' social networks when resources and supports were removed in year 3 of an innovative mathematics curriculum across a district.

Kampylis, P., Law, N., & Punie, Y. (Eds.). (2013). *ICT-enabled innovation for learning in Europe and Asia: Exploring conditions for sustainability, scalability, and impact at system level*. Luxembourg: Publications Office of the European Union. This in-depth 153-page report presents seven cases of ICT-enabled innovations for learning from Europe and Asia, describing scale, learning objectives, the role of technology, and implementation strategies. The report also presents relevant lessons learned and conditions for scalability, impact, and sustainability.

Looi, C. K., & Teh, L. W. (Eds.). (2015). *Scaling educational innovations*. Singapore: Springer. This is an edited volume comprising a collection of theoretical and empirical studies on scaling educational innovations that have a strong pedagogical focus. Some of the empirical studies are directly related to CSCL innovations.