Boundary Crossing as a Lens for Examining Scale in Collaborative Learning Sciences Innovations

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Abstract: Researchers are increasingly seeking to support the spread of tools, practices, and curricular innovations for more equitable STE(A)M learning, through the development of collaborative relationships with schools and districts. In this study we followed two STE(A)M curricular innovations at different stages of development, as they made attempts to scale across two years through collaborations with practitioners. Our comparative case study explores how instances of dialogical learning facilitated boundary crossing (Akkerman and Bakker, 2011), which played a key role in shaping scaling efforts and usability. We illustrate how scale can be conceptualized and studied as a learning problem, using the lens of boundary crossing. This work addresses the need for longitudinal studies of researcher and practitioner collaborations, as well as the need for research that goes beyond the initial stages of an innovation's implementation, contributing to our understanding of what makes a successful and sustainable scaling effort.

Keywords: scale, curricular innovation, boundary crossing, dialogical learning, usability

Introduction

In recent years the development of STE(A)M learning initiatives for large scale implementation has proliferated. Initiatives like *Exploring CS* and *CS for All* have attempted to develop and scale programs for use by K-12 public schools across the country (NSF, 2018). In addition, hybrid and web-based learning environments like Scratch have created spaces for choice-based collaborative learning across formal and informal contexts (Fields, Kafai, & Giang, 2016; Pinkard, Martin, & Arete, 2019). As choice-centered making and tinkering practices are increasingly being brought into the school day to support equitable STE(A)M learning, understanding what makes a successful and sustainable scaling effort is important.

While digital learning environments have long been an area of focus within the learning sciences, more research is needed that investigates the methods and processes involved in their scaling. McKenney (2018) argued that while our discipline focuses on the study of learning, we cannot promote quality learning environments without considering the factors that allow those learning environments to take shape, proliferate, and have a sustainable presence. She called for increased research efforts focused on the implementation and scaling of innovations that, "yield theoretical understanding that can help us describe, explain, predict, or change everyday learning in light of the contexts in which it takes place" (McKenney, 2018, p.1).

Many researchers are seeking to support the spread of tools, practices, and curricular innovations through the development of more collaborative relationships with schools and districts. These collaborations can help bridge gaps between researchers' and practitioners' goals, facilitate the uptake of ideas and findings from research, and address challenges educators face when implementing new tools and practices (National Research Council, 2012; Penuel & Gallagher, 2017; Tseng, Easton, & Supplee, 2017). Researcher and practitioner collaborations can take many forms, including Research-Practice Partnerships (RPPs) (Farrell, Harrison, & Coburn, 2018), and sustained critical engagements across research and practice (Bevan, Penuel, Bell, & Buffington, 2018).

In this study we followed two STE(A)M curricular innovations at different stages of development, as they made attempts to scale across two years through collaborations with practitioners. Our study illuminates some of the affordances, tensions, and opportunities for growth that can exist in such collaborations as they change in scale and stage of development across time, and what this means for the "usability" of curricular innovations (Fishman & Krajcik, 2003). Through our analysis, we use characteristics of *boundary crossing* (Akkerman & Bakker, 2011) to understand how these two collaborations successfully crossed boundaries to overcome challenges to usability. Our work addresses the need for longitudinal studies of researcher and practitioner collaborations, as well as the need identified by Fishman and Krajcik (2003) for research that goes beyond the initial stages of implementation, and carries through to ensure an innovation's functionality in varied classroom contexts.

Conceptual framework

Akkerman and Bakker (2011) define boundaries as, "sociocultural differences that give rise to discontinuities in interaction and action," which occur between two or more activity systems (p.139). In other words, boundaries are places where challenges arise due to differences in organizational or cultural practices, processes, or belief systems. As such, it is the boundary itself that serves as a frame for collaboration (Penuel, Allen, Coburn, & Farrell, 2015). When people effectively negotiate a boundary to work or collaborate across it, they are engaging in *boundary crossing*. When an artifact facilitates work across a boundary, it functions as a *boundary object*. Boundary objects serve a communicative function across boundaries for individuals in different roles, but "can never fully displace communication and collaboration" (Akkerman & Bakker, 2011, p.141).

In their review of literature on *boundaries,* Akkerman and Bakker (2011) examine the types of learning that can happen when boundaries are encountered, and how that learning facilitates *boundary crossing*. To understand how collaboration happens between researchers and their school partners, we looked at the characteristics of what Akkerman and Bakker (2011) called "dialogical learning", defined as, "new understandings, identity development, change of practices, and institutional development" (p.142). From this perspective collaborative work at the boundary necessitates and prompts learning. Akkerman and Bakker (2011) define four mechanisms of dialogical learning: *identification*, *coordination*, *reflection*, and *transformation*. Below, we outline each of these mechanisms for learning:

1. **Identification**: occurs through *othering* (i.e., defining practices at one site in opposition to the other) and *legitimating coexistence (i.e.,* recognizing some practices as shared across roles and domains or through participation in multiple groups).
2. **Coordination:** is the process of communication to facilitate joint work. It includes *communicative connection* and *efforts of translation* across sites and practices through *boundary objects*, *enhancing boundary permeability* to make the boundary crossing more seamless, and *routinization.*
3. **Reflection:** is the process of individuals coming to better understand their own practices and those of others. This can occur through *perspective making* (i.e., increasing self-awareness of one's role) and *perspective taking* (i.e., considering the perspectives of others in relation to one's own perspective).
4. **Transformation:** is the process that leads to meaningful change in practice. It includes surfacing difference through *confrontation* and *recognition of shared problem space; hybridization* of aspects of different cultural systems to create new practices; *maintaining uniqueness of intersecting practices* by maintaining core practices of primary discipline while incorporating new ones; and *continuous joint work at the boundary*. New or transformed practices are sustained through *crystallization*.

Context

Our comparative case study includes two STE(A)M innovations engaged in scaling efforts in collaboration with practitioners at partner schools. These innovations were chosen because both engaged students in STE(A)M learning, but differed considerably in their goals and strategies for forging partnership relationships and scaling. Members of the university-based teams had diverse roles and backgrounds, and many took on hybridized roles that included aspects of research, design, and support. Across projects, participating schools varied in student demographics, as well as teacher interest in, understanding of, and buy-in related to the purpose and goals of each collaboration. Below we outline the background of each innovation and scaling efforts they undertook.

Making Makers (MM) is a learning environment built to foster exploratory and interest-driven engagement in a broad variety of STEAM concepts and practices through learning "challenges". Schools implementing MM received access to a web-based platform, physical materials needed to engage in the challenge activities, and support from the MM team in the form of summer training and PD, and assistance with troubleshooting and implementation. MM was first adapted for a classroom setting through a close partnership with a local school district. It has since spread significantly in other cities and abroad, initially through word of mouth. Following this organic scaling, the team decided to engage in a deliberate scaling effort, using two partnership models—a paid model and a granted model where schools received the program for 2 years. The primary goal of this scaling effort was to increase access to the program and test its viability in diverse school settings. To date, there are more than 200 sites implementing MM across the United States and Europe. The project is researching questions of scale related to processes of local adaptation of the model, following the approach outlined by Downing-Wilson and colleagues (2011).

CT+ is a younger initiative aimed at the school-wide integration of computational thinking into high school science classrooms. In its second year of implementation, CT+ collaborated with three high schools and eight teachers in the Midwest, all located within an hour of the university-based team who launched this initiative. Participating teachers received professional development and implementation support from CT+ researchers in exchange for teaching a two-week science unit that integrated CT. Some teachers also co-designed their own CT-inspired units.

Methods

In our analysis, we sought to answer the following questions:

1. How do researchers and practitioners involved in collaborations negotiate boundaries and roles in their efforts to introduce and/or sustain a curricular innovation?
2. How does this process of negotiation and renegotiation relate to the current and potential usability of the curricular innovation?
3. How does the focus of scale and development of the curricular innovation contribute to opportunities and barriers for boundary crossing and role negotiation?

Protocol development and data sources

Interview questions for researchers and practitioners in MM and CT+ were developed with the goal of understanding how practitioners and researchers negotiated roles and relationships within the collaborations. These interview questions were adapted from those originally used in a comparative study of RPPs, (Farrell, Davidson, Repko-Erwin, Penuel, Quantz, Wong, Riedy, & Brink, 2018). Data were collected within the context of two separate evaluation studies, between the Fall of 2017 and Spring of 2019.

Making Makers

In year one of data collection interviews were conducted with six members of the MM research and design team, and eight school partners, including teachers and administrators. School partners in various locations across the US were either in their first or second year of implementation. All school partners interviewed were participants in the granted model. In year two, seven interviews with members of the MM research and design team, and 11 interviews with school partners were conducted, seven of whom had participated in interviews the previous year. Two interviewees were school partners in the first year of their grant, one was from a paying school that had implemented MM for a year. All interviews were conducted over the phone.

CT+

In year one of data collection, all 13 members of the research team were interviewed in January 2018, and again in June 2018. Six of eight participating teachers were interviewed in January 2018. Five of these teachers and two additional teachers were interviewed in June 2018. In year two, a round of interviews was conducted between November 2018 - February 2019, with seven of eight teachers and 10 of 11 researchers participating. In May 2019, a second round of interviews was conducted with seven of eight teachers and eight of 12 researchers. Over the two years, interviews were conducted both in person and over the phone.

Analysis

As our study originated in evaluation work that examined the health of each curricular innovation's partnership relationships, our coding scheme was in part modeled after Henrick et al.'s (2017) *RPP Outcomes Framework*. Codes were added to capture instances of learning for university and school partners, and change that occurred between the first and second year of the projects' scaling efforts. We then conducted a second round of analysis in order to identify examples and counterexamples of the mechanisms of dialogical learning at the boundary defined by Akkerman and Bakker (2011): *identification*, *coordination*, *reflection*, and *transformation*. Authors 1 and 2 created matrices that linked *a priori* codes with the dialogical learning mechanisms. In this way, we were able to analyze changes over time in both projects through the lens of learning at the boundary.

Findings

In this section, we describe key boundaries encountered as MM and CT+ worked to introduce, implement, and sustain their respective curricular innovations. Our analysis uncovered how and when *learning at the boundary* supported collaborators in MM and CT+ to take on new roles, new understandings, and new practices. We also encountered instances in both collaborations where partners were less successful at achieving change and transformation. While learning at the boundary manifested in a number of different ways in each collaboration, we focus here on key examples of more and less successful instance of boundary crossing for each innovation.

MM: Navigating and supporting transition to a new classroom model at scale

School partners and MM team members encountered distinct boundaries when taking MM from a set of learning goals, practices, and philosophies, to concrete implementation in classrooms across the country. As MM team member Mark said of his struggle to provide facilitators with guidance on problems of practice, “We have this lofty idea of what it should be and then people are like, well, these are reasons I can think of that that's not going to work. Then trying to meet the expectations versus reality.” Many of the boundaries encountered by teachers once they were implementing MM were related to the new demands of maintaining technology tools and materials, the new and unfamiliar role they needed to take on as facilitators of choice-based making activities, and the resulting shift in the culture of their classroom.

Technology and material demands

One of the most widely encountered boundaries for practitioners emerged during breakdowns in technology infrastructure. This often came in the form of broken 3D printers or issues with the software students used while engaging in learning challenges. As one teacher Allen put it, the learning challenges are, “based on free programming platforms or 3D design platforms, and kind of very much an open-source culture of things, which brings about quirky issues. There are many challenges that are just definitely not like, here, plug this in, and everything will work out just fine.” While some practitioners reported facilitating a technology class prior to MM, navigating this particular technology was new for many. This boundary was significant because technology breakdowns both created additional demands on practitioners’ time and had a direct impact on student engagement. Lisa, a middle school science teacher, explained, “in a classroom when you have 26 teenagers, if the software is down and everything's really finicky, they become...you can get one or two of them on task fixing the software, but it becomes easy for them to have an excuse about why they can't get their work done or why they're distracted.”

During year one, practitioners widely reported turning to the MM Slack community when they were unable to resolve troubleshooting issues on their own. The Slack community, which was set up by the MM team, acted as an important boundary object for *translation* and facilitating *communicative connection*. Many facilitators reported checking Slack to see if another practitioner had encountered and resolved a similar issue to one they were experiencing. If that was unsuccessful, they would then contact a member of the MM team for direct support. Practitioners reported relying on Slack less in year two, as they became more experienced and comfortable navigating the technology. This is one example of how practitioners successfully adjusted to the MM model over time.

While Slack functioned as a boundary object for practitioners able to troubleshoot by viewing past conversational threads, the ability to engage in quick, real-time communication also made it an important tool for continued *joint work at the boundary*. As creative director Nina said, “One of the reasons we set up the Slack community that we have was to be able to answer their questions in real-time. Because they don't have time to sit down and email us at the end of the day. They need to ask us right in the moment.” Allen was one of many teachers to express appreciation for these efforts, “They would get back to you within minutes on Slack, and that was really, really special."

As can be seen in Nina’s statement above, the creation of the Slack community was informed by MM team members’ *perspective-taking*. Slack, as a boundary object, also enabled continued *perspective-taking*, as it facilitated the communication of feedback. Between year one and year two the MM team learned, through feedback from school partners via Slack and other modes of communication, such as phone calls, emails, and research visits to schools, that they needed to create a variety of boundary objects to reach and support practitioners in increasingly diverse circumstances. They attempted to adapt to these needs by creating additional boundary objects, such as a suite of training videos.

Another boundary frequently encountered by practitioners was negotiating the management of the many materials required for MM. This was another area where a number of practitioners reported turning to Slack to try to find recommendations and models from fellow practitioners. To replace or replenish materials, practitioners submitted orders to the MM team. Andy, who managed these material orders, explained, “I think my role as it is exists because of their [practitioner’s] work demands...we're like "Okay, how can we make this shorter and more accessible to them? How can we take away one other thing they have to click on, or one other screen that they have to look at?" Andy’s statement demonstrates how practitioners’ encounters with the boundary of materials management prompted transformation for the MM team through the creation of a new role (his), and *routinization* designed to make the order process easier. Practitioners noticed and appreciated this transformation. According to practitioner Lena, “I have noticed that they've kind of been adding more, more people in to serve different needs, I think, which is good.”

Assessment and grading

Assessment, grading, and tracking student's learning and progress was another common boundary amongst facilitators. School partners commonly expressed an understanding of how traditional assessment clashed with the values of MM. Taylor, a school administrator, said of the training, "It was never, 'By doing MM, you're going to boost standardized test scores in math by 20%'. Because I don't actually think that- that's not the purpose of the program. And I think that's actually, that would be not in alignment with their overall vision or purpose for MM." Practitioners found it challenging to balance the requirements imposed by their school, district, or state, while upholding the core values of MM. Practitioners also reported needing assessment strategies to, as MM team member Amy put it, "have some evidence to show the admin or the school board that it's successful."

Both researchers and practitioners recognized assessment and grading as a shared problem space. While the MM team was aware of school partners' challenges with navigating assessment and grading in their MM implementations, there was ambivalence about accommodating school grading policies that were not aligned with MM's core philosophies about youth learning. One member of the MM team noted that while the team was aware of the tension and frequently discussed ways to mediate it, he felt that ultimately there wasn't a willingness to compromise on certain ideals. The team hoped, instead, to try to shift school partner's thinking on the issue as much as possible. As Eric, a leader within the MM team said, one of the goals of the partnerships was to address, "the surface concerns about schools, like around, maybe, grading and assessment and standards, and helping them pivot to see that MM has different strengths."

While a number of practitioners discussed struggling with the relative lack of support they received with assessment and grading strategies, there was also evidence of practitioners developing *hybridized* assessment practices that bridged the ideals of MM and the requirements of their school or district. For example, one teacher, Adam, reported:

> I remember asking a little bit last year about grading. I didn't get a lot of answers, but I understand why. It's so hard to figure out a grade for...how do you judge somebody on their creativity? You just can't. Or I don't think you can fairly. So I try to find a way to do it sideways, so make them post their work and then I at least can see that they're working with something creatively. No I didn't necessarily get the support. I also didn't necessarily- I'm not the type of person that usually asks for that kind of thing. I like to figure that out my own.

Some practitioners were also able to successfully make an argument for a class implementing MM to not have grades, successfully promoting a transformation in policy and practice. Taylor, an administrator, described how even though her charter school traditionally require grades for enrichment classes, the principal decided to forgo grading requirements because, "that's in the spirit of MM." On the other hand, Taylor told us that because of her state's accountability system, test scores matter a great deal, and, "because there's not the direct correlation between MM and kids getting scores, which there needs to be one, but because there's not one I don't think we could make that argument that the money would come from us," to pay for MM after grant funding ends. While Taylor was able to negotiate a no-grading policy in the short term, the lack of assessment strategies or connection to student outcomes threatened the long-term viability of the program at her school.

CT+: Moving from "cajoling" to "clamoring" through co-design

For the CT+ research and design team and the teachers with whom they partnered, boundaries related to teacher recruitment, as well as the design and perceived fit of the CT+ curricular units, prompted a number of dialogical learning opportunities and instances of role negotiation within the partnership. As co-PI Nate articulated during our first interview, "I really want this to be something that teachers are clamoring to use, instead of us really trying to beg and cajole teachers to use. I think we're somewhere in between those two extremes." In an effort to make sense of and overcome this "in-betweenness", members of the research and design team were forced to examine whether their original goal of schoolwide integration of computational thinking into science classrooms was not only feasible, but desirable.

Responding to issues of fit and scale

Between years one and two of our study, key instances of learning at the boundary arose for the CT+ team as they confronted the related challenges of recruitment and scale. Partly stemming from teachers' lack of experience and comfort using computational models in their classrooms, boundaries also arose from a lack of alignment between the researchers' and teachers' goals for implementation and student learning. In particular, research and design team members viewed the CT+ units as an ideal way to engage high school students in computational thinking within the context of science classrooms, while teachers tended to view the units as disconnected from what and how they typically taught. As a result of this disconnect, the majority of teachers viewed their first year of unit implementation as something they did *for* the research team rather than *with* the research team in service of student learning. In other words, the CT+ team was unable to successfully *translate* the intervention in a way that made teachers feel like it aligned with their goals for student engagement.

Speaking to this issue of translation, Daniel, a CT+ researcher, noted that teachers' perceptions of CT+ units as not "fitting" into their typical classroom instruction was in part a matter of framing. On the one hand, he explained, "I think that framing computer science as a separate discipline, [teachers] see it's very workplace relevant, and very modern day, and all those sorts of things--a 21st Century skill and all these hot terms." On the other hand, Daniel stated, "[Teachers] see it as this...separate competency that a student should do. Not a competency that could encourage more science learning or encourage deeper science learning." During the first year of the study, framing seemed to contribute to creating boundaries related to teacher recruitment and perceived fit of CT+ units in science classrooms. By acknowledging that the framing of the project may have stemmed from *and* contributed to "sociocultural differences" (Akkerman & Bakker, 2011), researchers' efforts to better *translate* by reframing the project prompted opportunities for mutual learning at these boundaries.

Specifically, the *shared problem space* of perceived disconnects between researcher goals and teacher goals, exposed the need to better *translate* how and why CT+ was mutually beneficial. Thus, between years one and two of the study, the CT+ research and design team more explicitly connected the computational thinking typology undergirding CT+ to the *Next Generation Science Standards* (NGSS)--the state's recently adopted K-12 standards for science learning. As researcher Holly explained, "We have fairly strong alignment with NGSS. I think that's a big hook, actually, when we're talking with teachers, being able to say that there is alignment there." This *effort of translation*, which framed CT+ units as NGSS-aligned, appealed to participating teachers at a range of stages in their career. For example, Ulyana, a veteran biology teacher, noted that her school was "moving very slowly towards NGSS" and that she could see how CT+ supported the transition "for the older teachers" like herself, who were used to teaching science content via lectures and traditional lab experiments.

Through *perspective taking*, members of the research and design team transformed curricular development practices to respond to teachers' feedback on the usability of CT+ units over time. Specifically, the research team shifted from asking teachers to implement premade curricular units to adapting these units based on teachers' needs and requests. Researcher Kyle explained the significance of this shift, "To me, it was sort of like, wait a second. All of the things that we believe of how students learn best, that's how we should be thinking about teacher learning…For me, it was just like, wait, the way we're thinking about getting this to teachers is not constructionist. If you believe in constructionism, that should change. For me, it was—that would just seem sort of obvious. A co-design process *is* a constructionist process."

The transformative processes of *confrontation*, *recognition of a shared problem space*, and *hybridization* enabled the CT+ team to shift away from implementation of "stand alone" units designed by researchers, toward a process of researchers and teachers co-designing units. Moreover, the move to embrace co-design promoted buy-in and enthusiasm for the CT+ project from the majority of participating teachers. For example, chemistry teacher Denise stated during her final interview, "As a teacher, obviously, if you write your own curriculum, it's yours and you're going to embrace it and love it because you wrote it." Physics teacher Natalie explained, "I feel like I could see more of the purpose of incorporating [computational thinking] into my classroom and the benefit for students where I might not have my first time around." In addition, Ulyana reflected on her experience across years one and two of the project in this way, "Before, I just did what they gave me. Then with this last [unit] that we did, I had a very important role in directing the curriculum. It was their models, but then they changed all of them to meet the scenario that I was already going to use in my class." Through co-design, Ulyana was able to work with the research and design team to construct a phenomenon-based unit that "was more effortless" and "just flowed" with her existing curriculum.

"A very promising direction": Scaling back in order to build up

As members of the research and design team came to view teachers as partners rather than participants in the project, different opportunities for learning at the boundary arose. Co-PI Nate reflected on this "new phase" of the project during our final interview while discussing plans to let teachers "remix" curricular units, "That opens up a whole bunch of new challenges and, I think, also opportunities...Ideally, this means that teachers are taking even more ownership and sharing what they're doing with a wider audience. It also means we have less control over messaging about what CT+ is and why it's important."

Indeed, the decision to move toward co-designing units with teachers brought with it additional opportunities to confront shared problem spaces and transform learning across the CT+ team. Through joint work at the boundary, the research and design team was able to reflect on the feasibility and desirability of their original goal of schoolwide integration of CT+ into science classrooms. By the end of the first year of our study, team members began to realize that their initial goal of schoolwide integration may have been a bit too lofty. While this realization was disappointing in some ways, it also prompted new opportunities for learning.

By the end of year 2, members of the research and design team had shifted their perspectives on the initial goals of the project and were able to reflect on the learning opportunities that arose from confronting the shared problem space of recruitment and fit with a core group of teachers. As project lead Ingrid explained, "We didn't do whole-school implementation at every school, but we learned what were the barriers to that. We learned a way to actually help that along that I think is actually a very promising direction, this teacher co-design direction." Similarly, project lead Hedyeh explained their decision to step back from the whole-school integration model in her final interview:

> 'Cause in the beginning, Ingrid and Luke were trying to recruit these teachers all the time and they were going to schools, having pizza parties. It's just like it wasn't working, you know? 'Cause there was just no relationship there and trying to attack at such a large scale from the bottom-up doesn't make much sense and so, we took a step back. Then it was like...let's build these really close relationships with a couple core teachers and see how that goes and see if we get what Luke called the 'infection model'. Let's see if it spreads and I think that worked super well.

CT+ teachers appreciated the research and design team's efforts to "take a step back" and forge closer relationships through co-design. According to biology teacher Madison, "I think it's difficult to walk in and force people to do things, so the more you can help people integrate certain things into their classrooms, provide that support, and then let others see the magic happen, the more likely [others are] to actually get involved."

While co-design was a tool that supported joint learning at the boundary, the dialogical learning mechanisms of *perspective making* and *perspective taking* played an essential role in supporting the CT+ team's transformation. In particular, these mechanisms of learning enabled members of both sides of the partnership to take up new roles and responsibilities while taking into account the strengths *and* limitations of their partners. As curriculum developer Luke explained, "This is a dance, and to a certain extent, we need them more than they need us." Similarly, researcher Holly spoke of her "ideal" partnership with teachers in the following way, "I don't like the model of us just handing down a unit. I don't think we're—there are multiple people in this relationship and there's expertise across both parties, so I think it's important to have teachers involved; give them the respect that they deserve for what they're doing—what they're bringing to their students".

In order to move toward a more collaborative, mutually beneficial partnership, the university-based team recognized the importance of determining what principles and aspects of the project were "hard and fast" and which were "loose and open" (Luke). As Hedyeh explained: "Alignment is just such a big thing, I think: what teachers think is important content-wise, what we think is important content-wise and CT wise, and pedagogy. What we think kids should be doing and where we expect them to go and how we're imagining the classroom would look and how much to compromise that." This opportunity for joint work at the boundary opened the door for a second phase of research which would more fully examine the affordances and limitations of embracing co-design as a tool for crossing boundaries.

Discussion and conclusion

Fishman & Krajcik (2003) write that closing the gap between capacity and innovation, to make a curricular innovation usable and sustainable, necessitates changes in both the innovation's design and the school contexts. Such gaps become apparent when designers' or educators' goals are blocked, or they encounter breakdowns that require some action to resolve, through what we and others (e.g., Akkerman & Bakker, 2011) have called boundary crossing. In both MM and CT+ we saw *learning* at the boundary that helped narrow that gap to facilitate greater usability, as each of these innovations scaled.

Learning at the boundary took multiple forms in these collaborations. It involved a continual process of *reflection* that informed the creation and iteration of boundary objects for *communication* and *translation.* This process ultimately increased the usability of the curricular innovations by increasing their adaptability by practitioners. For example, boundary objects like Slack prompted *reflection* for the MM team, by facilitating communication about what supports and scaffolds practitioners needed to be successful facilitators.

Some boundaries persisted, even in the face of efforts to cross them and support learning. Differences in the approaches to grading and assessment promoted in schools and innovations persisted for MM, in part due to fundamental differences in philosophy between the innovation's designers and policies in schools. Convincing teachers of the innovation's alignment to local priorities and standards was a persistent problem for

CT+, but not MM. Each team continued to struggle with its own *usability paradox.* That is, designers needed to support a curricular innovation that was not only responsive to teachers' needs and requests but that also upheld the principles that undergirded and motivated their work.

We also found that the type of boundary crossing needed in each innovation depended on the goals of their scaling efforts. What was required to make MM usable for practitioners changed as they scaled, and needed to meet the needs of an increasingly diverse set of partners and contexts that were geographically distal to the team. Due to MM's scale, it had become increasingly necessary for boundary objects to take on this role, as close collaboration with hundreds of partners wasn't feasible for a small team. On the other hand, the CT+ team came to realize that a transformation of their practices around both relationship building with partners, and the development of their curricular units, was needed to create an innovation that was perceived to be usable and valuable by teachers and to push their scaling efforts forward.

In this paper, we have illustrated how scale can be conceptualized and studied as a learning problem, using the lens of boundary crossing offered by Akkerman and Baker (2011). Studying scale as a learning problem is relatively new to the learning sciences (e.g., Cobb & Jackson, 2011), and is still in need of frameworks to help us see elements of the phenomenon of scale. Boundary crossing helps us center specific breakdowns and encounters with difference that require explanation and gives us a language for characterizing different forms of learning that can arise. With that language, we may begin to develop a more robust knowledge base of how to design more effectively for scale.

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