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of the Learning Sciences

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**The Interdisciplinarity
of the Learning Sciences**



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Volume 5

Edited by

Melissa Gresalfi &

Ilana Seidel Horn



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Editors:
Melissa Gresalfi and Ilana Seidel Horn

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Preface

Learning is essential to the human experience. It stands to reason, then, that many academic disciplines, whether explicitly or tacitly, investigate or make assumptions about the nature of learning. The content of what people are learning has profound implications for our understanding of the nature of the process. In addition, the theories that we propose and the assumptions that we hold fundamentally shape the questions we ask, what we notice, and what we design for. Rather than seeing these differences as impediments to progress, the field of the Learning Sciences is enhanced when we build on these debates and disagreements in order to strengthen competing claims and transform these into designs that have significant impact on learning more broadly.

The learning sciences, as a field, has historically focused on interdisciplinarity — to center learning as a phenomenon and interrogate it with different lenses. For ICLS 2020, we wanted to draw on and highlight the ways our understandings of learning can be deepened by revisiting the multiple ways of looking at learning, with an eye toward opening new conversations and enriching existing ones.

With this goal in mind, we invited papers that looked at central topics around issues of learning, with a special interest in analyses that highlight the sociopolitical dimensions of learning and social justice. We focused our collective attention to four areas of inquiry, including learning and identity, teaching, design, and scale, which we hope to examine through lenses of psychology, sociology, anthropology, linguistics, computer science, historiography, critical theories, and philosophy. Some of the research in our field already bridges disciplines, and we welcomed papers that work synthetically about key issues. In articulating these strands, our goal is to offer visions about the topics of research that are relevant to the conference, but they are not intended to limit the possibilities for contributions.

Although the COVID-19 pandemic prevented us from an in person conference this year, we are delighted to share with you the thoughtful, provocative, and groundbreaking scholarship from our Learning Science community.

- Melissa Gresalfi and Ilana Seidel Horn, Eds.

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Complexity and Proximity: Framing School Mathematics Challenges Inside and Outside Metropolitan Areas

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Abstract: We investigated the mathematics-related challenges identified by 50 mathematics leaders across one state, how the leaders framed those challenges, and whether their framings differed across different communities. Challenges were most often framed around standardized test outcomes (as opposed to students' experiences or equity), and this was especially the case among leaders outside of metropolitan areas.

Introduction

Beyond the few pockets of success that have been achieved in enacting high-quality, equitable mathematics teaching (e.g., Boaler & Staples, 2008; Steele & Huhn, 2018), we have, in the U.S., been largely unsuccessful in effecting change in how we do school mathematics at any significant level of scale. Much of what research in the learning sciences and mathematics education (and their overlap) has yielded about supporting mathematics learning has had little influence in many school settings. One change effort in U.S. education that *has* been remarkably “successful” are accountability reforms centered around state standardized testing. This “success” has not been with respect to the ostensible goals of ensuring that all U.S. children—and those historically marginalized in particular—have positive learning opportunities and outcomes (Au, 2016), but rather in shifting discourses and building infrastructure around problems manufactured by setting standardized measures of proficiency (Kitchen, Ridder, & Bolz, 2016). Many of the ways that states and school districts have responded to accountability pressures run counter to the vision for mathematics learning and teaching rendered by the last three decades of research in mathematics education (e.g., NCTM, 2014), and differentially affect different communities (Davis & Martin, 2008). Still, those responses structure the current policy climate in which teachers and others work to achieve particular goals—however narrowly defined—for students' mathematics learning and therefore require our attention if we hope to improve mathematics instruction at a wider scale. As McKenney (2018) argued, “substantial social, historical, and economic factors can render our best research efforts inconsequential if we do not also attend to the factors that shape those settings” (McKenney, 2018, p. 2).

One such “factor” that we are interested in—and one that is of central importance to design-based research and research-practice partnerships—are the ways that those in positions of authority in school districts view and define the problems on which they focus improvement efforts. In this paper we report on our investigation of the mathematics-related challenges identified by 50 mathematics leaders across one state, how the leaders frame those challenges, and whether their framings differ across different communities.

Framing problems of practice

Our analysis is rooted in an assumption that the discourses that district leaders employ to define challenges and strategies for addressing those challenges contribute to maintaining or transforming institutional cultures (Bertrand, Perez, & Rogers, 2015). We view this as a matter of *framing* problems of practice, and are interested in particular in what Benford and Snow (2000) characterized as *diagnostic framing*—describing a problem's underlying causes—and *prognostic framing*—identifying viable solutions or responses to a problem. Across these dimensions, we are interested in the complexity with which district leaders frame problems. In some ways, particularly given the current outcomes-focused climate in the U.S., this complexity is related to what Jackson, Cobb, Rigby, and Smith (2018) identified as different *orientations* among district leaders in how they respond to accountability policies. Rather than taking an instructional *management* orientation, which leads to simply re-configuring human resources in order to produce higher test scores, the leaders with whom they partnered adopted instructional *improvement* orientations, through which they focused on supporting teachers' learning and growth.

Guiding our analysis were the following research questions: 1) What mathematics-related problems of practice do leaders identify and how do they frame them? and 2) In what ways, if any, do leaders' frames differ with respect to community context? In the next section we describe our methods for identifying and interviewing relevant leaders in a statewide sample of 50 school districts in Missouri, and our analysis of those interviews.

Methods

Setting

We conducted our study in Missouri, a state located in the middle of the U.S. and home to more than 6 million people (the country’s 18th most populous). As shown in Figure 1, on opposite borders are the state’s two urban centers—Kansas City to the west and St. Louis to the east, with their surrounding metropolitan areas, approximately 2.1 million and 2.8 million people, respectively. At the other end of the density spectrum, about a quarter of the state’s population live in rural communities. As is typical, perspectives, practices, and access to resources often differ across the state’s different communities.

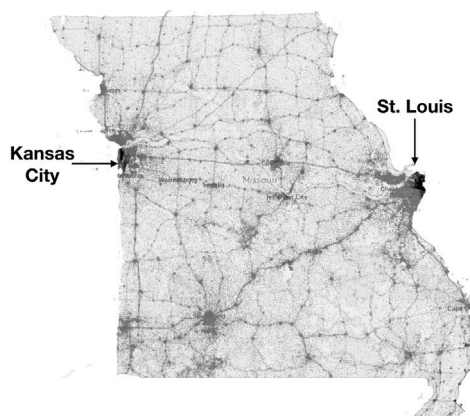


Figure 1. Missouri population density (with the two urban centers noted).

Interviews were conducted during a time that the state had experienced shifts in its standards for K-12 mathematics (from Common Core to the Missouri Learning Standards) and its standardized testing. These policy shifts applied to all districts in the state, regardless of location or size. However, given that there are different kinds of communities across the state, with varying levels of resources, we assumed there could be differences in the problems district leaders identified and the ways in which they framed them. Therefore, we purposefully sampled a range of districts with respect to population and proximity to metropolitan centers, our process for which we describe next.

Sampling and participants

We classified each Missouri municipality in two ways—by proximity to metropolitan centers and by population size. For the former, we categorized municipalities within counties designated as “metropolitan statistical areas” (U.S. Office of Management and Budget, 2010) as “metropolitan” and all others as “non-metropolitan.” For population size, we assigned four categories. We designated the state’s two urban centers, Kansas City and St. Louis, as “urban.” We distinguished between “large” and “small” using a 24,999 cutoff, which is the median of the U.S. Department of Agriculture’s (USDA) “frontier and remote” cut points. And, finally, we applied the label of “rural” to only non-metro municipalities with a population less than 2,500 (a cut-off from the U.S. Census Bureau).

Table 1 presents the size range and the total, sampled, and interviewed numbers of Missouri municipalities in each of the six classifications. Within each classification, we randomly ordered the municipalities, selected the number listed in the “Sampled” column in Table 1 from the top of the list, determined the school district the municipality’s residents attended, and invited one leader in that school district to participate in an interview.

Table 1: District sample and classifications

Classification	Population Range	Total in State	Sampled	Interviewed
Urban Metro	> 200,000	2	2	2
Large Metro	25,000 – 200,000	21	19	11
Small Metro	< 25,000	262	24	10
Large Non-Metro	25,000 – 200,000	6	6	5
Small Non-Metro	2,500 – 24,999	93	24	12
Rural Non-Metro	< 2,500	655	25	10
TOTAL	----	1,039	100	50

Of those initially sampled, we interviewed leaders in 50 school districts combined. In each case, we identified the district leader tasked with overseeing mathematics curriculum and instruction. In total, we interviewed four superintendents, 17 assistant superintendents of curriculum and instruction (or equivalent), 25 other district leaders in curriculum and instruction (18 of whom were in roles specific to mathematics—e.g., curriculum coordinator, instructional coach), and four secondary mathematics teachers. It is worth noting that smaller and/or nonmetro districts were less likely to have mathematics-specific district leaders or, in some cases, even leaders directly responsible for curriculum and instruction.

Table 2 lists average district enrollments and student demographics for 2017 (the year preceding most interviews) for each district classification. Districts that were metropolitan and/or larger had more racially and ethnically diverse student populations than districts that were non-metropolitan and/or smaller. Besides the two urban metropolitan districts, non-metropolitan districts, on average, had a larger percentage of their student population that qualified for free or reduced-price lunch than their metropolitan counterparts.

Table 2: Enrollment and demographic information across district classification

Classification	Avg. Enrollment	Avg. % FRL	Avg. % White	Avg. % Black	Avg. % Hispanic	Avg. % Asian
Urban metro	17,996	99.95	11.23	67.68	16.34	3.28
Large metro	13,975	44.64	56.59	27.65	7.86	2.59
Small metro	3,273	34.32	74.54	11.75	4.88	3.79
Large nonmetro	12,523	56.64	67.23	16.37	6.10	2.69
Small nonmetro	2,853	49.00	85.08	3.40	6.61	0.86
Rural nonmetro	1,067	54.61	91.10	0.46	3.39	0.64

Data sources and analysis

Interviewees participated in one semi-structured, approximately 45-minute, audio-recorded interview. The majority (45) were conducted in 2018, with five in 2017. As the focus of this analysis, in each interview we asked “are there currently any math-related challenges in the district that have been made an explicit focus?” with follow-up questions regarding perceptions of the source of the challenge (or problem) and how the district was currently addressing it.

All interviews were audio-recorded and summarized. We analyzed the summaries using qualitative analysis software to identify what each leader identified as the (a) primary problem of interest, (b) underlying causes of that problem, and (c) responses to the problem. With respect to the last, expanding on Jackson et al.’s (2018) characterizations, we assigned either a “strictly management” orientation or a learning orientation to each leader’s framing. The former focuses exclusively on changing district programs and structures (e.g., adopting a textbook, changing course sequence) and the latter on supporting and developing staff (e.g., professional development, hiring instructional coaches), possibly in addition to more “management”- oriented initiatives. Each summary was analyzed and categorized by the second and third authors, who resolved all disagreements by coming to consensus through discussion. We then looked across all interview summaries to identify themes and patterns across the districts with respect to proximity to metropolitan centers and population.

Additionally, we performed basic regression models to examine relations between districts’ average levels of proficiency on standardized state tests (taken from publicly available data) and the types of problems leaders identified. As an outcome variable we used the difference in each district’s percent of students scoring “proficient” or “advanced” and the state average. We used the comparison to state average, rather than a straight percent proficient, to account for the changes in state testing between years alluded to previously. We constructed two models. In the first, we examined the relation between 2018 proficiency rates and whether leaders described the most common type of problem, student outcomes (see next section). In the second, we added 2017 proficiency rates in order to examine whether leaders’ problem descriptions were related to change in student outcomes. In both models, we controlled for whether the districts were in metropolitan areas.

Results

Across the 50 interviews, four main types of problems were described: student outcomes (n=30), student experiences (n=6), equity (n=3), and unspecified (n=9), with two rural district leaders reporting no problems. Here we summarize how participants described those problems and the orientations through which they framed them.

Problems related to student outcomes

Of the 30 leaders describing outcome-related problems (10 metro, 20 nonmetro), 28 focused on externally-established indicators centered on state or national test scores and two focused on higher-level course taking patterns. Common causes of outcome-related problems identified by leaders included instructional quality, teacher retention, and a lack of curricular alignment—vertical (across grade levels), horizontal (across sections within grade levels), and/or to state standards. Leaders were roughly evenly split with respect to orientation. Those taking learning orientations described providing professional development (PD) to support teachers' content knowledge and/or instruction. Those taking strictly management orientations reported adopting new curriculum materials that better aligned with state standards, implementing student interventions, and/or changing mathematics courses/sequences. Leaders in non-metro districts were much more likely to frame outcomes-related problems with a management orientation: of the ten metro district leaders describing outcomes-related problems, only two took a management orientation, while 12 of 20 nonmetro district leaders did. Thus, not only were leaders in nonmetro districts more likely to identify outcomes-related problems, they were also more likely to take a management orientation in framing those problems.

Problems related to student experiences

Six leaders (5 metro, 1 nonmetro) centered students' classroom *experiences*—rather than outcomes—in describing problems and solutions. Five reported problems of student engagement and one reported a problem of a cohesive K-12 student experience. The five leaders describing goals for student engagement did so in a variety of ways: being excited about or enjoying mathematics; seeing its relevance/usefulness; and engaging through sense-making or personalization. All five reported pursuing pedagogical shifts toward either inquiry-based instruction, a “workshop” model, or instruction focused on problem solving and discourse. Interestingly, all five also cited teachers' mindsets about instruction as barriers to those goals. In response, three leaders reported pursuing learning-oriented solutions such as providing PD or teacher collaboration time, and two described management-oriented solutions such as adopting a new instructional program.

Problems related to equity

Leaders in the three districts (all metro) with equity problems reported addressing an “achievement gap” and/or a “wide range of student abilities and prior experiences,” attributing causes to a systemic lack of resources that under-prepares marginalized students or outside learning opportunities that advantage certain student groups (e.g., early childhood education). All three framed their equity problems with learning orientations. Two described a goal of closing a mathematics achievement gap for particular groups (e.g., African American students; students receiving free or reduced-price lunch), both of whom described providing PD on instructional improvement and either changed the math courses/sequence or provided interventions to support particular student groups. To meet a range of student “abilities,” the third district provided PD, though this followed a previous “management” approach of adopting an integrated mathematics sequence, which was subsequently abandoned due to community and parental pressure.

Unspecified problems

Nine leaders (5 metro, 4 nonmetro) discussed solutions and initiatives without clearly specifying the problem those solutions were intended to address. In other words, leaders in the unspecified category framed their problem as an absence of a solution. Solutions included promoting a particular instructional approach such as inquiry or differentiated instruction (n=3), pursuing vertical and/or horizontal curricular alignment (n=4), or instituting tracking, distinguishing between “college-bound” and “non-college-bound” students (n=2). Although the problems these initiatives were intended to address were not made explicit, some leaders did describe challenges they encountered as they pursued the initiatives. For example, some leaders pursuing instructional change said that teachers' and parents' mindsets about instruction and mathematics were barriers in achieving the instruction they envisioned. Those working on alignment described teachers' content knowledge, inconsistencies in the curriculum materials used, and teacher retention as barriers.

No problems

Leaders of two districts reported not having any problems related to mathematics. One described general problems with student attendance. The other discussed alignment to the state standards, though did not indicate what problem such alignment would address (likely because, as in every Missouri school district, it is an effort in response to new state policy).

Relating problem descriptions to outcomes

Table 3 lists the results of our basic regression analysis of whether there was a relation between the most common problem of those just described—student outcomes—and the very object of those concerns. Controlling for whether districts were in metropolitan areas, when we examined percentages of students scoring “proficient” or “advanced” on 2018 state standardized mathematics tests compared to the state average, we found that outcomes-related framings were associated with lower rates of proficiency (and this was true for 2017 as well). Of course, it may be *because* of low test scores that districts focus on outcomes-related problems. Controlling for 2017 scores in Model 2, then, helps to see whether such a focus is related to change in proficiency rates. With that model, we found no relation between 2018 proficiency rates and the type of problem leaders described, meaning that framing outcomes-related problems was not associated with improved outcomes (although changes may be unlikely after just one year of new initiatives).

Table 3: 2018 difference from state average in percent proficient on standardized tests

	Model 1	Model 2
Variable	Estimate (SE)	Estimate (SE)
Intercept	8.65* (3.70)	1.29 (0.92)
Outcomes-focused framing	-9.93* (3.79)	-0.87 (0.96)
Metropolitan	-1.51 (3.73)	-1.39 (0.89)
2017 Difference from state average in percent proficient	---	0.97*** (0.03)

* $p < .05$; *** $p < .001$

Discussion and conclusion

That problems related to student outcome measures were the most common among the leaders we interviewed is perhaps not surprising given this century’s accountability climate in U.S. public education and recent changes in standards and testing in Missouri. But we do wonder why leaders from non-metropolitan districts disproportionately described outcomes-related problems, and why leaders from smaller districts were more likely to take a strictly “management” orientation to addressing problems. One conjecture is that it might be related to resources and personnel. Larger districts are more likely to have an individual (or office) whose time is dedicated solely to overseeing districtwide mathematics curriculum and instruction. Given that mathematics is their explicit focus (and area of expertise), it could be that these individuals are more likely to frame mathematics-related problems with more complexity than are non-mathematics-specific leaders. Our data suggest, however, that it might not be simply a matter of size. Four of the ten (40%) small metro districts had personnel in mathematics-specific roles, whereas only one of the 22 small or rural non-metro districts had a leader in a mathematics-specific role.

One might interpret a relation between type of problem articulated and district responsibility as a potential confound in our analysis. We view the relation, however, as reflecting the reality of leadership work in different education systems related to size and resources. Specifically, the finding leads us to wonder whether, in districts where there is no leader charged explicitly with overseeing mathematics-related initiatives, identifying and addressing mathematics-related problems may receive insufficient attention, and problems may be framed with insufficient complexity. In particular, we wonder whether for those farther from metro centers, mathematics-related problems are, in effect, being framed “for them” by the system driven by standardized testing.

Regardless of the level of agency with which leaders who framed problems around outcomes were acting, the results of our quantitative analysis suggest that doing so is not associated with changes in the articulated problem. Leaders may be *responding* to disappointing scores on state standardized tests by framing problems around student outcomes (Model 1), but that framing may not (yet) be leading to improvements in the scores of concern (Model 2). To be clear, we do not invoke standardized test scores in our own analysis to assess which types of problem framings are “better.” Our inclusion of this component is only as a consideration point for leaders and researchers potentially engaging in problems related to outcomes: if such framings are not, within their own logic, “successful” (i.e., associated with improved test scores), then there may be more productive problems to address in the design of mathematics learning environments.

Beyond—although likely related to—the particular problems leaders describe, we wonder what implications different orientations (“learning” or strictly “management”) have for how districts address their problems. For example, all five leaders who reported problems of student engagement cited teachers’ mindsets about instruction as barriers to their envisioned pedagogical shift. But only three took a learning orientation in addressing their challenges, while the other two framed their student experiences problem with strictly management orientations. In considering cases like this, we wonder whether changing programs and structures can effectively address problems if adults’ perspectives and practices stay the same.

Given that what gets constructed as a problem is tied to eventual policy designs (Ingram & Schneider, 2005), and that school personnel in positions of authority are the most successful in influencing the direction of work (Penuel, Coburn & Gallagher, 2013), leaders’ framings of mathematics-related challenges are particularly relevant to the work of learning scientists engaged in design-based research and research-practice-partnerships. Our findings suggest that *where* that work occurs matters. Whether it is initiated within or beyond metropolitan areas may have implications for the starting point, the problems of practice around which we design and partner, and the complexity with which they are framed. As such, we raise these questions for leaders’ and researchers’ consideration in relation to the problems they are currently wrestling with, and whether/how they may productively address equity and students’ experiences in addition to outcomes.

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From Correspondence to Prefiguration: Mobilizing Learning Sciences for Alternative Social Futures

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Abstract: In this paper, we propose that Learning Sciences has a special potential to contribute to the making of a collective future aimed at social cooperation and planetary flourishing, rather than goals of unlimited economic growth and global competitiveness implicit in the discipline's inherited logics. To that end, we review studies of learning in contexts of social movements and activist projects, and discuss the movements' centering of *prefiguration* – the strategy of building and enacting alternative sociopolitical relations and infrastructures *in the here and now* with a future-oriented aim of dismantling and transforming oppressive institutions. We propose that *prefiguration* can also serve as a generative orientation and design principle for Learning Sciences and a *prefigurative analysis* of learning contexts can help to orient the contributions of the field towards more anti-oppressive and consciously open-ended sociomaterial arrangements.

Introduction

Learning Sciences (LS), as a field, strives to both empirically understand the fundamental processes of how people learn and engineer innovative educational designs responsive to the complex cognitive, social, and cultural dimensions of learning. This double commitment makes the field a powerful potential contributor to the deliberate shaping of social futures. But to what extent are the discipline's future imaginaries informed by and responsive to the current political realities and struggles, such as climate change, ethnic violence, and the global debt crisis? In this paper, we question the field's implicit future-looking commitments, and propose some alternative centerings aimed at deliberately transforming rather than reproducing the world.

Since its inception, LS has detached itself from school as the primary site of learning, treating the institution as more reflective of the industrial turn in social organization than one based on deep understanding of the processes by which people make meaning or develop expertise. This decoupling from the older, formal, industrial model of education has enabled the field to innovate methodologically and establish the legitimacy of learning experiences in community spaces, at home, online, and other settings. But what, in the imaginary of LS, ought to replace the form of the school? In the Cambridge Handbook of the Learning Sciences, Sawyer writes that “the world economy has changed to an innovation- and knowledge-based economy, and that education must change as well for a society to make this transition successfully” (2014, p.729). Following this imperative, Sawyer paints a potential picture of the future of education: learners of all ages, liberated from the factory-like buildings of schools, enabled by personal tablets and laptops and personalized education software, mastering subjects at their own pace at home or in local learning hubs, occasionally supported by expert learning consultants—knowledge workers who will replace teachers and whose skills will be valued on par with those of lawyers, doctors, and engineers (pp. 727-744). In other words, the (ideal) education of the future shall resemble the lifestyle of the precarious freelance knowledge worker of today.

In 1976, Bowles & Gintis proposed the “correspondence theory” of education, arguing that schools in a capitalist society mirror or correspond to the social and institutional relationships that characterize commercial production and employment, rendering students—the future capitalist labor force—fragmented in consciousness, unprepared for and uninterested in participatory decision-making, and subordinate to the interests of a power-holding minority—in other words, ready for work. In fact, many schools today still resemble the organization of an industrial, hierarchical, nationalist society, churning out unquestioning executioners of uncreative cognitive tasks. But assuming that a science-informed organization of education ought to serve the interests of the changing “world economy”—one that privileges entrepreneurship, innovation, and technocentric knowledge work—only updates the system to correspond to the new capitalist world order—a deregulated, privatized, and neoliberal one.

We resist the taken-for-grantedness that educational configurations ought to serve the needs of dominant economic order, implicit in much of LS scholarship. What if instead of centering “the economy” and the presumption of its infinite growth as a primary organizing principle for designing educational configurations, we dared to prioritize other goals—the preservation and flourishing of ecological and cultural diversity, global peace and social cooperation, and the increased access to leisure and educational abundance for all human beings? How might our vision for a “future of education” shift to meet these priorities? The field's “signature” methodologies of design-based research (Barab, 2006), social design experiments (Gutierrez & Jurow, 2016), formative

interventions (Penuel, 2014), expansive learning (Engeström, 2015), and longitudinal dynamic idioculture projects such as the 5th dimension (Cole, 2006) can be leveraged towards prototyping and articulating the social and institutional relations necessary to enact and sustain these desired futures.

To inform this re-orientation, we can learn from a growing number of LS scholars studying learning in the context of social movements and activist projects. These settings are conducive sites for deepening our understanding of potential alternative social learning arrangements and processes. Unlike schools or other discipline-centric or age-segregated settings that aim to provide access to existing/dominant forms of expertise and activity, social movements are oriented towards actively creating social change, through multi-scaled and often decentralized forms of activity such as political campaigns, media and communication strategies, direct action, and public pedagogy projects. Additionally, social movement projects often critique and iterate their own internal organizational forms (such as by recognizing and addressing racist or sexist discourse among their members) in order to better reflect their envisioned political relations.

In what follows, we review relevant studies of learning in the context of social movements and activist projects and articulate their shared commitment to *prefiguration*—the strategy of building and enacting alternative sociopolitical relations and infrastructures in the here and now with a future-oriented aim of dismantling and transforming oppressive institutions. We then propose that the concept of prefiguration can serve as a generative analytic tool for LS more broadly, to trace, articulate and inform the politically proleptic dimensions of educational configurations. Finally, we use examples from our own work and from the global youth-led environmental movement to demonstrate the application of a *prefigurative analysis*—an interrogation of the means and ends of learning.

Learning in the context of social movement and activist projects

A growing number of Learning Scientists have explored the organization of learning in the context of social movements and activist projects (Jurow et al., 2016; Kirshner, 2008; Curnow, Davis & Asher, 2019; Veá, 2019). Social movements, as sites for learning, are more complex to study than classrooms and other contained educational spaces: projects often span multiple years or even decades, participation may fluctuate as different members join and leave, and traditional roles of teacher/student or expert/novice are not explicitly inscribed as leadership may shift with time and changing priorities of the movements themselves. Movement activities are understood to happen simultaneously at multiple scales — interpersonal, local, network, state, national, and even global. There is also no convenient sequestering of academic disciplines in movement work; instead multiple literacies and ways of knowing get mobilized to inform and advance movement projects. For instance, in analysis of animal rights activists, Veá (2019) traced how movement members developed and spread multimodal representations, such as social media memes and virtual reality experiences, to help broader audiences experience affective connections to non-human animals and incite an ethical response to animal suffering. Here, the multimodal literacy practices were tools not only for expression and communication, but for shifting the scale of the movement’s political activities. Similarly, in a study of local resistance to government austerity cuts in Toronto, Canada, Esmonde, Curnow & Riviere (2014) documented a variety of ways activist members engaged with mathematical reasoning and representation, such as interpreting and generating budget statistics, using measurements and estimates to make flyers and posters, and analyzing online engagement data. Mathematics was an essential and critical aspect— but not the central focus— of activist activities.

Correspondingly, studying who and what learns or changes as part of movements’ activities requires engaging with multiple units of analysis: practices, epistemologies, individual and group identities emerge, solidify, get modified, become standardized, and spread across networked activist sites. For example, in their study of a campus-based environmental justice group, Curnow, Davis & Asher (2019) documented the processes of politicization among members. In particular, they noted how different participants learned to see and work against marginalizing processes within the movement itself, such as by facilitating “go-arounds” to ensure more equitable vocal contributions from all members, orienting towards relational ways of knowing and being in solidarity with indigenous communities, and introducing productive theoretical and political concepts such as “standpoint feminism.” The taking up of new practices and epistemologies also influenced some members to take up new political identities within the group, identifying as “radicals.”

While deep and consequential learning occurs as part of movement participation, it happens in the context of meaningful collective action. In his study of learning in three youth activism organizations, Kirshner (2008) noted that “each of the groups organized long-term projects motivated by an authentic problem or task,” ensuring that youth participants “confronted problems whose solutions were ill defined and subject to the constraints of the real world” (p. 91). Whereas authentic, problem-based, and project-based tasks are valued in LS as effective educational approaches in classrooms, responding to actual political struggles in the context of social movements often involves significant behind-the-scenes or “invisible work,” not easily measured or even clearly defined

(Jurow et al., 2016). For example, in their longitudinal participatory research project with a food justice movement, Jurow et al (2016) documented a number of practices that fell outside of the anticipated work of community leaders (known as promotoras) enlisted to support gardening in a neighborhood identified as a “food desert.” This unanticipated work, which promotoras were not prepared or trained for, included troubleshooting technology provided for gardening activities, counseling residents on personal domestic violence and health issues, and marketing the positive impact of the organization to the public. This project also demonstrated the potential of a research-practice partnership between LS and a social movement to support the design of a software tool that articulated and made the invisible work visible, to facilitate its execution, and to increase the community leaders’ technical literacy and fluency.

Because movement work spans multiple physical spaces and temporalities, the boundaries of where and when learning happens in social movements become blurry and stretched. In their case study of an activist youth media project, Ferman and Smirnov (2016) argued that beyond the teaching and learning of media skills and literacies involved in producing a youth-led news show, youth and adult members engaged in significant amounts of behind-the-scenes work and learning required to execute it, including institutional partnership building, developing infrastructures for distribution, facilitating community screenings and discussions, and mentoring one another on academic, personal, and professional issues. Inadvertently, in researching social movement and activist projects, LS scholars not only articulate “the how” – the empirically observed processes and practices of learning – but grapple with the “for what” – the political aims, “for whom” – the communities affected, and “with whom” – the stakeholders included in or marginalized by the research (Philip, Bang & Jackson, 2018). As Zavala (2016) reflects on doing participatory research with a grassroots campaign to resist the privatization of an elementary school, activist learning contexts “won’t hold still” for researchers, as political understandings mature, collective tensions emerge and get negotiated, and strategic priorities shift. These conditions make it more challenging to center researcher-defined questions. However, what we lose by giving up experimental control, we may gain in ecological validity that comes with studying learning “in the wild” and the reward of contributing knowledge to building more just alternative futures.

We think researchers can learn from the complex, real-world learning contexts of social movements and activist projects. However, we also believe that LS, as a field, in its joint attention to theory, practice, design, and scale has much to contribute to the pressing needs of social movement work. LS research can help social movements diagnose naive political and economic mental models, develop strategies to foster deep conceptual change regarding ideologically thorny issues, effectively diffuse organizational practices across geographically and demographically varied activist network sites, and engage diverse stakeholders in collaborative inquiry and design to build desired alternative social futures. To consciously shape social futures and not just reproduce ones compatible with the dominant economic order, researchers must contend with how alternative sociopolitical relations are made available and enacted within a learning context. The simultaneous holding of an alternative future – one that contrasts with the dominant institutional and political forms – while attempting to enact the desired sociopolitical relations in the present – is the political strategy of *prefiguration*. We explain prefiguration next.

Prefiguration

Marxist, social movement scholar Carl Boggs coined the term prefiguration (1977). Boggs defined prefiguration as the “embodiment, within the ongoing political practice of a movement, of those forms of social relations, decision-making, culture, and human experience that are the ultimate goal” (1977, p.100). Prefigurative strategy was born out of anarchist and anarcho-syndicalist efforts to foster participatory involvement in revolutionary practice; as such, prefiguration contrasts with “statist” revolutionary models such as Leninism, which rely on hierarchical, centralized, and heavily bureaucratic organizational strategies for instituting political change, which end up reproducing the main relational forms of capitalism, including specialized and alienated labor. Scholars have since drawn on notions of prefiguration to analyze more recent social movements such as the alter-globalization movement (Maeckelbergh, 2011), Occupy Wall Street (Graeber, 2013), and Catalan anarchist “social centres” (Yates, 2015), specifying some features and nuances of the prefigurative strategy that may be potentially relevant to and compatible with LS.

Undergirding theories of prefiguration is the union of action and ideology; how one engages in the world is how the world ought to be. As Maeckelbergh argues, “prefiguration is a practice that assumes the ends and the means to be inextricably linked, where the means are the result of past ends and result in future ends, and therefore prefiguration rejects a focus on either means or ends to the exclusion of the other” (2009, p. 90). More than simple platitudes, like “be the change you wish to see” or “practice what you preach,” prefiguration is a mode of experimental actualization that does not distinguish between practice and thought (Van de Sande, 2013), and must involve a change in material arrangements (Yates, 2015). While the actual practices, norms, values and relations

of prefiguration “will look different based on the communities that take it up, via the spaces that make it possible” (Zavala & Golden, 2016, p. 213), movements and projects carrying out the prefigurative strategy tend to share a dual commitment to continuously working to decentralize power through horizontal and democratic decision-making (Maeckelbergh, 2011), and interrupting forms of racial, classed, gendered, colonial, heteronormative and able-ist oppression, including/especially within the movement’s own relations and activities (Luchies, 2014, p.100). Drawing on a study of three activist social centres in Barcelona, Yates (2015) proposed that prefiguration is made up of five dynamic and interrelated processes: (1) collective experimentation, (2) production and circulation of political perspectives, (3) development of new social norms and conduct, (4) consolidation of norms and values in movement infrastructures, and (5) diffusion of ideas and practices to wider audiences and networks. In other words, prefiguration involves the iterative construction of alternative sociopolitical and material relations that simultaneously embody and bring forth the movement’s desired collective future, while staying constantly humble and open to what that future ought to look like, as it can only be prefigurative if it is responsive to and inclusive of all participants.

We believe that the notion of prefiguration, as defined above, is deeply compatible with the goals and methods of LS to better understand the cognitive, social, and cultural processes involved in learning and to use this knowledge to design learning environments to help people learn more deeply and effectively (Sawyer, 2014, p. 1). Bringing the language of prefiguration and LS together, we can think of prefiguration as the iterative design of learning environments that embody desired sociopolitical relations. Because LS contributions are not always conscious or explicit about their political orientations, a commitment to prefigurative LS is a commitment to non-authoritarian, anti-oppressive, and open-ended research and design. And because prefiguration depends on experimentation, development of concepts and practices, consolidation of norms and values in infrastructures, and diffusion of ideas across movement networks, LS contributions of cognitive theories, design principles, implementation strategies, and socio-technical tools can be productively leveraged to serve the needs of prefigurative social movements. In fact, the earlier review of LS studies in the context of social movements and activist projects demonstrates this compatibility: Veal’s (2019) finding of activists’ use of affective power of “embodied encounter” and multimodal literacies to engender an ethical response towards non-human animals is a form of production and circulation of political perspectives (Yates, 2015). Curnow, Davis & Asher’s (2019) tracing of the emergence and take-up of the “go-around” practice in the activist group is a strategic form of anti-oppressive norm, experimentally arrived at and consolidated into the movement’s infrastructure.

An understanding of prefiguration can also invite LS researchers to stay honest and be wary of studies that signal at certain political ends (e.g., “equity”) while implicitly centering, corresponding to, and reproducing dominant social and economic relations and oppressions as the means of “getting there.” As such, we propose applying a kind of *prefigurative analysis* – an interrogation of learning contexts in terms of the prefigurative processes and alternative futures they embody. We illustrate this approach next.

Applying prefigurative analysis

As scholars who have committed our own careers to studying learning oriented towards social justice and political engagement, we decided to pose the prefigurative challenge first to ourselves. We asked: to what extent do the contexts we research embody prefigurative social and political relations? What alternative futures do these contexts envision and make available (if any), which possibilities do they preclude, and what existing political structures and trajectories do they take for granted, center, and correspond to? We also asked these questions of the growing youth-led environmental movement, to examine what prefigurative processes and strategies are involved.

For this paper, we considered several prior research projects the authors engaged in as well as examined interviews and the online presence of youth climate activists. The first case considers an ethnographic study of undergraduate engineering and the ways in which LGBTQ students were working to transform engineering practices to be more accepting of their sexual identities (Weidler-Lewis, under review). The second case compares two technology-mediated civic learning contexts—a school-based government simulation and an out-of-school participatory design of a civic learning platform (Smirnov, 2019, 2016). Our last case compiles the individual acts of youth climate activist and shows how they are part of the social movement enacting a climate-just future. We have chosen to foreground Yates’s (2015) operationalization of prefiguration to highlight the prefigurative work in each.

The limits of disrupting sex-based inequity in a historically male-dominated discipline

Weidler-Lewis began an ethnographic study of the LGBTQ student group, GLE, in order to investigate learning from an intersectional perspective specifically questioning how sex, gender, and sexual orientation were made consequential in undergraduate engineering education. Queer and feminist scholars have long argued that

heteronormativity imposes a false alignment of sex, gender, and sexuality such that it appears natural that a binary biological sex (male, female) is the basis for gender (masculine, feminine), which in turn evokes sexual desire, with heterosexuality the assumed natural order (Butler, 2002). In order to disrupt this alignment, the relations among these axes (sex, gender, and sexuality) must be interrogated. Furthermore, understanding how inequity produced in one axis informs inequity in another axis is imperative from a prefigurative standpoint.

The students in GLE were an ideal group in which to apply a prefigurative analysis as they all had dispositions as problem-solvers and world-changers (author, year). While each student had an individual pathway into an engineering future, collectively they were acting to reorganize the social world to make being openly gay in engineering acceptable. Yates's (2015) operationalization of prefiguration makes apparent the work GLE students engaged to create a new world. A short example is provided for each. The students *experimented* with expressing their sexuality to others by wearing symbols like a rainbow pin or adding affiliations with LGBTQ activism on their resumes. They *circulated* their political perspective by holding informational sessions and promoting the group through t-shirts. Their meetings showcased *conduct* such as stating pronouns to reflect the political position. They reconstituted the material environment, *consolidation*, by having an all-night party in the engineering center and to claim the space as their own. Lastly, they worked to *diffuse* their message by meeting with other similar student groups locally and nationally. The micro-actions within the GLE group can be mapped onto the distal changes in the broader societal discourse that is increasingly accepting of LGBTQ identities in STEM disciplines and is evidenced by national groups that reflect this discourse such as oSTEM and Lesbians who Tech (oSTEM, 2019; Lesbians who Tech, 2019).

Although the students in GLE were organizing for a more equitable future based on sexual orientation, the women in GLE experienced sex-based discrimination and gendered expectations that the men did not. This suggests disrupting heteronormativity and Butler's (2002) heterosexual matrix through sexuality alone is not enough to disrupt the expectations of alignment between sex and gender. This finding does not take away from the prefigurative work the students are enacting, but rather is a reminder that all axes of oppression must be continually interrogated. Also, while the students were working towards having their sexuality accepted within their chosen career trajectory, they were unquestioning of the dominant ideologies present in the engineering field such as its deep entanglement with the military-industrial complex. A prefigurative analysis gives shape to the limits of change happening in this discipline and the directions we must attend to in order to create a more egalitarian world.

Civic participation vs civic futuremaking

Smirnov's work on civic learning in technology-mediated contexts can help illuminate when education spaces orient to prefigurative arrangements (i.e., ones that imagine and embody alternative, anti-oppressive futures) versus arrangements that provide access to the workings of the current societal systems. In her study of a citywide initiative to develop an online social network for youth civic engagement (Smirnov, 2016), the design process was organized to allow the youth leaders to study and critique existing social media platforms, define values and vision for the platform they wished to create, anticipate cultural and communication challenges that might be inherited from other societal contexts, and develop technical features and community routines to counteract these anticipated scenarios. For example, based on their experiences with Facebook and other social networks, youth anticipated that bullying or hateful speech might seep into the positive online space they were developing. In a participatory design workshop, they tested out different ways these interactions might emerge and strategies that could prevent or resolve them, such as clearly highlighting positive community guidelines, creating rules for intervening, and the young designers themselves taking on roles as leaders and community welcomers. As such, in developing a new sociotechnical environment, the youth creators engaged in *experimentation*, *production of new norms and conduct*, and *consolidation* of them in a digital and community infrastructure (Yates, 2015).

Alternatively, another civic education context—an American Government class that engaged high school seniors in a simulation of the U.S. legislative process was differently prefigurative (Smirnov, 2019). On the one hand, students had that the experiential opportunity to imagine, author, debate, amend, and vote on new legislative policies – circulating political meanings and experimenting with bill proposals as potential solutions. On the other hand, the learning environment explicitly mirrored dominant political norms and relations. For example, in the beginning of the simulation, students had to choose a political party (Democrat or Republican) to identify with. They were discouraged by the teachers from identifying as independent or a third-party members because doing so would make them less able to participate in all the processes of the current bipartisan U.S. government system. In conducting their debates, students had to follow traditional parliamentary procedure, which, while facilitating a structured system for contributing perspectives, did not necessarily counteract implicit discursive biases and oppressions based on race, gender, class, and ability. In other words, the learning arrangement was designed for students to learn to effectively participate in the existing activity structures and bipartisan biases of the U.S.

legislative process. While learning how the existing system works also enables someone to see opportunities for reforming it, the simulation did not allow the space and time to encourage this kind of radical re-imagining. It effectively *corresponded* to the dominant political system and its practices, but did not *prefigure* an alternative sociopolitical system.

Shaking the system: Global youth climate activists

Inspired by teen activists taking a stand against gun violence in America, one of the most recognizable youth climate activists, Greta Thunberg began protesting for climate justice outside of the Swedish parliament every Friday holding a wooden sign with “Skolstrejk för Klimatet” (Goodnow, 2018, 2019). When she was eight years old, Autumn Peltier encountered “toxic” water for the first time and realized that access to clean drinking water was not available to all people; since then she has become a clean water activist and at age fourteen was named the chief water commissioner by the Anishinabek Nation (CBC, 2019). Helena Gualinga says she has been fighting for climate justice and indigenous rights her entire life, and uses social media to shed light on the plight of her Ecuadorian community and the efforts to stop oil companies and government repression from land abuse in the Amazon (Brueck, 2019). Although it is easy to assign individual accomplishment to these youth, we argue that they are part of a network of youth activists engaged in refiguration for a climate-conscious, just future.

Each of these youth, and there are many more who could be named, began with imagining a world that could be otherwise. Thunberg *experimented* by not attending school on Fridays and instead held the first version of what would become known as #FridaysForFuture – a global school strike by children and their allies concerned about the future of the planet. As she says, “What is the point of learning facts in the school system when the most important facts given by the finest science of that same school system clearly mean nothing to our politicians and our society?” (Thunberg, 2018). Gualinga’s preferred mode to *circulate* her political message is Instagram, where she draws attention to not only action in her community, but global action such as the youth-led climate strike in New York City in the Fall of 2019 (@helenagualinga, 2019). Thunberg’s use of zero-carbon emitting transportation such as sailing instead flying and Peltier’s new role as water commissioner are examples of the youth activists changing their *conduct* to reflect their position on climate activism. Every instance of #FridaysForFuture, every protest in the streets, and every march for climate activism is a way of *consolidating* this movement into the material environment. Each has spoken before the United Nations, *diffusing* their message internationally. Their actions are implicated in global climate action movements including the 2019 U.S. Youth Climate Strike.

The media attention Thunberg has received over the other youth activists is problematic as it devalues the ways in which all of these activists see the interconnections between economic, racial, and environmental oppression. Thunberg herself acknowledges her position of privilege and she specifically calls out how her home country of Sweden must act on climate change, arguing that developing countries will be unlikely to care about the climate crisis, “if we who already have everything don’t care even a second about it” (Thunberg, 2018). Furthermore, this recognition is part of the reason why she uses her position of privilege to act, despite her inclination to not speak due to her Asperger syndrome and selective mutism (Thunberg, 2018). Gualinga sees the inseparability of indigenous peoples’ rights with climate activism; she argues, “by protecting indigenous peoples’ rights, we protect billions of acres from exploitation” (Gualinga, 2019). Peltier sees access to clean water as disproportionately affecting the poor and non-white communities (Volkov, 2018). As the leader of the youth-led “This is the Zero Hour Movement,” Nadia Nazar says, “together, the youth are shaking the systems that have supported the climate crisis, including racism, patriarchy, colonialism, and capitalism” (Burton, 2019).

Conclusion and implications

Applying the prefigurative analysis to our prior work shows the gaps between the socially just worlds we wish to create and the means by which learning contexts aim to get there. The students of GLE worked hard to transform practices towards greater inclusion of their sexual identities, but more work is needed to dismantle the practices that reinforce the dominant ideologies of engineering related to capitalism and patriarchy. The second case demonstrated that prefiguring civic engagement must be organized to allow for the reimagining of possibilities outside our current two party structure. Incorporating youth climate activists into our analysis shows how climate justice is being globally prefigured: not by one lone Scandinavian, but by youth who are part of collectives working now to make their future possible. We are already beginning to see the effects of their activism materialize: recently, Italy became the first country to make climate the center of its core curriculum, declaring that “the 21st century citizen must be a sustainable citizen” (Horowitz, 2019). It is now our turn to leverage our collective knowledge as a field to support youths’ imagining and make it an enduring reality.

Our call to action is to commit our work to prefiguring alternative futures by centering radical possibilities of dignity, compassion, abundance, and justice, not only to corresponding to economic futures already

dominating our world. This means that when we design for learning we need to make explicit our political commitments rather than claiming neutrality, a stance particularly important in disciplines often regarded as ‘neutral’, such as math or science. If we continue to unconsciously replicate existing systems, we risk reproducing oppression inherent in historically produced disciplines. A commitment to prefiguration might also require us to consciously commit to a research and design process that interrogates oppression in all its forms, because as the youth climate activists profiled in this paper show us, in the act of re-imagining a more just alternative future, all systems of oppression are implicated. Finally, our designs for learning must be purposefully open-ended, allowing for ongoing experimentation and negotiation. After all, the core of prefiguration is an embrace of radical participation, and that is an expertise that belongs to those who dare to go against the common, settled, and even so-called “best” practices.

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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 *legitimizing 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 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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Studying Whole Class Discussions at Scale With Conversation Profile Analysis

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Abstract: Design research aims to generate theories and empirical evidence about complex, contextually bound mechanisms of learning. This often motivated a methodological toolkit that makes use of small numbers of participants in order to closely analyze talk, gesture, and artifacts related to learning. Yet, design research also aims to inform theory and practice on a large scale. This can create tension because the theory and mechanisms generated from small scale studies can be difficult to implement and study at larger scales. In this paper, we aim to contribute to other efforts to conceptualize design research as an act of scholarship that extends across multiple scales by sharing an approach to characterizing whole class discussions across a large number of diverse students, teachers, and settings using an approach we refer to as Conversation Profile Analysis.

Introduction

Design research (DR) is motivated by commitments that often lead to tension and challenges with scale. On the one hand, DR is used to develop empirically grounded knowledge about learning that is contextually bounded in a particular setting, and each setting is “a complex, interacting system involving multiple elements of different types and levels” (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003, p. 9). This commitment often requires data and methods that are carried out in a small number of settings, both for practical reasons and for epistemic reasons. After all, if learning mechanisms are contextually bounded in social, cultural, and historical ways, then research methodologies ought to be specified for a particular time, place, and people (Cobb et al., 2003). Yet, DR also aims to do more than just characterize one learning ecology in a particular setting: It also aims to generate theories about relationships between learning and design that can inform a broader set of contexts. As Sandoval (2014) states, “The basic tension in educational design research is the dual commitment to improving educational practices and furthering our understanding of learning processes” (p. 20).

The first commitment of DR - *improving educational practice* - motivates a methodological toolkit that is attuned to generating evidence about conjectured correspondences between elements of a designed learning environment and evidence of student thinking manifested in discourse, action, or inscriptions in classrooms. Sometimes called conjecture mapping (Sandoval, 2014), this research approach typically relies on video and/or audio recordings of classroom activity and interviews, student artifacts, and field notes to create detailed characterizations of the realized learning environments. This methodology allows researchers to test a particular operationalization of their instructional theories, provide evidence about the relationship between researchers’ instructional theories and learning theories, and can even produce new theoretical frameworks to model relations between instruction and learning (Cobb et al., 2003; DiSessa & Cobb, 2009; Bakker, 2019). Although these data records can include many units of time (days, weeks, months, or even years) they typically stretch across a much smaller number of participants.

The second commitment - *deepen our understanding of the processes of learning* - creates the need to generate knowledge about how these instructional theories take shape when designs are used across larger scales. This is a challenging endeavor, though, because DR is oriented towards understanding mechanisms for learning that can be difficult to measure or study across large numbers of participants. In addition, DR recognizes that designers are always in a state of prolepsis, imagining a learning environment as if it exists while simultaneously acknowledging that learning environments are rebuilt in each local context. This has motivated the development of design perspectives and research methods for implementing and studying innovations at scale. These perspectives include frameworks for co-design with local practitioners around relevant problems of practice (Penuel, Fishman, Cheng, & Sabelli, 2011), designing infrastructures to coordinate goals and learning across different levels of large institutions (Cobb & Jackson, 2011), generating data about design features that are usable and informative to practitioners on the ground (Penuel, Van Horne, Jacobs, & Turner, 2018), and analytic techniques for studying theoretical constructs related to designed learning environments on a large scale (Sherin, 2013). What these efforts make clear is that design as an act of scholarship extends across multiple scales, and that the simultaneous act of designing and researching brings new questions and challenges on a large scale.

One of the challenges of carrying out DR on a larger scale is to generate evidence about mechanisms of learning across large numbers of participants and diverse contexts. In this paper, we present our efforts to address

this particular challenge by describing work to characterize the structure of dynamic—and often unpredictable—*whole class discussions* in a way that can provide insight about conversational structures across large numbers of participants. We have chosen whole class discussions because of the potential they hold for supporting student learning in mathematics classes, but also because of their dynamic nature which often makes it challenging to study them on a large scale. Conversational structures are often a powerful research finding from DR, though typically at a small scale. For example, the structure of Accountable Argumentation provides insight into role different participants take on during a discussion, and how these roles relate to one another through conversation (Horn, 2008). We aim for a contribution similar in form, to better understand conversational structures across diverse students and settings, and to explore their usefulness in advancing our understanding of whole class discussions. Our goals are twofold, both methodological and empirical. First, we aim to describe an approach to DR on a large scale that explores the structure of whole class discussions across large numbers of participants, and to relate this structure to design conjectures about student learning. Second, we argue that our findings provide new knowledge about how whole class discussions about data, statistics, probability, and inference take shape across large numbers of classes, and how variations in these discussions are related to opportunities for students to discuss key mathematical and statistical ideas.

We carried out this project in the context of a large-scale efficacy study of an innovative design for supporting middle school students to learn about data and statistics which we call Data Modeling (Lehrer & Kim, 2009; Lehrer, Kim, Ayers, & Wilson, 2014; Lehrer, Kim, & Schauble, 2007). This context was productive for both our methodological goals and empirical goals because the design principles guiding the curricular innovation have a strong base of empirical support from smaller scale DR studies which we aimed to build from, and our findings inform our understanding of whole class discussions in the Data Modeling units. In our work, we were guided by the following research questions:

1. Do stable patterns of talk emerge in middle grades discussions about data, statistics, and probability across large numbers of classrooms?
2. When are the patterns more or less likely during the course of a whole class discussion?
3. How are the patterns related to opportunities for students to discuss mathematical and statistical ideas related to learning goals?

Whole class discussions in data modeling classes

The Data Modeling instructional sequence engages students with concepts related to data display, statistics, chance, modeling, and inference as tools to answer two (seemingly) simple questions: 1) what is the length of our teacher's arm-span?, and 2) how precise were we as a group of measurers? With these questions as the driving motivation, the Data Modeling materials support teachers to facilitate the development of three epistemic practices in their classrooms: representing variability, measuring variability, and modeling variability. The practices are epistemic because they provide the means by which the original questions (about the teacher's arm span) are answered.

Throughout the instructional design, students have opportunities to *invent* data displays, statistics, and models to help answer their questions, and teachers facilitate *whole class discussions* about the invented approaches to support students to share, compare, critique, and revise their approaches. Each whole class discussion focuses on particular inventions and mathematical ideas, and how these ideas can inform students' practices around representing, measuring, and modeling variability. As students talk about their invented approaches to displaying data and measuring characteristics of the data, the teacher facilitates the conversation to compare different approaches and to discuss how the ideas help them answer the questions that motivate the data.

Teachers are critical in orchestrating classroom discussions that can support students' epistemic learning. Teachers must be able to recognize and sequence student inventions in ways that help students see similarities and differences, and then support students to compare their ideas and approaches, and connect their ways of thinking to conventional mathematical tools (Stein, Engle, Smith, & Hughes, 2008). These conversations are intended to approximate the professional statistical practice of negotiating the value of novel techniques when representing, measuring, and modeling variability. With this in mind, the teacher also has the responsibility to support students in developing goals, values, and discourse norms that are productive in collective activities that resemble disciplinary ways of generating and revising knowledge (Ford & Forman, 2006; Forman & Ford, 2014). As these conversations are carried out interactionally among teachers and students, teachers' facilitation moves and students' contributions create a discourse structure that emerges throughout the conversation.

Methods

Research context

This project was conducted during a two-year, large scale efficacy study of the Data Modeling curriculum (Lehrer & Kim, 2009; Lehrer, Kim, Ayers, & Wilson, 2014; Lehrer, Kim, & Schauble, 2007). The 6th grade classrooms in our study were located in 40 schools in a large, Southwestern United States city. These districts had diverse student populations who represented a wide range of economic, racial, ethnic, and linguistic backgrounds.

This project supported teachers to develop new pedagogical practices using focused and sustained professional development and coaching from teachers with experience using Data Modeling. Teachers participated in 12 days of in-person professional development led by the author of the Data Modeling curriculum materials and middle school teachers with experience using Data Modeling. Six of the days were conducted during a one-week summer workshop and six days occurred on Saturdays during the school year. The professional development engaged teachers with opportunities to explore key mathematical concepts and practices related to data and statistics. Teachers also engaged in activities to support the development of knowledge about student thinking in these domains (Ball, Thames, & Phelps, 2008), and had opportunities to develop competencies in core teaching practices necessary to support whole class discussions by rehearsing these practices with colleagues in the professional development sessions (Pfaff, 2017). During the school year, coaches and project staff supported teachers by helping with planning, co-teaching (and debriefing) class sessions, and providing feedback focused on continuous improvement.

Observational measurement system

To characterize the class discussions, we identified variables (Table 1) related to student contributions and teacher facilitation moves. We developed these variables by drawing on research related to facilitating whole class discussions (e.g., Stein, Engle, Smith, & Hughes, 2008) and from years of design based research conducted in the development of the Data Modeling curriculum (e.g., Lehrer & Kim, 2009). The variables were binary, indicating the presence or absence of the characteristic. We scored these variables in *5-minute, adjacent segments of time* during each whole class discussion. Observers scored a variable if it was observed at least once in a five-minute segment. For example, if one student contributed a comment on the conceptual aspects of a student-invented procedure then the *sInvented* and *sProcedural* variables were scored.

Table 1: Whole class discussion observation indicators

	Variable Name	Description
Student Contributions	sInvented	Did students discuss inventions?
	sConceptual	Did students make comments or ask questions about the <u>conceptual</u> elements of the inventions?
	sProcedural	Did students make comments or ask questions about the <u>procedural or calculational</u> elements of the inventions?
Teacher Facilitation	tInitSelect	Did the teacher select student-invented products to be shared?
	tCompare	Did the teacher compare different student approaches?
	tDiscussQ	Did the teacher use discussion questions?
	tConnectOthers	Did the teacher make connections between students' ideas?
	tConnectBigIdeas	Did the teacher connect student thinking to important mathematical/statistical learning goals?
	tPressExplain	Did the teacher press students to explain their thinking?

Data collection

We observed whole class discussions in Data Modeling classes across two years. During Year 1, 21 teachers participated in the Data Modeling professional development and used the materials in their classes. During the

second year, 39 teachers used the Data Modeling materials and PD. During the two summers of the project, a team of observers conducted weeklong training. After training, observers scored whole class discussions in videos of previous Data Modeling classes, and were required to agree with anchor scores at least 80% of the time in order to conduct live classroom observations. We also led ongoing trainings for four different Saturdays across each school year. During the weekend meetings we would discuss issues arising from the ongoing observations and practice the observation variables for upcoming units. During the second year we also conducted random double observations (by two observers) to maintain an ongoing measure of our agreement. The double observations in live classrooms typically produced more agreement than for the videos, so there were no observers that met the original benchmark but failed to agree at or above 80% during live observations.

We observed classes during six different units that focused on data display, statistics, probability, modeling, and inference. In all, we observed 3,249 5-minute intervals across 302 whole class discussions.

Data analysis

We used a Latent Class Modeling (LCM) approach (Collins & Lanza, 2010) to identify patterns of talk within 5-minute segments of time, which we refer to as Conversation Profile Analysis. In general, LCM is useful because it can inform researchers about groups, or *latent classes*, that describe response patterns with similar characteristics. Moreover, the LCM output is both the estimation of groups as well as the probability that each 5-minute segment response pattern is associated with a particular group. This can reduce the complexity of the response patterns by identifying common categories, but the categories are only informative if they are conceptually meaningful and distinct.

While LCM identifies groups (and probabilities associating each segment with the groups), it does not determine the number of groups. To guide this decision, we made use of a number of criteria, including the Akaike and Bayesian Information Criteria (AIC and BIC) as measures of how satisfactory the model fit the data, the homogeneity and separation of the classes, and concerns of interpretability and parsimony in order to identify a solution that best accounted for the variability in the data. We used the *poLCA* package (Linzer & Lewis, 2011) to carry out the analysis in the R statistical software (R Core Team, 2019). We then qualitatively interpreted the latent class profiles to determine if the categories could be characterized using our understanding of the discussions from previous research on the Data Modeling approach.

After identifying a class solution, we examined how the categories fluctuated across ten-minute time intervals in a conversation through the use of a χ^2 analysis for contingency tables (between latent classes and time intervals). We combined the 5-minute intervals into 10-minute intervals because the 5-minute segments proved to be too difficult to analyze due to the number of segments that can occur in one whole class discussion. We also explored the relationship between the 5-minute segment latent classes and mathematical ideas in the curriculum using the same χ^2 approach (for the contingency table between latent classes and the presence of key mathematical ideas). Since the mathematical ideas are different across the units, we created scoring rules to generalize the variables across units through the use of the following three categories: 1) Mathematical or statistical idea not talked about, 2) Mathematical or statistical idea is talked about, but students did not discuss the epistemic role of the idea, 3) Mathematical or statistical idea talked about in ways that are consistent with the epistemic role of the idea. To interpret the results, we first examined the overall χ^2 test statistic to determine whether there were different frequencies across the cells in the contingency table than would be expected by chance overall, and—if differences were found to be present—then interpreting the standardized residuals for each cell of the table. Because the χ^2 test statistic indicated that there were differences for all three steps, we next examined the standardized residuals to explore which cells deviated most from a random, uniform distribution.

Findings

We determined that a four latent class solution to the LCM provided the best fit to the observation data (Figure 1). These four categories were conceptually and theoretically distinct in the ways they characterized the types of discussion within 5-minute segments. This solution demonstrated good fit in terms of the information criteria relative to three- and five-latent class solutions, adequate class homogeneity and separation, and was satisfactory in terms of concerns of interpretability and parsimony. In addition, the profiles of variables in each latent class were interpretable based on our understanding of the conversations in Data Modeling classes and our theories about how teachers' facilitation moves and students' comments are related to each other. Figure 1 represents the four categories, with each bar corresponding to the estimated probability of an indicator being observed during a 5-minute segment that is classified in the given latent class.

We analyzed the qualities of each latent class profile in order to describe the groups in terms of the aims of the Data Modeling curricular design. After reviewing the data profiles for each latent class, we characterized the four groups as *Low Activity*, *Discussing Ideas*, *Inventing & Discussing*, and *Inventing & Connecting*. There

are some extreme differences in the distribution of probabilities across the latent classes, but we found that close analysis revealed finer grained differences that provided explanatory power in characterizing the nature of dynamic whole class discussions in these settings.

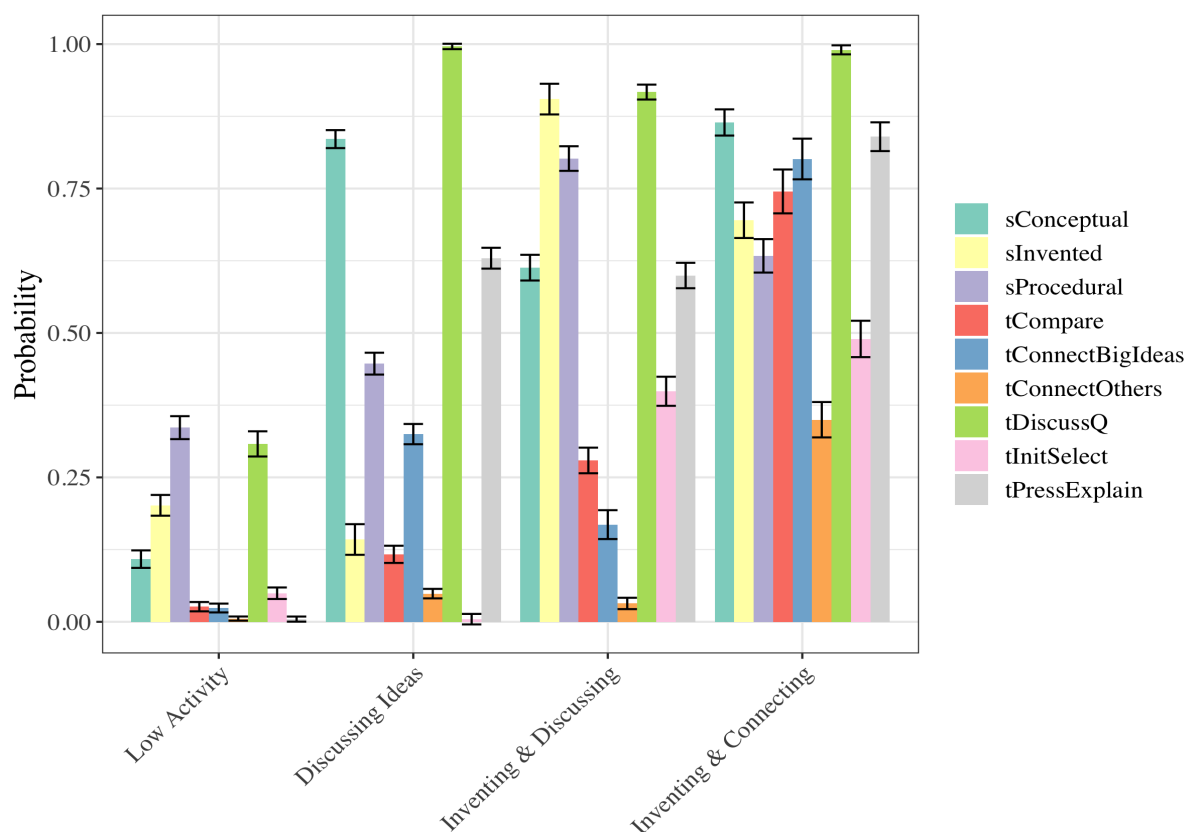


Figure 1. Latent class profiles.

Characteristics of latent classes

The *Low Activity* category represents segments of discussion in which all of the observation variables have a low probability of being observed within the 5-minute segment of time. Our label for this category is not meant to suggest that teachers and students in the class were not engaging in any activity, or any activity that was meaningful to them, but rather that they were not engaged in the types of conversation that the Data modeling materials were designed to support. In *Low Activity* segments, student procedural talk and the presence of teachers' discussion questions were more likely to be observed than any other variable. However, we note that the discussion question variable is scored generously since it is difficult to determine the quality of a discussion question in real time. In *Low Activity* segments, there is a 40% probability of observing students talking procedurally and a 25% chance of observing a teacher using discussion questions. Additionally, there is a 13% chance of seeing students talking about their invented methods. All other variables have less than 10% probability of being observed. The co-occurrence of teachers' questions, students talking procedurally, and students talking about their inventions suggests that the majority of questions about the invented methods were about procedural elements of the methods, which elicited primarily procedural answers.

The *Discussing Ideas* category is characterized by a high probability that teachers are asking discussion questions, students are talking both procedurally and conceptually, and the teacher is pressing students to elaborate their thinking and attempting to connect student thinking to key mathematical learning goals. There is a very high—99% chance—the teacher will ask discussion questions, 61% chance that he or she will press students to further describe their thinking, a 34% chance they will make connections between students' ideas and key mathematical concepts, and a 12% chance that they will work to compare different students' ideas during these segments. For students, there is an 81% chance of talking conceptually, a 45% chance of talking procedurally, and a 13% percent chance of talking about their invented methods. This category highlights why it is not sufficient

to simply determine if students are talking about invented methods when characterizing the conversations, because the probability is identical between Low Activity and Discussing Ideas. However, teacher facilitation moves and student contributions are very different, and in ways that suggest that when teachers are asking questions they are eliciting conversations about both conceptual and procedural elements, and connecting these comments to relevant mathematical learning goals.

The *Inventing & Discussing* category describes 5-minute segments of discussion with the highest probability of students talking about their invented approaches both conceptually and procedurally, and a high probability that the teacher is using multiple facilitation moves in order to support the whole class discussion. There is a 91% chance that students are discussing their inventions, a 79% chance they are talking about procedural aspects, and a 60% chance they are talking conceptually in these segments. Teachers in these segments have a 90% chance of using discussion questions, a 59% chance of pressing students to elaborate their thinking, a 40% chance of intentionally selecting which invention to discuss, and a 27% chance of comparing different students approaches to each other. There is only a 14% chance that teachers connect student ideas to mathematical learning goal, and a 5% chance teachers connect students' ideas to each other. This suggests that these segments of discussion are characterized by students talking about their inventions, and both the procedures that define them and the concepts that the procedures embody. In addition, teachers are supporting this conversation with multiple facilitation moves, but are not working as often to connect students' ideas to each other or to mathematical learning goals.

Finally, the *Inventing & Connecting* category was similar to *Inventing & Discussing*, but with increased probability of teachers working to connect students' ideas to each other and to mathematical learning goals. Students still have high probabilities of talking conceptually and procedurally about their inventions, with a 71% chance they are talking about inventions, a 64% chance of talking procedurally, and an 87% chance of talking conceptually during the 5-minute segment. Teachers also use multiple facilitation moves, with a 99% chance of asking discussion questions, an 85% chance of pressing students to explain their thinking, and a 49% chance of intentionally selecting which invented methods to feature. In addition to these, though, the teacher also has an 81% chance of connecting students' ideas to mathematical learning goals, a 74% chance of comparing different student approaches to each other, and a 34% chance of connecting different student ideas to each other.

Latent classes and design conjectures

Whole class discussions are not static, but rather unfold over time and develop in ways that are sometimes unexpected. Because of this, we hypothesized that the four categories would not be equally likely across the arc of a whole class discussion, but that some would be more likely earlier and others more likely later. Also, the instructional theories that guide the Data Modeling curricular materials suggest that the four categories should be differentially related to the mathematical ideas students talk about. For example, we expected that students would talk about mathematical ideas in more sophisticated ways during the moments of discussion that were assigned to the *Inventing & Comparing* and *Inventing & Discussing* than those assigned to the *Low Activity* category. In this section we report on our analyses to test these conjectures, and the implications for the meaningfulness of the categories to characterize the dynamic, complex conversations.

Table 2: Frequencies of segments in each category across time. Green highlights reference frequencies that are statistically significant in the positive direction and red in the negative

	Class Discussion Timeline					Total
	0-10 Minutes	10-20 Minutes	20-30 Minutes	30-40 Minutes	+40 Minutes	
Low Activity	206	102	95	85	266	754
Inventing & Connecting	32	73	92	93	147	437
Inventing & Discussing	130	157	164	149	306	906
Discussing Ideas	156	191	169	179	457	1152
Total	524	523	520	506	460	3249

We found that these profiles were not randomly distributed across conversational arcs in Data Modeling classes, but were more or less likely at different time points in the discussions. Table 2 reports on the frequencies

of segments classified in each latent class by 10-minute segment, with red cells indicating those where a category is significantly less likely to be observed and green those that are significantly more likely to be observed as judged by a χ^2 test with $p < .05$. *Low Activity* segments were more likely within the first ten minutes of a conversation, but less likely to be observed between the 10-40 minute marks. *Discussing Ideas* was more likely to occur after 40 minutes of conversation. *Inventing & Discussing* was more likely to occur between ten and 40 minutes of the conversations. Last, *Inventing & Connecting* was less likely to occur within the first ten minutes, but more likely between the 20-40 minute marks.

This table also shows that these categories were highly dynamic, as the majority of cells have frequencies that are not more or less than what we would expect if the categories were randomly distributed across time. This suggests that for much of the time, the categories are highly unpredictable, which is not surprising in a whole class discussion that is responsive to students' ideas. Yet the aggregate does suggest a structure that is sensible given our conceptualization of the groups. For example, it makes sense that in the first ten minutes of a class, discussion would be more likely to be characterized as *Low Activity*, as teachers and students might be engaging in informal discussion about past or upcoming assignments or reminders about previous activities and discussions. It is also sensible that discussing students' inventions in ways that attend to conceptual and procedural elements, and that make connections among students' ideas and mathematical learning goals, are more likely between 20-40 minutes of conversation. Although we did not previously have an empirical basis for identifying these segments, it is sensible that it would take considerable time to build the conversation to this point because it takes time for students to discuss their inventions, and for the teacher to have enough inventions in the conversation to compare across them. This analysis also suggests that whole class discussions less than 20 minutes in length are not as likely to spend time discussing inventions in this way.

Finally, we found that some classifications supported discussion about key mathematical ideas more than others. Table 3 shows that 5-minute segments classified as *Inventing & Discussing* or *Inventing & Connecting* were significantly more likely to also have students talking about mathematical ideas in ways that address their epistemic role in making claims with data. *Low Activity* segments were less likely for students to be discussing any of the mathematical ideas. During moments in the *Discussing Ideas* category, students were more likely to be discussing mathematical ideas, but not in ways that addressed the epistemic role.

Table 3: Relationship between discussion category and students' discussion of big ideas. Green highlights reference frequencies that are statistically significant in the positive direction and red in the negative

	How students Talked About Big Mathematical Ideas			Total
	No Big Ideas	Big Ideas Only	Big Ideas & Epistemic Issues	
Low Activity	534	151	69	754
Inventing & Connecting	28	54	355	437
Inventing & Discussing	184	244	478	906
Discussing Ideas	282	428	442	1152
Total	1028	877	1344	3249

These findings suggest that although the conversations are dynamic, and constantly in flux, the relationship between the categories and students' discussion of mathematical ideas is much more predictable than the relationship with time. The relationship with time suggested a general structure, but there was much more randomness compared to students' talk about mathematical ideas. For example, only 5% of the segments of time where students are talking about mathematical ideas and epistemic issues related to the ideas were classified as *Low Activity*. Moments of discussion where students were talking about their inventions, and teachers were using multiple facilitation strategies, were much more likely to also exhibit student talk about epistemic roles of mathematical ideas. This structure aligns with our conjectures about the relationships, providing additional evidence that the categories and our conceptualization of them are useful in characterizing the discussions.

Discussion

The ICLS conference strand on scale attunes researchers to the complexity of implementing and studying designed learning environments across large numbers of participants and contexts. This means *methodological* innovation is needed to drive *conceptual* innovation. The conversation profile analysis we report on here is an example of how these types of innovation can inform each other when studying designed learning environments on a large scale.

Methodologically, indexing discrete characteristics of the dynamic discussions provided a data structure where patterns informed more than the discrete variables could on their own. The Conversation Profile Analysis approach provided a probability model that allowed for the complexity and unpredictable nature of the discussions, but also supported us to find patterns that informed our understanding of the conversations. This is how the *methodological* innovation drove *conceptual* innovation in this project. For example, the students' talk about their invented methods differed in terms of the extent to which they compared different approaches. This distinction was related to mathematical and statistical concepts in epistemically meaningful ways, which is important knowledge that has the potential to inform future teacher support and research. It is possible that these categories may be stable across diverse settings, although more work needs to be done to generate evidence about this question. In addition, the aggregate structure of how the categories unfold across the timeline of a conversation has the potential to inform our understanding of time constraints on teachers and students. For example, the *Inventing & Connecting* category was most likely to occur between 20 and 40 minutes into a whole class discussion, and this latent class was more likely to support students to talk about mathematical and statistical ideas in epistemically congruent ways, this suggests that teachers need to be supported to allot more than 20 minutes of time to carrying out these discussions. This work also suggests many new questions and areas for further work. Are there better indicators to look for during whole class discussions? Can this approach inform the study of other participant structures across large scale implementation? How might we leverage findings such as these to inform future large-scale implementation efforts? Although there are many questions left unanswered, we believe that conversation profile analysis provides a contribution to the challenge of studying designed learning environments on a large scale, and has the potential to inform similar work within the Learning Sciences.

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Spread and Scale in the Digital Age: A Conceptual Framework

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Abstract: Funders, policymakers, and designers are increasingly interested in spreading new instructional approaches to larger numbers of learners in school and non-school contexts. This paper presents a conceptual framework for research on spread and scale in a digital age that accounts for the interactions among environments, organizations, individuals, and educational innovations. Most existing scholarship on scale-up comes from the pre-digital age. Digital technologies often reimagine how learning occurs, requiring new capacities for adults who use them with children and new pathways for scale-up. Drawing on interviews, case studies, and a comprehensive literature review on scale in education and other fields, the framework provides guidance for designers who seek to spread and scale digital learning innovations and for researchers who seek to study these processes.

Introduction

As interest in large-scale learning innovations continues to grow, learning scientists have drawn attention to the urgent need for frameworks and theories that can help designers and other stakeholders configure conditions to support and sustain educators' equitable implementation of innovations (e.g., Penuel, 2019; Philip, Bang, & Jackson, 2018). While it is generally understood that learning at scale is multidimensional (Coburn, 2003; Morel, Coburn, Catterson, & Higgs, 2019), the field lacks conceptual tools that can help investigate the dimensions that enable or hinder the ways in which new ideas and resources are taken up in school and non-school contexts (McKenney, 2018). Further, much of the existing work on scale-up comes from the pre-digital age. Advances in digital technologies have expanded learning possibilities, and digital innovations have also expanded pathways for spread and scale. This paper presents a framework for research on spread and scale in the digital age that identifies factors that influence the processes and outcomes of scale. It accounts for interactions among individuals, organizations, environments, and innovation, and, in doing so, aims to provide conceptual tools for designers seeking to implement digital learning innovations at scale and scholars studying innovations at scale.

The problem of scale—how to move successful ideas, programs and approaches to more people and places—has challenged educational leaders, program designers, practitioners, and researchers for over three decades. While researchers have paid a great deal of attention to scale, efforts to study it have surfaced a lack of clarity around the use of the term. Conceptual ambiguity around what it means to “scale,” “scale up,” “spread,” and implement “at scale” has created difficulties in identifying appropriate research designs, distilling lessons across studies to inform future research, and developing new knowledge about strategies for effectively fostering scale (Morel et al., 2019).

Early research on scale lacked conceptual grounding, often defining scale in terms of the amount or number of users of an innovation. Educational researchers critiqued this view of scale as incomplete and offered more multidimensional conceptions (Coburn, 2003) or focused on student outcomes (McDonald, Keesler, Kauffman, & Schneider, 2006). Yet, the widespread adoption of social and digital media has created new pathways for spread and scale, warranting a conceptual reassessment of scale in education.

Much of what we know today about scale-up and its challenges comes from research and experience in the pre-digital age. New technologies have created exciting new possibilities for learning and scaling learning opportunities, but they have also introduced new actors, new social relations, and new challenges (Clarke & Dede, 2009). On the one hand, the Internet and more recently the explosion of social media have created novel ways for educators to get access to innovative approaches and new means to bring people together across time and space to support their learning. It also brings new ways of conceptualizing what it even means to be at scale, as ideas and approaches from the open source and software design communities move into the educational arena, raising questions about traditional relationships between designers and users. Yet ongoing engagement with digital technology does not always fit easily into the everyday work of front-line educators, which limits its use in supporting substantive and sustainable change. Furthermore, unequal access to wireless technologies and a lack of material and human capital to engage with these new technologies has the potential to exclude the very children that may most benefit from educational innovation. New technology, therefore, requires that we rethink the strategies we use to foster spread and scale. And, it requires us to move beyond visions of achieving scale as a

top-down, unidirectional, and transactional process to consider the ways it can be lateral, bi-directional, and interactive.

Given the rapid pace of technological change, research and writing about spread and scale has not caught up with these new realities. Even when researchers have focused on contemporary examples, they have paid only limited attention to the role that digital media might play in efforts to spread and scale. As a result, designers, educators, and educational leaders seeking to reach youth with innovative learning approaches have little research-based guidance to inform their efforts. Frameworks that can inform innovation implementation for consequential, long-term change are uncommon but urgently needed in the learning sciences (McKenney, 2018). We seek to address this need with a framework that provides research-based guidance to today's practitioners, researchers, and funders who seek to spread and scale innovative educational experiences to learners in school and out-of-school settings.

The argument underlying our conceptual framework is that appropriate and effective strategies for promoting spread and innovation depend upon: 1) how one conceptualizes scale as an outcome; 2) what is being spread; and 3) the organizational, environmental and policy contexts of the people and places one seeks to reach, and 4) a reformer's capacities, institutional home, and position in the broader environment. By identifying the range of things one might spread—and the relationships between them—we seek to bring more clarity and specificity to discussions of spread and scale. By identifying and naming the key elements of context that are consequential for spread, we seek to direct attention to the role of the environment and public policy. And, by identifying a range of strategies that address the technical, learning, cultural, and social structural dimensions of the challenge, we seek to broaden the field's understanding of the set of strategies they can marshal as they seek to spread innovative approaches to diverse settings and learners.

Methods

The framework emerged from a study funded by the John D. and Catherine T. MacArthur Foundation. Since 2006, the MacArthur Foundation, as part of its Digital Media and Learning (DML) Initiative, has invested over \$150 million dollars on development of digital media innovations. After an initial exploratory phase devoted to understanding how learning is changing as a result of digital media, the Foundation supported several innovative programs that drew on new understandings of digitally mediated learning to design model learning systems for youth in school and non-school settings. The DML initiative faced the challenge of spreading these new programs to more schools, libraries, and other youth-serving institutions in order to meet its goal of “creating, at sufficient scale, the conditions to continually test, refine, and expand the ideas, practices, and policies that emerged from Phase 1 and now constitute Connected Learning” (John D. and Catherine T. MacArthur Foundation, 2012). The Foundation leadership asked the authors to develop a framework to guide their strategic thinking about spread and scale as they moved into the next phase of their grant making.

Framework development

We developed the framework over the course of a two-year grant from the MacArthur Foundation. During the first year of the grant, the authors undertook a range of activities to develop a conceptual framework for spread and scale in the digital age. We interviewed 65 strategically identified thought-leaders, researchers, and practitioners in education, high tech, and other fields to gain their insights on the impact of digital technology on pathways for spread and scale. Although the majority of interviewees (40) were associated with DML, including project leaders and staff involved in the work on the ground, additional interviewees with expertise in spread and scale in education and who were not associated with DML were also included.

Interviews were supplemented with 16 days of consecutive observations of DML projects, events, and meetings. The authors spent most of their time learning about Quest to Learn in New York City, Hive in New York City, Chicago, Pittsburgh, and Toronto, and YOUmedia in Chicago, New York City, and the Learning Lab sites. We supplemented interviews and observations at these sites by viewing/listening to multimedia artifacts (e.g., written materials, videos, webinars, podcasts) produced by members of the DML. We visited and observed these innovative programs at various stages of spread and scale to learn about educators' experiences, strategies, and challenges. Our efforts went well beyond the kinds of digital innovations that the MacArthur Foundation funded, to investigate the role of digital media in the spread and scale of a wide range of instructional approaches, programs, and tools: digital and non-digital, school-based and non-school based; instructional approaches and whole school reform models.

Additionally, we conducted a comprehensive literature review of research on spread and scale in schools, libraries, and youth-serving organizations. Finding that the existing research on spread and scale only rarely considered the affordances and constraints of digital media, the authors also reviewed research on spread and scale in digital media environments in other fields. We also conducted a targeted review of research on social

networks, social movements, and the role of technology in organizational change. In all, 75 articles, books, and book chapters were reviewed. We also drew on other works we were familiar with from our backgrounds in new media, digital literacies, organizational change, data use, social networks, and social movements.

We drew on the interviews and the literature review to develop our conceptual framework. Once the conceptual framework began to take shape, we tested its utility by using it to think through the specific case of spread and scale in DML. This dialogue with the issues faced by the DML project helped us to revise the conceptual framework and gain better clarity about individual dimensions of the conceptual framework and the relationship between them.

Finally, we presented the framework to a gathering of foundation staff and key DML leaders. The conversation over a day and a half generated numerous insights, which we subsequently incorporated into the version of the conceptual framework presented here.

Findings

As noted previously, the argument underlying our conceptual framework is that appropriate and effective strategies for promoting spread and innovation depend upon: 1) how one conceptualizes scale as an outcome; 2) what is being spread; and 3) the organizational, environmental and policy contexts of the people and places one seeks to reach, and 4) a reformer's capacities, institutional home, and position in the broader environment.

Conceptualizing scale

The literature review indicated that there are fundamentally different ways of conceptualizing the goals or outcomes of scale. We identified two constructs: spread and scale. Spread we define as the process by which the innovation one wishes to spread reaches more people. Scale we define as the desired outcome of spread. The way in which one conceptualizes scale is important because it influences how one crafts strategies for fostering it and how one knows when it is achieved. Digital media have impacted both traditional notions of scale and introduced new ways of thinking about scale. We identified four main conceptions of scale: adoption, replication, adaptation, and reinvention. While each conception of scale emphasizes reaching increasing numbers of people, organizations or places, they have fundamentally different ideas about what it means to do so: the role of individuals and organizations as they engage with new ideas, tools or practices; how the object of spread changes or remains the same; and the ultimate outcomes, whether it be adoption, implementation, and/or innovation. We describe each conception below.

Adoption: This conception equates scale with achieving widespread use of an innovation. The exact nature of that use, however, is not articulated (e.g., Jenkins, Ford, & Green, 2013). Those holding this conception may also consider an innovation "at scale" when it has achieved a user base of a certain size (e.g., Guadagno, Rempala, Murphy, & Okdie, 2013). In education, those who conceptualize scale in this way primarily focus on the degree to which an innovation is present in a large number of schools or classrooms (e.g., Stringfield & Datnow, 1998). Despite criticisms of this approach (Coburn, 2003; McDonald et al., 2006), some affordances of this approach have also been identified. For example, social movement scholars have noted that widespread adoption can build legitimacy for new ideas and lead to changed practices and beliefs (Strang & Soule, 1998)

Replication: For this conceptualization, an innovation is considered at scale if it is widespread, implemented with fidelity, and produces specific outcomes. Proponents of this approach view student achievement as a primary goal of education and consider widespread impact as a marker of scale (e.g., Slavin & Madden, 2007). The assumption is that well-designed innovations, if implemented with fidelity, will reproduce reliable results in different settings. Replication is conceptualized in two related ways: outcomes and uses. Some view replication in terms of the production of "similarly positive effects in different settings [among] ... a greater number of students" (McDonald et al., 2006, p. 16). Others conceptualize scale as the replicated use of an innovation to reproduce particular outcomes or as the replication of capabilities required to engage in certain types of work (e.g., Peurach & Glazer, 2012). Replication as an approach to scale has become common in educational research and often guides those who view learner outcomes as an outcome of scale.

Adaptation: This conceptualization understands scale as the widespread use of an innovation that is modified according to local context needs and within the bounds of predefined "core principles" of an innovation. Scale according to this approach is "transferring and adapting [a] new set of interrelated innovations to new contexts" (Dede & Nelson, 2005, p. 111). Modifications can be appropriate or inappropriate, with appropriate adaptations adhering to a set of core principles or practices that remain unchanged. As with reformers who view scale as replication, those who understand scale as adaptation are often concerned with the achievement of expected outcomes (Dede & Nelson, 2005). However, appropriate modifications that are attuned to local needs and knowledge, which are perceived as key to an innovation's effectiveness (e.g., Means & Penuel, 2005).

Reinvention: Digital media impact not only pathways to spread and scale, but how we can conceptualize scale as an outcome. Reinvention is a conceptualization that is prominent in the digital media world and is making in-roads into education as well. This approach emphasizes that innovations catalyze further innovations (e.g., Bogers, Afuah, & Bastian, 2010). Rather than reproducing or adapting an innovation, actors recreate the innovation in their local context (“remix” it, in the language of digital media scholars) to create something new (e.g., Jenkins et al., 2013). What the innovation looks like, what it means, how it is used, what problems it solves, and what outcomes it produces is entirely dependent on creative reinvention by local actors. Although the ethos of reinvention is marked in open-source communities and the digital remix culture (e.g., Santo, 2018), reinvention is not an exclusively digital phenomenon.

This typology of scale builds on existing conceptualizations of scale in three ways. First, it suggests that there is a range of legitimate conceptualizations of scale. Second, it expands the catalogue of possible outcomes of scale. Third, it builds upon the dimensions of conceptualization articulated by Coburn (2003). Depth of implementation, sustainability, and ownership likely have continued relevance for these different conceptualizations of scale. However, what these dimensions look like will vary for each conceptualization.

What is being spread

Choosing appropriate strategies to foster spread and scale not only depends on how one conceptualizes scale; it also depends upon what one is trying to spread. In general, the spread and scale literature does not examine how the nature of what is spread impacts spread processes. We found that the nature of what is spread matters crucially to how it is spread. There are different processes and mechanisms at work for the spread for different types of things. Through our review of the literature we identified a range of things that spread (see Figure 1), including *identity* (people’s understandings of who they are, of what kind of people they are, and how they relate to others [Hogg & Abrams, 1988]), *ideas* (a governing conception or principle; a plan or design according to which something is constructed), *tools* (externalized representations of ideas used as mediating devices to shape action [Sherer & Spillane, 2011]), *work practices* (coordinated activities of individuals and groups in socially negotiated and understood ways), *products* (branded items that are meant to increase brand visibility and foster identity and affiliation), *models* (integrated systems of tools and practices in which the relationship between ideas, tools, and practices is specified to some degree), and *organizations* (groups of people who are intentionally structured to achieve a particular purpose). For example, many reformers seek to spread ideas (e.g., principles of constructivist learning). Ideas spread best when they are linked to existing values, ideas, or social trends that have salience at a given historical moment (e.g., Rao et al., 2003). Practices, on the other hand, are difficult to spread and often involve tacit forms of knowledge that can require face-to-face interaction and strong connections between people in order to spread. This suggests that it is imperative to attend to the features of what is being spread.

Contexts where spread occurs

Spread—and strategies to promote it—depends crucially on features of the contexts into which innovators are reaching. Local contexts—including individual and collective capacities, organizational conditions, and environmental and policy contexts—shape how open individuals and organizations are to new ideas, tools, and work practices. These contexts also have conditions that are more or less conducive to learning, change, and innovation. Different contexts also present varied strategic points of leverage for fostering and encouraging spread.

There is a two-way relationship between contexts and what spreads. On the one hand, local contexts influence the dynamics of spread. Simply put, organizational conditions matter for the degree to which individuals are able to engage with new tools, ideas, or practices. On the other hand, ideas, tools, practices, models, and organizations can also influence local contexts, possibly creating greater capacity or a more receptive environment. For example, new tools can foster the development of greater knowledge in a local site and new identities can create greater receptivity to new ideas and practices. In any case, however, what is spread must take account of the existing local context. We represent this relationship with a two-way arrow between contexts and what spreads (see Figure 1).

We define individual and collective capacities as the knowledge, skills, and identities of the people who mediate spread. Individual and collective *knowledge* in a local setting plays an important role in who takes up new ideas, tools, and work practices and how people engage with them in ways that facilitate or inhibit spread and innovation. *Skill* is also a key component of local capacity. In educational settings, for example, teachers and mentors need more than domain-specific knowledge, they also likely need the skill to use tools and practices to design activities for youth, maintain a safe learning environment, and differentiate students’ learning experiences. Furthermore, many tools, practices, and models implicate multiple people in a setting. For this reason, they require the collective ability to coordinate new forms of practice across multiple kids, adults, and

program leaders. Finally, *individual and collective identity* influences people's willingness to engage with new ideas, tools, and practices in the first place (Kellogg, 2011). Individual identity reflects values and practices that a single person takes on independently of others, while collective identity is an identity that is shared within a group or collectivity. For example, "I am a constructivist educator" indicates the development of an individual identity, while a faculty uniting against an overly prescriptive curriculum might assert professional autonomy as a collective identity. Like knowledge and skills, individual and collective identities both influence and are influenced by what spreads.

Organizational contexts play a key role in what and how things spread. By organizational contexts, we mean features of the home institution that influence individual and collective capacities, and the way individuals and groups engage with ideas, tools, practices, and models. Organizational context includes (but is not limited to): time, staffing, materials and technology; presence of expertise and mechanisms for accessing it; organizational norms, routines, and culture; leadership; and organization-level policy and priorities.

Individuals and organizations exist in broader environments that shape their resources, norms, leadership, learning opportunities, and priorities in profound ways. These contexts also influence what strategies are possible for reaching organizations and the people within them. There are several facets of the environment that appear to be consequential for spread, such as the availability of resources and knowledge in the environment, along with regional and national networks that provide access to it.

Finally, individuals and organizations sit within multiple and layered policy contexts that impact their work. For public schools and public libraries, the policy context typically includes the school district or central library system, the city, the state, and the federal government. Policy contexts matter because they provide (and take away) funding and other resources, apply normative pressure, create mandates, legislate work rules, shape market conditions, and set priorities that directly and indirectly affect an organization's work.

Strategies to foster spread and scale

The challenges of scale are not solely technical. The task is not simply creating the right infrastructure to get new ideas, tools, and work practices into the hands of more people, organizations, and communities. Rather, scale implicates issues of learning, culture, and social structure. We identified seven families of strategies that reformers use to address the technical, cultural, and learning dimensions of spread and scale: *communication* (using traditional and new media and rhetorical language to link ideas, tools, and practices with interests and values in a given environment), *capacity building* (developing structures to facilitate ongoing learning), *participation* (providing opportunities for people to actively engage with ideas, tools, and practices), *infrastructure development* (introducing digital and nondigital infrastructures to support spread and scale), *market development* (creating commercial networks and pathways to expand the potential market to reach more users), *policy* (using the power of policy to generate attention to an issue or approach), and *funding* (financially backing the spread of ideas, tools, models, and organizations). While this list is not all-inclusive, it illustrates a range of strategies that reformers might consider. Innovators can use some combination of these strategies to foster the spread of identities, ideas, tools, work practices, models, and organizations (as indicated by the center arrow from strategies to what spreads in Figure 1). However, they can also use these strategies to influence the multi-layered contexts that shape the work, creating more or less fertile conditions for spread and scale (indicated by the bottom left arrow). Finally, these strategies can be spread as well, as indicated by the arrow at the top of the diagram in Figure 1. This happens, for example, when reformers create professional development modules or even whole systems of professional guidance that they then seek to spread.

Who spreads

Strategies to foster spread are orchestrated by individuals and groups. These individuals and groups typically work in organizations that undertake this work either alone or in collaboration with other organizations. As King (2013) argues, "If you want to scale an idea or concept, you can't do it without an organization that is behind the work. Ideas don't enter the mainstream without an organization in place working relentlessly to implement them" (p. 5). As suggested in Figure 1, features of these organizations—the nature of the institution (whether it is a university, foundation, commercial enterprise, professional association, etc.), its capacity, the nature of external partnerships, among others—matter for the kinds of strategies available to reformers, and their ability to carry them out well.

First, the *nature of the institution* is consequential in several respects. Some types of institutions are not legally able to undertake certain strategies. For example, 501(c)(3) not-for-profit organizations are prohibited from lobbying. The institutional home also matters because the social organization of work, organizational mission, and existing work practices influence what is possible. Second, *organizational capacity* plays an important role, including the skills and knowledge of existing staff, available staffing and resources, and the

technical and human infrastructure to carry out a given strategy. Finally, *external partnerships and networks* also enable and constrain strategic choices. Organizations are rarely able to achieve spread and scale in the absence of partnerships. Furthermore, many initiatives are undertaken by a network or coalition of organizations, rather than by a single organization. The nature of these external partnerships and networks, their level of coherence, coordination, the resources, skills, and knowledge they bring to the table, and their position in relation to the targets of spread (i.e., do they create greater reach) influence the nature of strategies an individual or group of organizations can undertake as they seek to spread ideas, identities, tools, and practices.

Dynamic nature of spread and scale

It is important to note that the framework positions scale and spread as dynamic processes. Considering scale as polysemous in nature also opens the possibility that scale is dynamic. Accordingly, the relationships among and between the different dimensions of our conceptual framework likely shift considerably over time. For example, conceptions of scale may shift depending upon where an initiative is in its development. As conceptions of scale shift over time, the strategies that reformers undertake to support objectives must also shift. Existing studies do not make explicit how and why conceptualizations of scale may change, nor how research designs might capture shifts in how an innovation's path to scale is conceptualized.

Conclusions and implications

This framework aims to bring more clarity and specificity to discussions of spread and scale in our advanced digital age. Practitioners, designers, and researchers have been grappling with the challenges involved in spread and scale for quite some time. However, these discussions have been hampered by incomplete conceptualizations about what one seeks to spread toward what end. While the issue of diversity of contexts has been addressed, too often attention has been focused on individual and workplace contexts with less attention to the environment and public policy. Furthermore, discussions of strategies to foster spread and scale have been constrained. They tend to focus primarily on the technical aspects of spread while paying less attention to the diversity of human learning and development, culture, social structure, and issues of power that are pervasive across contexts (Thomas et al., 2018).

The conceptual framework we present here is meant as a starting point to begin addressing some of these issues. By creating a typology of scale conceptions, we endeavor to highlight and name the different goals that might be present in different initiatives. By identifying the key elements of context that are consequential for spread, we seek to direct attention to a larger range of contexts than are typically considered. And, by identifying key strategies that can be used to address learning, cultural, and social structural dimensions of the challenge, we seek to highlight a broad range of strategic actions that innovators can take to foster spread, build capacity, and address the organizational, environmental, and political contexts for the work.

We offer the conceptual framework as a tool to guide strategic thinking for designers and researchers. For example, an initiative could use the framework to analyze the relationship between the individual capacities and organizational conditions necessary for spread, on the one hand, and the current knowledge and conditions in locales one seeks to reach, on the other. This could then inform efforts to develop strategies to adequately address those conditions. Researchers might use the framework to identify key dimensions of the problem of scale to target for inquiry. For example, there is limited research on the conditions that support innovation in schools and informal learning settings, particularly conditions that foreground human diversity. There is also little research that investigates when and under what conditions different conceptualizations of scale are appropriate and effective.

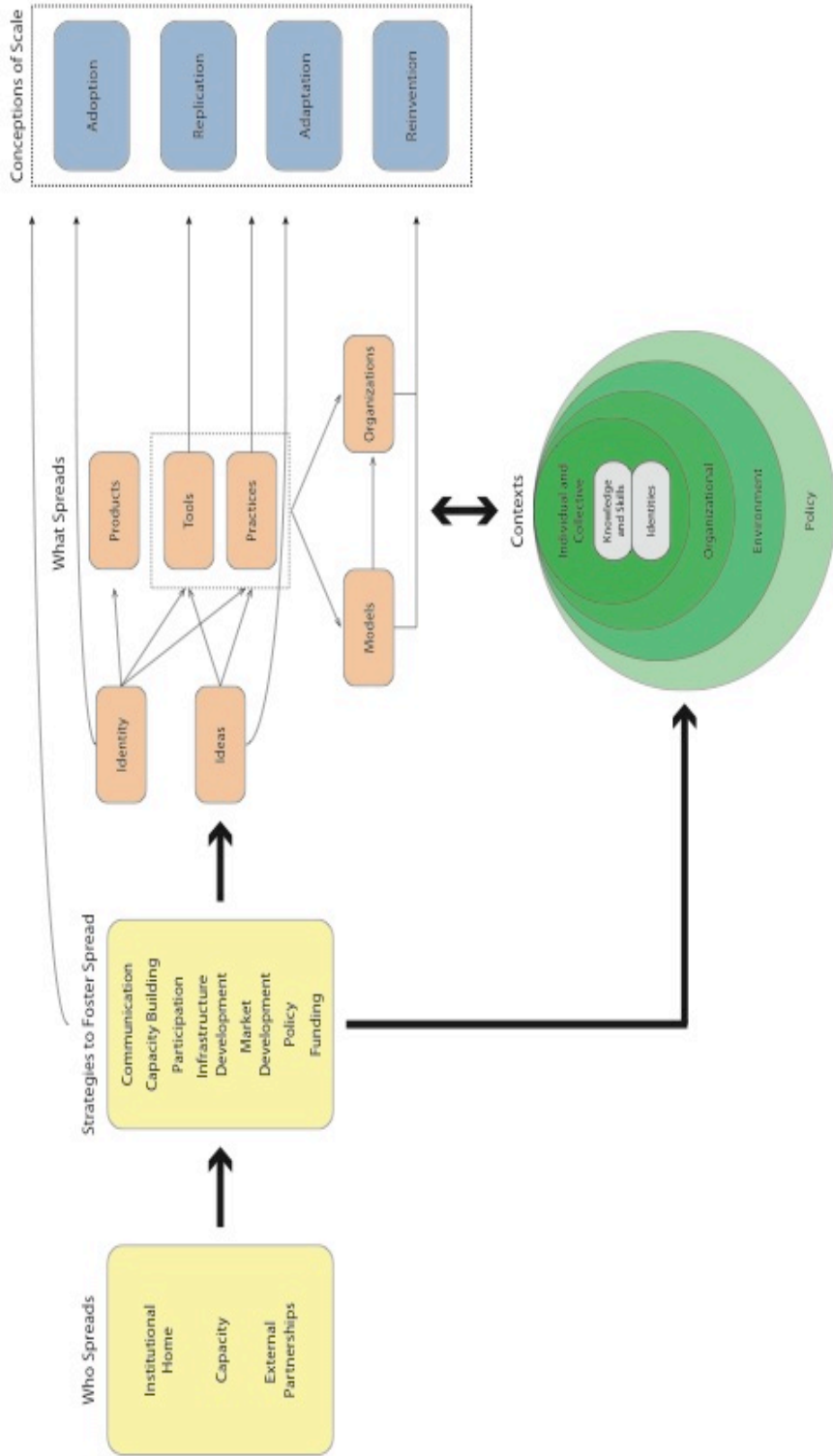


Figure 1: A framework of the dynamic processes of spread and scale.

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Mutual Learning at the Boundaries of Research and Practice: A Framework for Understanding Research-Practice Partnerships

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Abstract: Given the rapid growth of research-practices partnerships (RPPs), we need a framework that helps the field understand how RPPs can facilitate mutual learning for those involved. Drawing on both cultural-historical and organizational learning theories, we argue that learning can happen in RPPs for both researchers and practitioners at the boundaries of research and practice. The conditions for learning depend on the development of boundary spanners, practices, and objects that facilitate joint work. Engaging productively at the boundaries of is moderated by the prior conditions of educational organizations and their research partners. Where mutual learning occurs at the boundaries, we are more likely to see changes in collective knowledge, policies, and routines for participating organizations.

Introduction

Research-practice partnerships (RPPs) are long-term collaborations that aim to promote educational improvement and transformation through the production and use of research (Farrell, Penuel, Daniel, Steup, & Coburn, 2020). Though they have gained in popularity in recent years, significant gaps remain in our understanding of their dynamics and outcomes (Coburn & Penuel, 2016). Addressing these gaps is important because there are significant challenges in developing and maintaining partnerships. Not all partnerships create the conditions needed for mutual learning of RPP participants or longer-term organizational change (Cohen-Vogel et al., 2018; Farrell et al., 2018).

Here, we present a conceptual framework that helps the field understand how RPPs can create conditions that support mutual learning. Drawing on both cultural-historical and organizational learning theories, we argue that learning can happen in RPPs for both researchers and practitioners at the boundaries of research and practice. The conditions for learning depend on the development of a set of hybrid practices, objects, and roles that facilitate joint work. Engaging productively in these practices is moderated by the prior capacity of educational organizations and research partners. When partnering is productive, it increases the likelihood that participating organizations experience organizational learning outcomes. This framework is a useful tool for those looking to start or maintain a partnership, as well as a resource to develop testable propositions that can guide future research.

RPPs as a strategy for educational improvement efforts locally and at scale

Many worry that the innovations from educational research have a limited impact on the lives of educators, students, and families (National Research Council, 2012). Studies have shown engagement, interaction, and sensemaking around research ideas are important for the degree to which they are used in practice (Johnson et al., 2009). Partnerships between practitioners and researchers can help improve the relevance of research by focusing on questions of concern to educators and communities (National Research Council, 2012). In recent years, major investments from federal government and private foundations have helped grow the number of RPPs (Arce-Trigatti, Chukhray, & Lopez-Turley, 2018).

Though the evidence of impact of RPPs is small, it is growing. RPPs can support the design of interventions that improve student achievement (Booth et al., 2015), support more equitable participation in classroom learning (O'Connor, Michaels, & Chapin, 2015), and enhance the quality of teaching (Penuel et al., 2017). Research shared from an RPP can also contribute to shifts in district routines and policies (Farrell, Coburn, & Chong, 2019) and support implementation of those policies in schools and classrooms (Henrick, Klafehn, & Cobb, 2018). Yet, RPPs can face significant challenges in their work, including leadership turnover, different paces of work, and struggles engaging key decision makers with authority to act on findings (Cohen-Vogel et al., 2018).

Existing conceptual frameworks have limited our ability to understand the conditions under which RPPs are productive. For example, one dominant framework for relating research and practice rests on the metaphor of translation: RPPs are viewed as a means for making it easier for researchers to “translate” research findings into practice. Yet, focusing on translation activities of research is an overly simplistic way to characterize the breadth of activities of an RPP. It does also not account for the multi-directional nature of learning in a partnership, where researchers gain insights from their work with partners (Greenhalgh & Wieringa, 2011). Other frameworks draw on the idea of “two communities” of research and practice (Caplan, 1979). Here, practitioners and researchers are cast as two separate communities that are poorly connected, operate under different rules, speak different languages, and motivated by different rewards systems (Farley-Ripple, May, Karpyn, Tilley, & McDonough, 2018). While this view does account for bidirectional sharing between groups, it does not attend to the organizational conditions that shape researchers and practitioners’ abilities to engage productively in joint efforts or to the fact that many researchers have been and continue to be educators who are familiar with the world of practice, or vice versa (Newman, Cherney, & Head, 2015).

The field needs a framework for understanding how practice and research organizations can create conditions for mutual learning within partnerships, given existing organizational conditions. This is the gap our framework aims to fill. We began with relevant theories from learning sciences and organizational studies. We draw on ideas from cultural-historical accounts of learning (Engeström, Engeström, & Karkkainen, 1995; Engeström, Engeström, & Kerosuo, 2003; Suchman, 1994), particularly the ideas of boundaries, boundary practices, and boundary objects (Akkerman & Bakker, 2011; Star, 2010; Star & Griesemer, 1989). We then introduce the idea of absorptive capacity (Cohen & Levinthal, 1990) to understand the conditions under which a partner organization is likely able to learn from partnership interactions, and with what implications for organizational learning outcomes.

Learning at the boundaries of research and practice

We conceptualize joint work in RPPs through the lens of learning at the boundaries of research and practice through boundary practices, objects, and spanning. The existing conditions of the partnering organizations likely influence the encounters at these boundaries, with consequences for organizational learning and the production of relevant research for the field. We explore each of these claims below.

Navigating boundaries of research and practice

While engaged together in an RPP, participants encounter multiple boundaries where the world of research the world of practice meet. Here, boundaries refer to cultural encounters in which participants who need to negotiate differences in terminology, context, practices, or expectations engage with one another, which is likely to engender conflict over roles or understandings (Denner, Bean, Campe, Martinez, & Torres, 2019). The concept of boundaries is a particularly useful one for understanding how cross-organizational, professional collaboration is accomplished (Akkerman & Bakker, 2011; Engeström et al., 1995; Suchman, 1994).

Whether partnerships stall and disband or move forward and are sustained depends on what happens when partners encounter boundaries. Boundaries here refer to sociocultural differences that give rise to “discontinuity in action” or halting of a partnership’s work (Akkerman & Bakker, 2011, p. 133). Though discontinuity implies a threat to a partnership, such moments of discontinuity are fundamentally opportunities for learning for those involved (Engeström, Engeström, & Kärkkäinen, 1995; Spinuzzi, 2011; Wenger, 1998). As partners navigate discontinuities, they may develop new understandings, practices, and identities that transform their work together. When productive, RPP engagements can create opportunities for learning, as people engage with and make meaning of ideas and tools within their own context and based on past experiences (Coburn & Stein, 2010). An RPP’s ability to collaborate and respond to challenges productively is due, in part, to the “boundary infrastructure” (Bowker & Star, 1999), a network of structures or practices that help overcome difficulties. Particular roles (boundary spanners), interaction structures (boundary practices), and artifacts (boundary objects) play roles in supporting partnerships in creating successful conditions for mutual learning.

Boundary spanning

Boundary spanning refers to an individual’s transitions and interactions across different sites of practice (Akkerman & Bakker, 2011). In the case of research–practice partnerships, this might entail a researcher going to a community center to meet with families, or it might involve a district leader trying to map or represent an unfamiliar territory of the district to researchers in the context of a partnership meeting (Penuel, Allen, Farrell, & Coburn, 2015). Individuals who move across boundaries and facilitate connections between groups are called boundary spanners or brokers (Hopkins, Weddle, Gluckman, & Gautsch, 2019; Mull & Adams, 2017). Within a partnership, certain individuals may emerge as boundary spanners, or they may be designated for the role (Levina

& Vaast, 2005). However, boundary spanning can occur outside of an official role. It is the doing or enactment of the roles – or boundary spanning practices – that matter more than an official designation.

Boundary spanners can take a number of actions to facilitate mutual learning in boundary practices (Ansett, 2005; Mull & Adams, 2017). Boundary spanners can help *create social networks*, improving communication pathways within the partnerships. Such pathways facilitate learning because complex ideas about practice that are typically the focus of partnerships' joint work require intensive communication (Hansen, 1999). Boundary spanners can *reframe ideas* from one group into ways others may understand more easily (Penuel & Gallagher, 2017) or help others see how different organizational goals might overlap (Davidson & Penuel, 2019). Boundary spanners may also be a resource for *managing or repairing partnership relationships*, particularly critical when there are missteps or histories of mistrust (Booker, Conaway, & Schwartz, 2019). They can also help *broker connections* to researchers and research beyond the direct partnership (Hopkins et al., 2019).

Boundary practices

Boundary practices are partnership activities that bring together multiple participants from the domains of research and practice. Boundary practices are interactive, hybrid activities that neither partner would typically engage in within their home professional or organizational practice. Boundary practices provide a forum where research-based ideas, tools, and processes enter into educational organizations and where research teams engage with ideas and constraints from practice. Examples of boundary practices in RPP might include co-design meetings (Bell et al., 2016), Plan-Do-Study-Act cycles of networked improvement communities (Russell et al., 2017), or joint meetings where researchers share findings with practitioners (Moeller, Seeskin, & Nagaoka, 2018).

There are several features of boundary practices that may create conditions that support learning within the partnership. First, a boundary practice can be structured in ways that *elicit and make use of relevant perspectives and knowledge of participants*. For example, a design circle involving parents seeking to re-design workshops to promote parent engagement can surface parents' experiences directly about barriers to involvement (Ishimaru & Bang, 2016). Through formally established practices for making expertise visible, participants can bridge what they had brought to the table with the work of the others and come to appreciate the other's unique contributions (Campano, Ghiso, & Welch, 2016). Boundary practices that are designed with explicit attention to differences in social power are may be especially important in an RPP (Bang, Medin, Washinawatok, & Chapman, 2010). Not doing so can unwittingly reinforce inequality among participants and diminish the voices of particular partners (O'Connor, Hanny, & Lewis, 2011).

Second, boundary practices can *establish roles, responsibilities, and expectations* for participants that clarify what is expected of participants and how they can contribute to the activity as a whole (Farrell, Harrison, & Coburn, 2019). Such roles can be specified ahead of time, but they can also emerge as people become more comfortable with participation. When people create expectations and fulfill them, trust can develop, which is essential for productive partnering (Rousseau, Sitkin, Burt, & Camerer, 1998).

Boundary objects

Boundary objects are material and conceptual tools used in a partnership that are critical for joint activity (Akkerman & Bakker, 2011). Something is a boundary object if: a) it serves a *coordination function* between different groups that work in different organizational settings; and b) it *mediates activity* within each organization, albeit differently for each (Star, 2010). Both characteristics—coordination and mediation—are necessary for something to function as a boundary object that can develop and maintain coherence across intersecting groups (Bowker & Star, 1999). Boundary objects can also serve to make aspects of partners' *practices and expertise visible*, and it can carry some of the meaning of other settings with it within a partnership.

An example of a boundary object and its functions within an RPP comes from Johnson et al. (2016). Here, researchers, teachers, and districts leaders together engaged around a set of mathematics tasks and associated rubrics which served as a boundary object. For teachers, the tasks and their analysis functioned as resources to support student learning. For district leaders, the tasks and their analyses were a means to help teachers understand new standards. To the researchers, educators' analysis of the tasks and subsequent professional development was a line of research to which they could contribute. Initially, the tasks were rated using a researcher-developed task rubric which the teachers were expected to use, but most did not. Therefore, it ran the risk of serving as a "boundary roadblock" (Carlile, 2002). Eventually, though, the rubric did serve to coordinate and mediate activities, thus becoming a boundary object in use, once the practitioners adapted it to their local needs. Other examples of possible boundary objects central to RPPs might include on-track indicator reports (Allensworth, 2013), visual diagrams that represent a partnership's theory of change (Thompson et al., 2019), or co-designed classroom materials (Kwon, Wardrip, & Gomez, 2014).

Organizational conditions that support learning at the boundaries

Not all practice or research teams are equally positioned to engage productively in the learning opportunities at the boundaries of research and practice. Organizational theory, particularly the concept of “absorptive capacity,” provides some useful ideas to help us understand what kinds of conditions are necessary to support mutual learning at boundaries. Scholars Cohen and Levinthal (1990) introduced the idea of absorptive capacity, describing it as an organization’s “ability to recognize the value of new information, assimilate it, and apply it” (p. 128).

Here, absorptive capacity refers to an organization’s ability to learn productively from its interactions with external partners (Farrell & Coburn, 2017; Farrell, Coburn, et al., 2019). Although the term “absorptive capacity” may suggest a metaphor of unidirectional knowledge “absorption,” we conceptualize absorptive capacity in interactive terms. In other words, it involves making sense of information and construct new knowledge through activity and social interaction within boundary practices (Lane, Koka, & Pathak, 2006; Zahra & George, 2002), engaging relevant prior knowledge, communicating internally, strategic knowledge leadership practice, and mobilization of resources. These conditions likely matter for all partners in an RPP.

Engaging relevant prior knowledge

Educational systems are complex systems, and people’s positions within those systems give them a particular view of problems and opportunities for change (Campano et al., 2016). The degree to which engagement in an RPP supports learning depends, in part, on the knowledge, expertise, and perspectives participants bring to the interactions (Cohen & Levinthal, 1990; Szulanski, 1996). Relevant prior knowledge is critical, as knowing something about a given issue enables an organization to better discern the value of knowledge from partners and be able to incorporate it into practices. This is not any and all expertise on the part of the partner(s), but instead, the knowledge or expertise relevant to the goal(s) of the partnership. The potential for learning is greatest when knowledge resources from the educational organization and research partner are complementary, that is, similar enough to enable communication and facilitate learning but dissimilar enough so that there is value to the partnership (Cohen & Levinthal, 1990).

Available expertise in the partnership matters for mutual learning at the boundaries for several reasons. First, the nature and complementarity of prior knowledge shapes the ability of RPP members to engage in joint work at the boundaries. For instance, the degree of complementarity may also be important for productive work together. Too much overlap in expertise, and there may be little for groups to learn from one another. If there is a wide distance between the sources of expertise, however, RPP members may struggle to span boundaries effectively. Interpretations of shared tools may be too divergent to serve as an effective boundary object. Or, divergent knowledge sources may require more extensive or elaborated boundary work to make explicit expertise to support shared learning.

Engaging in internal communication

The communication pathways within partner organizations matter for the potential for learning at the boundaries of research and practice. First, communication pathways within organizations can influence the expertise available to the partnership. For example, in a school district with highly siloed departments that do not communicate frequently, the RPP may have limited access to perspectives to inform the problem at hand – particularly an issue when the partnership’s focus requires multiple perspectives. In contrast, strong within-organization communication may better at ensuring there are relevant sources of expertise and perspectives in the boundary practice. Internal communication pathways can also support the representation of others’ perspectives even if they cannot be direct participants in the boundary practice.

Strong internal communication pathways within organizations can also play a role in supporting successful boundary spanning across partner organizations. What makes someone a good boundary spanner is not just that they have extensive ties to the outside organization but also strong ties within the organization to others (Tushman & Scanlan, 1981). People with strong internal ties who play boundary spanning roles can help with work at the boundaries because it facilitates their knowledge of the work or perspectives of different team members. Conversely, people with weak internal ties may be unaware of the activities of others, leading to missed opportunities for boundary crossing work within the RPP.

Strategic knowledge leadership practice

RPP leaders set an RPP in motion and provide important oversight both within and beyond the partnership. A specific type of leadership, strategic knowledge leadership (SKL), is key to these efforts (Van den Bosch, Volberda, & de Boer, 1999; Volberda et al., 2010). Dimensions from past studies of strategic knowledge leadership in RPPs include 1) assessing current internal expertise, identifying gaps or potential opportunities, and scan the field for available partners; 2) designing boundary practices; 3) creating or supporting communication

pathways that make that expertise available to the partnership; and 4) anticipating how knowledge from the partnership can connect to current routines, policies, or practices with the organizational setting (Farrell & Coburn, 2017; Farrell, Coburn, et al., 2019).

SKL practice likely matters for RPP members' ability to engage productively in boundary practices. First, strategic knowledge leadership is involved in launching partnerships before boundary practices can begin in earnest. In an RPP, this might involve having a sense of available expertise in their own organization and identifying partners who may have complementary knowledge. Then, SKL can play a role in the authorization, design, or refinement of boundary practices (Farrell, Coburn & Chong, 2018). The design of boundary practices can create different opportunities for surfacing and synthesizing different areas of expertise and knowledge (Potvin, Kaplan, Boardman, & Polman, 2018).

SKL practice and boundary spanning are also interrelated. Because SKL involves attending to the expertise available to the partnership, a leader with SKL may be effective in acting as a boundary spanner by linking different stakeholders together or helping to build connections between participating organizations to expand available sources of knowledge. This can involve identifying gaps of available expertise and bring other perspectives to the partnership when necessary or in replacing people when they leave the partnership.

Mobilization of resources

Partnerships require organizational resources – budget, time, staffing, materials – to engage productively at the boundaries of research and practice. The work of developing and engaging in boundary practices require devoting a budget that supports the time of key stakeholders. In some cases, resources support dedicated staff to support coordination of boundary practices or to serve in boundary spanning roles. Resources can also be required to the develop or sharing boundary objects integral to the work. When partners underestimate the resources needed, interactions, it can undermine the effectiveness of work at the boundaries, particularly if boundary spanning work is seen as additional to RPP members' current responsibilities (López-Turley & Stevens, 2015).

Outcomes of mutual learning at the boundaries

We draw on organizational learning theory to broadly conceptualize the outcomes that result from the mutual learning in RPPs. We focus on outcomes at the organizational level as they could potentially outlast the learning of any individual educator or researcher. Organizational learning is the degree to which a participating organization integrates ideas from their RPP into collective knowledge, routines, and policies that guide their organization's behavior (Feldman and March 1981; Levinthal and March 1981; Levitt and March 1988; March 1991). We hypothesize that both practice and research organizations can demonstrate organizational learning as a consequence of mutual learning in RPPs.

Shifts in collective knowledge

Mutual learning at the boundaries of research and practice might involve *shifts in collective knowledge*. Levitt and March (1988) argued that one of the most powerful consequences of engagement with new ideas and experiences is the “transformation of the givens,” or the “redefinition of events, alternatives, and concepts” (p. 324). For example, researchers stand to gain new collective understandings about the issues in education, based on the on-the-ground conditions and implementation challenges (Cohen-Vogel et al., 2015). Researchers may acquire new collective understandings around partnering, and what it takes to do the work of partnering with their practice organization (Holmqvist, 2003; Larsson, Bengtsson, Henriksson, & Sparks, 1998). Similarly, educators may gain new ideas about the issues in education. For instance, Coburn et al. (2008) described how one partnership shifted district leaders' thinking around professional development – from one-time trainings to professional development that was ongoing and situated in day-to-day work.

Shifts in organizational policies or routines

Learning at the boundaries could contribute to *shifts in the organizations' policies or routines*. We define policy broadly, including formal policies as well as rules, plans, and guidelines. In the case described above, the organizational learning for the educational organization went beyond new collective understandings about professional development (Coburn et al. 2008); the district also changed its policy regarding teacher professional learning. Instead of a series of workshops throughout the year intended to provide follow up for intensive institutes in the summer, the district leadership reconfigured the calendar so that students had a late arrival four times during the year to allow for time during the school day for ongoing, situated professional development. For research organizations, while a research organization may adjust hiring or evaluation policies to honor partnership efforts. Research organizations can create new routines for co-presenting with their practice partners (Penuel & Gallagher,

2017). Others create new roles that help with facilitating learning at the boundaries (Kim, Shen, & Wentworth, 2019).

Conclusions

Given the rapid growth of RPPs and wide variety in their impact, we need to learn more about the processes and structures through which RPPs operate, and how differences in these processes facilitate or impede learning outcomes. Specifically, we bring together theorizing on the mechanisms through which learning at the boundaries of research and practice occurs, with attention to the organizational conditions that shape researchers and practitioners' abilities to engage productively in joint efforts. In doing so, we pave the way for important comparative work that will hopefully illuminate whether and under what conditions RPPs can foster educational improvements locally and at scale.

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Complexifying the Generation of an Aim in a Teacher Preparation Networked Improvement Community

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Abstract: Although networked improvement communities (NICs) have emerged as a popular approach to improvement and research-practice partnerships, research has not focused on unveiling and examining the processes that comprise the launching and enactment of NICs. In this study, we examine an important process in launching a NIC: converging on an aim. We focus on engagement with tensions that emerge in this process and how members' engagement with a central tension—language acquisition versus multilingualism—unfold to shape the network's aim. Our analysis revealed that the evolving ways members engaged tensions over time shaped the network's aim and theory of improvement in ways that came to also shape the NIC's institutional logic. Our study highlights the need to study convergence as critical processes that shape how NICs come to be enacted.

Introduction

Networked improvement science has emerged as a prominent approach to research-practice partnerships in the field of education (Coburn, Penuel, & Geil, 2013), and is particularly new to the field of teacher preparation. Research has revealed that inquiry in teacher preparation has typically involved studying changes in beliefs and attitudes relative to teacher preparation program activities for one group of teacher candidates, in one course, at one point in time (Cochran-Smith et al., 2015). Contrastingly, networked improvement science centers addressing *problems of practice* rather than studying specific activities; using *measurement* to gauge improvement on a problem rather than studying the effects of an activity; engaging in *iterative cycles of testing* to learn about changes in contrast to implementing an activity at scale; and working in networks, centered around an organizing hub, called *networked improvement communities* (NICs) to learn about addressing the same problems across settings rather than working in silos and learning about activities in a single course (Bryk et al., 2015).

NICs are frequently discussed as organizations (e.g., Cannata, Cohen-Vogel, & Sorum, 2017; Russell et al., 2017); however, the unfolding interactions and enactment of these organizations has not been prioritized as an area of research. We contend that examining the *processes* that comprise these NICs in the context of teacher preparation—a particular type of organization—offers insight into how teacher preparation programs might work together on shared problems, addressing a pressing need to study teacher preparation across multiple sites (Cochran-Smith et al., 2015). Studying interactions that comprise these networks is critical to understanding how networks can be successfully launched across contexts and problems of practice. Unveiling the ways in which the enactment of these networks unfolds also offers lessons for understanding research-practice partnership processes more broadly, particularly as RPPs continue to grapple with the varied techniques, strategies, and decisions that comprise these partnerships (Coburn & Penuel, 2016).

We focus our study of these interactions on one core “phase” of initiating a NIC: developing a shared aim (Russell et al., 2017). In NICs, aims are statements that specify what will be improved, by how much, and by when. In the limited scholarship on networked improvement science, the process of generating an aim statement is typically described as taken for granted. In an example highlighted in Russell and colleagues' (2017) framework for initiating a NIC, the authors state that during the launch of a NIC, “the initiation team identified the NIC's focal problem, low success rates in developmental math courses, by beginning with a larger concern: that of low graduation rates in community colleges.” Largely absent from the literature is how NICs come to define shared problems. We seek to complexify and understand this process by asking: What tensions emerged among teacher educators in the development of a shared aim and how did network members' engagement with those tensions unfold over time? We focus on stakeholders' engagement around one tension, between language acquisition and the promotion of multilingualism, to illustrate how people in the NIC successfully converged on a shared aim.

Theoretical framework

We conceptualize tensions using cultural-historical activity theory (Engeström, Miettinen, & Punamäki, 1999). In framing social life and organizations as comprised of activity systems that are constantly changing, cultural-historical activity theory conceptualizes tensions as competing and contradicting components of a given system of activity that, when engaged, are sources of transformation and change. Drawing from this conceptualization,

we seek to identify emerging tensions by attending to activity systems that comprise a teacher preparation NIC and how they shape the ways NICs are enacted.

Additionally, we adopt a processual lens to investigate how tensions are engaged in the development of a shared aim. We frame NICs as types of organizations comprised of actors and processes. Traditionally, studies of organizations have centered on the ways structure dictates agency and actions, positioning organizations as a set of structures that are unilateral, determinative, and static (Ortner, 1984; Langley, 1999). We employ a *processual lens* which views organizations as constantly becoming; comprised of a series of constantly unfolding processes; and made up of and situated within structures that constrain and enable action, and actions that simultaneously maintain, reinforce, modify, or transform structures (Giddens, 1984; Langley et al., 2013; Tsoukas & Chia, 2002). Adopting a processual lens offers insight into the complex processes that comprise a NIC to illuminate how tensions shape these networks.

We focus on tensions because they play a central role in transformation, change, and emergence (Engestrom, Miettinen, & Punamaki, 1999). We center interactions that occur among participants in the network to trace how tensions emerged and were engaged, and how tension-engagement evolved to produce a shared aim. We examined the tensions that emerged when a group of teacher educators sought to establish an aim related to the preparation of teacher candidates to support multilingual students. After a series of meetings, stakeholders constructed an aim centered on improving teacher candidates' dispositions, noticing, and practice for building on multilingual students' strengths. We seek to a) identify tensions that emerged in teacher educators' interactions, and more centrally, b) examine processually how members engaged a central tension en route to an aim.

Methods

Research context

This study's focal NIC is comprised of 44 teacher educators from seven different teacher preparation programs—all committed to issues of social justice and educational equity—based in research universities across California. Using survey data collected from the seven programs from a governing body, the directors of those programs, along with the California Teacher Education Research and Improvement Network (CTERIN), identified a general problem around which a NIC could be organized: candidates and mentor teachers expressed low confidence that candidates were adequately prepared to teach multilingual students. Each director took this problem back to their home campuses and worked to gauge interest from faculty for working on this problem. With this problem identified, teacher educators from each campus were recruited to join the network to work on this problem. In 2018-19, the network's efforts focused on identifying an aim, developing and refining a theory of improvement, and designing improvement measures. Teacher educators began to meet remotely during the summer of 2018 and participated in a two-day convening in September 2018. The convening focused on generating an aim and theory of improvement. After the convening, members agreed to meet remotely every month throughout the year. Subsequent meetings centered on receiving feedback from members on a proposed aim and theory of improvement. After the October 2018 monthly meeting, network members agreed to an initial aim and a theory of improvement. The central tool that was used to do this was a *driver diagram*, a visual tool that uses *primary and secondary drivers* to make conjectures that connect specific activities, experiences, and changes to the aim.

Data collection and analysis

The first author acted as the primary improvement facilitator for this project, as well as the primary person responsible for collecting data on the process of improvement in this network. Data for this paper consists of transcribed audio and video recordings from the following contexts: two, 90-minute, remote meetings in the summer of 2018; a two-day in-person convening in September, attended by all 44 teacher educators; and a video recording of a remote meeting in October 2018. To surface tensions that emerged among teacher educators as it pertained to the network's aim, we analyzed data from the September 2018 in-person convening. Using activity theory as an analytic tool, we drew from the work of Barab and colleagues (2002) by conceptualizing tensions as dualities, manifested as either competing elements within an activity system or as competing elements across multiple activity systems. We analyzed members' conversations, both in the whole-group and small-group interactions, specifically examining members' turn-taking and sequences as possible indicators of disagreement (Goodwin & Heritage, 1990). We also coded for dualities using versus coding (Saldaña, 2015) to surface the tensions teacher educators experienced while working in their respective teacher preparation programs. For each group, we wrote analytic memos capturing possible tensions that emerged. We identified 23 tensions and created categories that made visible the kinds, and salience, of tensions that emerged as the NIC attempted to converge on a shared aim. Five categories of tensions emerged, with four unique tensions that did not fall under any category. To find our focal tension that we would trace across teacher educators' interactions, we chose the

category that was discussed the most at the different small groups: preparing candidates for systems of schooling and preparing candidates to promote multilingualism.

To trace teacher educators' engagement with this tension, we examined data from the first summer meeting to the network's October 2018 meeting. We looked for instances in which teacher educators: a) challenged the idea of language acquisition or academic language; b) problematized standard English; and c) named the issue of language dominance and the positioning of some languages as more valuable than others. These three dimensions served as specific indicators for when teacher educators were engaging the tension.

Findings

We begin by providing a summary of the five broad categories of tensions that teacher educators surfaced and grappled with during the September 2019 convening. The first related to identifying the focus of improvement. This tension was primarily concerned with where preparation takes place: in fieldwork or university program experiences. The second tension centered on locating the responsibility for changing candidates' dispositions. For example, some had expressed a desire for multilingual candidates to take responsibility for their peers' dispositions towards multilingual students, where others had located this as the responsibility of the program. The third tension centered on the tension between preparing candidates for promoting multilingualism and preparing candidates for language acquisition. This included determining whether programs should prepare candidates for making multilingualism normative in schools or whether programs should prepare candidates for existing systems of schooling that promote language acquisition. The fourth tension centered on rethinking notions of differentiation. Some teacher educators expressed that differentiation was often seen as "technical" and "official" but had hoped to instead see it as a way to meet the "constellation of students' needs." The last tension centered on viewing students' strengths in relation to communities in families. For example, one teacher educator noted that "leveraging students' assets" often felt like a strategy to "take advantage" of what students bring and "leave their [family] behind" rather than "bringing" their family with them.

We focused on the tension between preparing candidates to teach students to acquire language versus preparing candidates to promote multilingualism because teacher educators' engagement with this tension was consequential in shaping the network's aim. To do this, we organize our findings in the phases of improvement work: defining and framing a problem; scoping the problem to an aim; and constructing an aim and theory of improvement. We describe how the tension evolves through each phase.

Evolving engagement with the tension between language acquisition and multilingualism

We highlight the extent to which members mentioned or engaged in conversation around the tension between language acquisition and multilingualism. We trace engagement with this tension through the network meetings, beginning with the summer meetings. In these meetings, we engaged members in a critical conversation that occurs in the early phases of improvement work (Bryk et al., 2015): framing and understanding the complexity of the original problem statement. Network members' engagement and interactions over this tension during these first two remote meetings were brief. In the first meeting, two teacher educators mentioned language dominance at two separate times. In the second meeting, three teacher educators problematized language acquisition and what one participant called "monolingualistic conceptions" of schooling. The tension between language acquisition and multilingualism was initiated but not taken up by other teacher educators for discussion.

However, this tension took center stage at the in-person convening in September 2018. Our analysis revealed seven separate conversations that centered on problematizing language acquisition, standard English, and language dominance. Discussions around the tension moved from brief and untouched by other teacher educators in the first two remote meetings to involved and salient during the in-person convening. Engagement with the tension also changed and evolved within the convening as the days unfolded. When the group shifted to the next phase of improvement work at the beginning of the in-person convening—developing a shared understanding of the problem—the tension around multilingualism and language acquisition came to the fore. We offer an example of an interaction that occurred during this phase of the work to illuminate: a) the evolution of engagement with this tension from previous meetings and b) the nature of the conversations at the intersection of the network's focus and the tension between language acquisition and multilingualism.

In this exchange, two teacher educators discussed an improvement science tool called a *fishbone diagram* (Bryk et al., 2015) meant to visualize an understanding of the problem and its causes. The fishbone diagram was organized around a problem statement that read, "Variation in how well-prepared UC teacher candidates are to teach multilingual students." Prior to this exchange, the improvement facilitator had asked teacher educators from different campuses to talk in small groups to interrogate and revise the diagram. One teacher educator, Patrick, worked as a lecturer and supervisor at his campus. The other teacher educator, Laura, worked as a supervisor at

her campus, while also working with her local school district on English learning initiatives. In the exchange, Patrick first articulates his desire to see the network focus on multilingualism and multiliteracy.

Patrick: the thing that feels missing for me on here, is that a lot of these are good teaching for ELLs. Guadalupe Valdez says she's hesitant to use emergent multilinguals, because that's a promise we don't know how to—we don't have models institutionally...we've structured English acquisition. What does it mean to have schools where kids grow up confidently multilingual, multiliterate? [...]

Laura: are you saying that you're agreeing with the label of multilingual students, or frame our problem like that, or you would change that?

Patrick: I think that ought to be the goal—

Laura: the overarching goal to create—multilingual students, which includes dual-language programs, dual-immersion programs [...]

Patrick: Yeah, biliteracy all the way through. Yup. And I feel like I love using the ELA/ELD frameworks to teach language arts and to teach English teachers. But I feel like as a system we don't know how to prepare—[...] but all of that has to take into account the social and political and cultural factors that—

Laura: We don't have the structures in place, yeah, I agree with you 100%. [...] we have the chance to change it, but then you have to have the personnel to do that [...] we don't have the infrastructure [...]

Patrick shared his vision for what he would like the network to focus on, noting the unfulfilled promise that the term “multilingualism” implies. Laura's response was to agree with his critique of the realities of a system that prevents that vision from becoming realized. This interaction highlights the tensions that existed in three separate activity systems. In the activity system of this network, the lack of clarity around the network's object at this phase, and the teacher educators' role in interrogating the focal problem and fishbone diagram, led these two teacher educators offering up disagreements about what the focal problem of the network should be. At the intersection of the activity systems of teacher preparation programs and schools, the object of schools, language acquisition, is potentially in conflict with the desired object of teacher preparation programs that Patrick describes, multilingualism and multiliteracy. Other members also surfaced this tension for discussion with their group. For example, Mick examined the fishbone and noticed a contradiction:

The bias towards basic or proper English in K-12 classrooms and programs may not understand how to teach English for supporting academic language. Those two seem to contradict each other a little bit, right? We want to teach students to use and understand academic language but there's a bias towards proper English so in my mind [...] there is a difference but it's also confusing.

When asked to clarify and expand, Mick, a doctoral student teaching in his university's teacher preparation program, responded that if he were an English/Language Arts teacher, he would want his students to use a “certain vocabulary,” but also added that “you don't want students to talk in a certain way or essentially lose their own culture.” Although Mick had not articulated a stance the way Patrick or Laura had, he also experienced a contradiction through interrogating the fishbone diagram. In both exchanges, members positioned the fishbone diagram as a tool for surfacing an opportunity to identify or change the network's focus (in the case of Patrick) and in surfacing a contradiction (as was the case for Mick). Additionally, these exchanges highlight how these interactions around this tension changed when attempting to focus on a shared problem. For Mick, this tension was salient, challenging, and even “confusing” for trying to understand the focal problem; for Patrick, the focus of the network should center on how programs prepare candidates for what schools should be; and for Laura, the focus of the network should attend to the ways in which schools are currently structured.

After these exchanges on the first day of the convening, members' engagement with the tension evolved to center on definitions of multilingualism and how a more inclusive definition should shape the network's improvement efforts. To highlight this, we offer an example from the second day of the convening. On the second day, the facilitators centered the meeting on scoping the network's focus on a desired outcome in order to construct an aim. This whole-group exchange served as a share-out following 18 minutes of group discussion about five possible, broad outcomes that were presented to the group derived from the two summer meetings. Teacher

educators were asked to interrogate and modify these outcomes and share out what they had done before selecting which category should be the focus of the network. Esmerelda, a teacher educator, responded that she and her group had framed the problem differently than how the fishbone had framed the problem, saying that “we are all teachers of language” and “language does not equal English.” To this, her colleague, Madeline, who also sat at her table, responded, saying that this framing “changed the [outcomes]” to which the network should focus, noting that one of the outcomes in particular—the one focused on language development and acquisition—“shifts when the only language being acquired is not English.”

Their groupmate from a different university, Charlotte, followed by naming multilingualism as aspirational: “and the kind of implicit norm that English is the norm or that monolingualism is the norm. And so we were seeing multilingualism as the norm, or the aspirational norm. But everything looked very different once we looked through that lens.” These exchanges indicated a shift in the way the tension was taken up by the group in that moment. After Esmerelda had mentioned that “language does not equal English” as a way to reframe “language acquisition,” the members at her table contributed to the whole-group conversation by reframing what “multilingualism” had meant, instead opting for a more “aspirational” definition that included students’ various ways of speaking and communicating, in English and in other languages. This group problematized the framing of the problem where “multilingual students” was synonymous with “English language learners,” and by extension, challenged whether the categories of outcomes made sense under this new definition. In the rest of the whole-group conversation, which lasted 40 minutes in total, we saw no evidence of disagreement with this proposed definition, although some members of the group either offered agreement or attempted to re-center the conversation around this new definition of multilingualism. Together, these exchanges highlight that members’ engagement with the tension between language acquisition and multilingualism evolved from a focus on reconciling existing systems of schooling with teacher preparation program aspirations, to a focus on a definition of multilingualism that was broad enough to be inclusive of all students and did not center academic English.

We note that while we observed little disagreement with this shift to a more inclusive definition of multilingualism, not all members of the network agreed with this direction. Laura, who surfaced a desire to focus on language acquisition, was not present during this second day of the convening or any future meetings. Another teacher educator, Alicia, mentioned to the facilitator at the in-person convening that there needed to be an attention to the way schools were organized. Alicia did not feel comfortable sharing this because she was new to her position at her teacher preparation program. We found this convergence on a commitment to multilingualism, and subsequent decentering of concerns around existing systems of schooling, consistent with Mehta’s (2015) claim that any problem statement and its framing centers and values some perspectives in the collaborative work of education reform over other perspectives. In this case, teacher educators with orientations to what schooling *could* look like, what Emirbayer and Mische (1992) term the projectivity element of agency that centers possibilities, became foregrounded. These exchanges highlighted that while teacher educators came from different programs, many carried an orientation to imagining futures and alternatives to existing systems of schooling.

The facilitators centered the next phase of the work on attempting to converge on an aim statement using the aims that teacher educators generated. During this phase, engagement with the tension between language acquisition to multilingualism moved from grappling with definitions of multilingualism to codifying a resolution in a driver diagram. After the whole-group discussion around the categories of outcomes ended, the facilitator asked teacher educators to brainstorm a list of aim statements based on the conversation around definitions of multilingualism. Following the convening, the research team then categorized the newly generated aim statements from the teacher educators into like categories, identified the most common type of aim statement, and constructed a driver diagram. In this first draft of a driver diagram, the aim centered on improving candidates’ noticing, dispositions, and practices for leveraging multilingual students’ assets. Two primary drivers emerged from the categories: empathizing with multilingual students and designing instruction. Additionally, we identified and articulated eight secondary drivers—drivers that are attached to primary drivers that are typically more specific concepts or processes (Bryk et al., 2015). To understand the evolution of engagement with this tension, we highlight exchanges related to two secondary drivers: a) help candidates be aware of their positionality, privilege, and the myth of meritocracy; and b) help candidates identify linguistic and sociolinguistic assets.

These two secondary drivers proved to be important for teacher educators who had advocated for a broad definition of multilingualism that decentered standard English to guide the network’s improvement efforts. During the October 2018 monthly network meeting, the facilitators introduced a draft of the driver diagram to the network. The facilitator asked members to interrogate and modify the driver diagram. In this conversation, Charlotte noted and approved of the secondary driver containing language about positionality, saying “I think it’s important that we include that statement about positionality that I saw in the driver diagram [...] it’s a good thing to make our norm be multilingualism, as opposed to monolingualism.” Charlotte pointed out that the language around “positionality” in the secondary driver “helping candidates be aware of their own positionality, privilege, and the

myth of meritocracy” was important for centering a broader definition of multilingualism, locating this commitment within the diagram. She then offered a suggestion to make explicit that some students learning a second language are positioned differently, saying, “we don't want to lose the fact that not everyone learning another language [...] has the same kind of social capital. [... It's important for] our candidates to [be aware of] the sociopolitics and the social positioning of languages and their speakers.” Charlotte's framing of her suggestion as not wanting to “lose” something signaled to the hub that issues of language positionality were absent. In the next iteration of the driver diagram, the hub revised the driver to “Candidates become aware of positionality, privilege, and sociopolitical language ideologies.” In these exchanges, the driver diagram served as an important tool for codifying and reifying teacher educators' commitments and values around language and language instruction. After engagement with the tension between language acquisition and multilingualism became enacted through defining multilingualism, it then became lived in the driver diagram as central to the theory of improvement that guided the network's improvement efforts. Although we hesitate to claim that the tension was “resolved,” we note that the successful attempt to codify and navigate the tension using a driver diagram helped to make clear to network members the commitments and values under which the network would operate.

Through these phases of improvement work—defining and framing a problem; identifying an aim; crafting a theory of improvement—we highlight how a tension emerged and is engaged with in ways that shape the network. Engagement with the tension between language acquisition and multilingualism evolved from treatment of the tension as peripheral, to identifying the tension as one that exists between competing activity systems, to engaging with the tension through attempts at defining multilingualism, and finally to navigating the tension by codifying a decision to center multilingualism in the network's driver diagram. Having portrayed members' evolving engagement with this tension, we turn to a discussion of this unfolding engagement. We offer implications for research and practice of improvement, particularly NICs, and its relevance to teacher preparation

Discussion and conclusion

In taking a processual and activity theoretical lens to examining the processes through which a NIC converges on a shared aim, we highlight how people participating in these networks must engage with core tensions in order to move the work forward. Our analysis revealed the ways in which engagement with a salient tension in teacher preparation—preparing candidates for language acquisition versus preparing candidates for promoting multilingualism—unfolded in ways that shaped how the launch of a teacher preparation NIC was enacted.

While members focused on framing, defining, and understanding the problem, attempts at converging around a shared problem created space for members to surface contradictions between existing school systems and promoting multilingualism. These interactions were evidence of competing objects of two systems of activities involved in the preparation of teachers: schools and teacher preparation programs. The object of schools and school districts centered around language acquisition; and the object of teacher preparation programs was to prepare candidates for a different status quo, in this case, multilingualism. These interactions also made visible what Emirbayer and Mische (1992) call situated temporal agentic orientations, where action is driven by varying degrees of orientation to the past, present, and future. Engagement with the central tension surfaced disagreement between those who were more oriented to the past (existing school systems centered on language acquisition) and those oriented towards the future (imagining possible futures where multilingualism is normative). Together, competing objects of multiple activity systems and situated agentic orientations shaped engagement with a core tension in improving teacher preparation for multilingual students. We argue for a need to attend to the competing objects of the central activity systems implicated in improvement work, the specific agentic orientations that emerge, and how participation structures (Goodwin & Heritage, 1990) and the make-up of the people in the room constrain and enable particular orientations.

The phase of the work focused on convergence around a shared aim created opportunities for teacher educators to advocate for a shared aim around promoting multilingualism. This was characterized by participants attempting to define what multilingualism meant for the group, while decentering an attention to language acquisition and existing school systems. The decentering of language acquisition and existing systems is in line with Mehta's (2015) claim that framing a problem positions some perspectives as more peripheral or central. In this case, perspectives centered on language acquisition became peripheral as the network's efforts came to be framed as promoting multilingualism. We view the turn to promoting multilingualism as the network's primary goal to be a function of the rather consistent institutional logics (Thornton & Ocasio, 1999) among the teacher preparation programs in this study. Each of the programs have stated commitments to social justice and equity, and these commitments may have played a role in many teacher educators' receptiveness to a broad and inclusive definition of multilingualism that centered the sustenance of students' language and cultures.

The commitments to multilingualism then became codified in a driver diagram that came to represent many of teacher educators' commitments and values inasmuch as it represented a concrete theory of action. The

diagram mediated teacher educators' and the facilitators' participation by a) making explicit the object of the network's activity (Engestrom, Miettinen, & Punamaki, 1999), b) articulating a theory of improvement that would then help facilitators guide improvement efforts, and c) allowing teacher educators to locate their values, commitments and concerns within the network's theory of improvement. Typically, driver diagrams are discussed as tools that articulate a NIC's aim and theory of improvement. However, our study highlights the role a driver diagram played in making visible a NIC's institutional logic by making explicit intended enactment, commitments, and values.

We conclude by advocating for a processual and activity theoretical lens to the work of enacting NICs. Our study highlights the need to attend to *how* improvement work is carried out and *how* stakeholders engage central tensions in the work of improvement. We sought to complexify and problematize the processes of converging on an aim that are, at times, somewhat oversimplified in networked improvement science texts (e.g., Bryk et al., 2015; Russell et al., 2017). Our study revealed that processes of convergence contain sensitive and important moments for surfacing tensions that must be engaged to move the work forward. An important practical implication of our work is the need to attend carefully to *how* participants are engaged with tensions central to advancing improvement work, in order for a shared aim to emerge. Improvement work is foundationally concerned with changing systems (Bryk et al., 2015) and understanding the processes through which tensions—critical sources of transformation and change—are engaged in the context of improvement work is critical for sustaining and advancing a continuous improvement approach in education.

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Idea Development Across Social Levels for Knowledge Building in Four Grade 5 Science Communities

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Abstract: This research contributes to addressing a core gap of knowledge in CSCL to understand idea emergence and interaction across multiple social levels including individual, small group, community and community networks in order to inform designs to foster extending inquiry trajectories. Using design-based research methodology, this study investigated how students in four grade 5 knowledge building communities worked across the boundaries of the social levels to develop deep understandings of human body systems with the support of Idea Thread Mapper and Knowledge Forum. As students conducted focused inquiry and discourse in their own community, they formulated a challenging question for the four classrooms to collaborate on: how people grow. Qualitative and quantitative methods were used to investigate how new ideas emerged in individual classrooms and rose above to the cross-community discourse to understand this challenging issue, with new insights further diffused to different classrooms for further inquiry and connected discourse.

Introduction

Educational researchers have made substantial advances to develop computer-supported collaborative learning environments and support collaborative knowledge building among students (Engle & Conant, 2002; Scardamalia & Bereiter, 2006; Slotta, Suthers, & Roschelle, 2014). Further research is needed to extend interaction to higher social levels and scales (Stahl, 2013), so students can build on the knowledge of other communities across school years for sustained knowledge building. This requires designs for cross-boundary interaction and collaboration, which has gained interest in the broader fields (Star & Griesemer, 1989) but still lacks systematic investigation in the field of computer-supported collaborative learning. This design-based research tests and refines designs of cross-classroom interaction for knowledge building with the support of a new collaborative learning platform: Idea Thread Mapper (ITM) (Zhang & Chen, 2019). Based on previous research (Zhang, Bogouslavsky & Yuan, 2017, Yuan & Zhang, 2018), this research designs cross-community interaction using a multi-level emergent interaction approach, focusing on idea emergence and movement across multiple social layers. In the multi-level emergent interaction framework, at the micro-level students co-generate the interactional frame of Knowledge Building (KB) norms, metacognitive meeting rules, and distribute workloads and collaborative responsibilities in the community. As students conduct their inquiry studies over the school year, they further create reflective knowledge synthetics (Yuan & Zhang, 2019) to share their knowledge with peers. The stable material content structures which has with four scaffolds in writing (Our research question...; we used to think...; Now we understand...; We need further research...) emerged and directed their future learning. The collective knowledge of the classrooms taps into the knowledge accumulated at the individual class level as the individual class is the basis of organizational knowledge creation (Figure 1). At the macro level, the design of the “Super Talk” fulfills the needs of cross-community interaction. The Super Talk as a collaborative online space enables students from four classes work together to address the same challenging research problem. The learning results further impact downward and transform the learning dynamic back to each class and individual student as students who participated in the Super Talk read and write notes and bring what they have learned back to the home class. Idea Thread Mapper provides a technology infrastructure with a trustworthy and vetted background database created by students about their learning subjects.

This paper attempts to deepen the understanding of the cross-classroom interaction in a set of four grade 5 knowledge building classrooms supported by ITM. Our research question asks how students interact across multiple social levels to build knowledge in knowledge building learning communities.

Classroom design and context

This study was conducted in four grade 5 classrooms (with a total of 89 students who were 10-to-11 years old) that studied human body systems over six months using ITM from January 2018- June 2018. The four classrooms, labeled as Class 1-4, were taught by two teachers each teaching two classes. Students in each classroom generated interest-driven questions in human body systems, co-organized research areas focusing on various topics, and conducted research using various resources. They conducted reflective knowledge-building

conversation (called “metacognitive meetings”) in their classroom to build on one another’s ideas and questions while reviewing their progress. At the same time, for students to continue their conversation in the online space, the teacher organized the same online discussion space in ITM which is called the *Wondering Area* that matches their face-to-face research topics. As progress was made in each idea thread, students co-created and edited a Journey of Thinking (JoT) to reflect on their synthetic knowledge (for details, please refer Yuan & Zhang, 2018).

In the fifth month of this study, as students accumulated enough knowledge and made efforts to advance their knowledge, students in Class 2 proposed a challenging problem for Super Talk across the classrooms: How do people grow? Students in four classes contributed their ideas collaboratively to advance their understanding. Their ideas were further used by another class to advance their understanding.

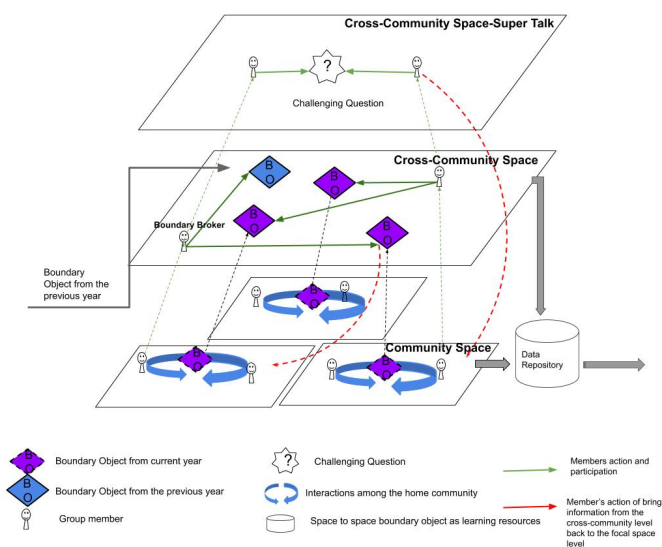


Figure 1. The visualization of the multi-level emergence design of KB Interactions across classrooms conceptual framework.

Data sources and analyses

The data sources include classroom observation notes, video records, transcriptions of classroom conversations, and students’ online discourses in ITM. Guided by the research question, we conducted a detailed qualitative analysis of students’ inquiry process in their home classes in connection with students’ interaction across groups and cross-classroom interactions. We conducted content analysis (Chi, 1997) based on the complexity of ideas (from unelaborated facts to elaborated explanations; see coding scheme in Zhang et al., 2007).

To further investigate the quality of the notes posted in the Super Talk, researchers compared students’ notes in the Super Talk (cross-community level) and notes in their home class Wondering Areas (group-level). To increase analytic efficiency in this longitudinal data analysis, this study used LightSIDE (Mayfield & Rosé, 2013) to train and build analytic models. First, one researcher coded 550 notes from the previous school year’s Ecology unit (September 2017 – December 2017). A second coder coded 12% of the data independently for inter-rater reliability (Cohen’s Kappa = .87). The manually coded data were used as the training data to create Natural Language processing models for automated analysis using LightSIDE. Then the researcher used the model to predict the idea complexity of the new data set that contains 633 regular ITM notes from their home Wondering Areas (January 2018 – June 2018).

To understand how students’ ideas emerged from home class and contributed to the Super Talk (Figure 3), we read/re-read our detailed field notes and examined the classroom videos to understand the classroom processes, and combined with the detailed video analysis to further understanding the Super Talk generation process.

Results

From Individual to Group: How do individual ideas and interests shape the emergence of groups?

At the beginning of the learning unit, all students in four classes joined the human body kick-off activities. For instance, one activity was to let students participate in doing a high-kick for one minute and measure the

heartbeats and breath before and after the exercise. Based on their reflections and observations, they created their own discoveries and proposed their initial research questions. Based on the nature of their questions, they formed into groups based on similar interests naturally. In general, the brain, heart, lungs, digestion are big groups across four classes. At the early stage, students' questions also closely related to the kick-off activities and their pre-knowledge (Table 1). Moreover, by posting their questions, students have a sense of group engagement since they get familiar with peers who share the same interests.

Table1: Examples of Students' Individual Initial Research Question from Class 3

Wondering area	Heart	Blood	Breathing	Digestion	Brain
Research questions	CL23: Does how fast the blood travels through my veins effect my heart rate? How fast does the air in my body take to go through my whole body? CL13: Why does our hearts beat faster after we exercise? CL4: How does the heart go faster when exercising why and how? CL15: Why does your heart beat faster when you work out? Why do you need more blood vessels when you work out? CL9: Why was my heart beating louder after exercise? CL3: Why does your heart rate gone when you exercise? CL18: How do you feel your heart beat near your throat or on your arm near the wrist?	CL23: Does how fast the blood travels through my veins effect my heartrate? How fast does the air in my body take to go through my whole body? CL13: Why does our hearts beat faster after we exercise? CL16: How does the immune system work? How does the human body use blood? CL17: How does our body use blood? CL21: Where does the blood go when your exercising and eating?	CL14: How does the human body use air? CL5: Where does the air go in the body when inhaled or exhaled? How does it help you? How does the body help the air travel in it? CL19: Why does your heart rate so faster when you exercise? CL10: How does asthma effect our body? CL20: How does human body use air? CL12: How does air we breathe get around our body? How do we use it? CL22: How does the air in your breath get around the body? Where does it go in the body? How does the body use the air?	CL1: Why does the heart rate and respiratory rate go up when we exercise, where does the food go after the digestion system? CL7: What parts of the human body are used in the digestive system?	CL2: How does your brain command your body? Common vs reflex? CL8: How do eyes get their color? The brain controls your systems, but how?

After the kick-off activity, students from 4 classes generated 108 initial research questions, among them, 84% are open-ended questions start with how and why. 16% of the questions are fact-driven questions that start with where, what, and when.

Group-Community: How did ideas emerge and interact across areas in the community?

To further elaborate this learning process, we traced two ideas, *pituitary* gland and *mitosis*, from the Class 3 as examples as these two ideas were shared and exchanged in both group-level and the cross-classroom level discussions.

After the kick-off activity, student Eva (CL2) joined the brain group and posted her first note in ITM about the brain. She first mentioned that the brain has different parts and the pituitary gland by explaining "This is the pituitary... released a hormone that made you grow. This pea-sized gland plays a HUGE role in puberty". At the same time, other group members were using books and online learning materials investigate this brain topic. After the brain group accumulated much knowledge, at the end of the first month, they suggested to have a metacognitive meeting about the brain and shared their learning results with the whole class (Figure 2). Before the metacognitive meeting, the teacher suggested everyone go on ITM and read the notes in the brain idea thread to have a background understanding of the sharing content. To better support students notetaking and reduce the distraction from obscure scientific words and misspellings for Grade 5 students, the teacher pre-wrote the academic words on a white chart (Figure 2). This strategy facilitates students to better focus on their

sharing. The pre and post comparison of students notes suggests that students wrote down more scientific words correctly with more content during the metacognitive meeting in compare with the metacognitive meetings that didn't have pre-written scientific words. During the metacognitive meeting with the main leading theme of brain, Eva stressed the function of the pituitary gland to her classmates, and they discussed how the brain controls the body. After the metacognitive meeting, the brain group designed an online assessment to understand how well their peers understand the knowledge in the brain (Figure 2), the results show that most of their peers had a high level of understanding as they achieved high scores in most of the questions, and the brain group made an instinct explanation on questions that received low scores to clarify the misunderstandings on the spot.

As the learning from each group progressed, in week 5's metacognitive meeting, which has the central theme of how the lungs work, students found that the brain and lungs work closely together, and the oxygen gets to the tissues through red blood cells. Thus, students start to build their basic understanding of the human body at the cellular level. Further, in week 6, the main theme of the metacognitive meeting was the circulatory system. During the meeting, students found that blood circulates through the body and why tissues in the body need oxygen. Student Kevin (ID: CL9) contributed his knowledge about cells as "The cells contain sugar except they need the oxygen to turn it into energy." Halen further builds on saying "oxygen is carried by hemoglobin; it is a molecule that plays a vital role in the metabolism cycle." This suggests that students made closer connections between organs and started to share knowledge at the cell level. In week 7, during the metacognitive meeting, Kevin, as an expert from the heart and lungs group, shared his knowledge about white blood cells in the blood. He mentioned that: "Neutrophils look for things that shouldn't be in your body, and macrophages look for and digest dead germs...Amino acids are what make proteins", and during the reflection, the teacher asked what tissue of our body needs oxygen, and students said everywhere, because we need our oxygen to survive. This information is critical because it advanced the study of cells one step further. As the learning processed, students in Class 3 became familiar with the molecules and cells, which created a good foundation for the brain group. In the following week 8, students in the digestive system led the metacognitive meeting; however, a research question remained: how did the small intestine absorb nutrients and minerals? Since digestion was one of the main kick-off activities, so students were all interested in the topic. The teacher played a video about the small intestine for further explanation of the digestive system to the whole class. This video functioned as another critical piece of information since digestion systems first made connections between energy, cells, and blood, since nutrition is absorbed from the small intestines and then travels through the body in the blood stream.

On March 15th, Kevin posted another note in ITM stating "Mitosis is the process of one cell splitting into two new cells as it is a complex process with many steps". In the same week, when the teacher asks whether they need new threads, and if they feel what they are studying cannot fit in any of the current threads. Kevin suggested the teacher to create a new thread called "How do we grow?" This is the thread that was first established in Class 3. However, this new topic did not get much attention from the home class since there were only two students working on this topic. This advanced idea did not catch others' attention at the end of the 5th month until Class 2 initiated the cross-classroom collaboration with the same question of "How do we grow?". Kevin finally found peers interested in the same topic, so he joined the collaboration and uploaded his note about mitosis to the cross-classroom thread in ITM. Eva did the same, posting her first notes about pituitary glands. At the end of the semester in the 6th month, the teacher held a metacognitive meeting asking about connections to the study of the human body in Class 3. She asked the whole class, "What are some deep questions that they are trying to figure out?" Kevin shared that mitosis connects to cells because it also relates to genes and DNA as it is the basic unit of the body. To grow, the cell has to divide through mitosis. Thus, the concept of mitosis was both explained in the home class and the cross-community area.

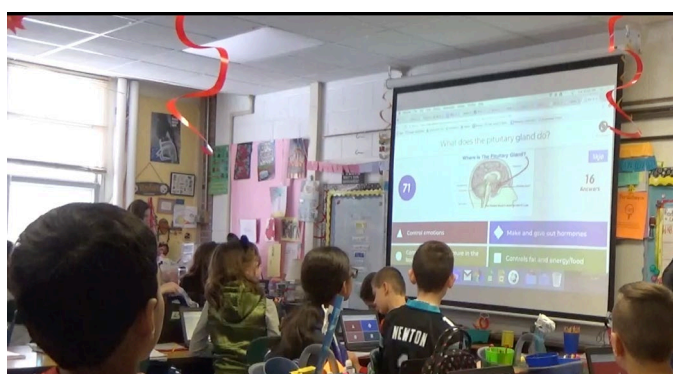
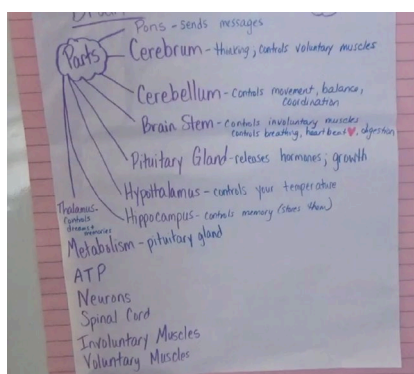


Figure 2. Metacognitive meetings about the concept of the Pituitary Gland.

Cross-community interaction: How did ideas move across classrooms and influence the work in each classroom?

The Super Talk was generated at the beginning of May and lasted to the end of May with a total of 22 students from the four classrooms participating in the discussion. At the beginning of May, at a metacognitive meeting, students in Class 2 noticed the new ITM feature of Super Talk. The teacher explained that this function was for all the classrooms to explore big challenging questions and put their knowledge together. Then Class 2 started to discuss possible challenging questions for Super Talk. Three questions were proposed in total: How are all the systems connected? Which two systems are most connected? and Why do people grow? A few students reflected on what they knew about how muscles grow, and several other students showed interest in the growth topic, as they had grown a lot during the school year. Then they agreed to focus on one topic for the Super Talk and decided to have a vote for the one that they felt was challenging and which they were most excited about. The topic of “How do people grow?” was selected. This Super Talk topic was proposed and added in ITM and visible to other classrooms. In the following week, students from Class 2 first started to contribute knowledge about how the brain, bones and muscles grow, drawing upon their knowledge about these body systems. The teachers then started to advertise the Super Talk question in other classrooms. Teachers read the notes already posted by Class 2 and discussed what counts as a good note for the Super Talk to guide students’ participation and reflection. In the following week, students from the other classrooms started to build on the ideas in the Super Talk (Figure 3). Students collaboratively explained how people grow involving main topics from bone and muscles, brain and nervous systems, cells and genetics, and digestive systems. Approximately 50% of the notes are build-on, reflecting a higher level of collaborative responses.

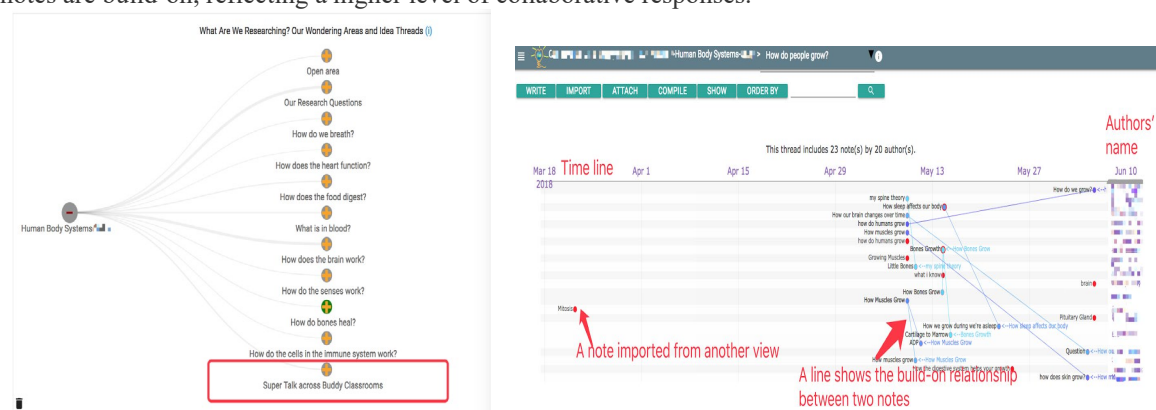


Figure 3. Students’ collective wondering areas about human body systems (Left) and the Super Talk area (Right).

To further investigate the quality of the Super Talk, researchers used the LightSIDE software to train and build a Natural Language Processing model. The researchers compared 633 regular ITM notes in the human body unit and 23 notes in the Super Talk page. One experienced researcher examined the labels and manually revised the results as needed. Nine levels of labels were used (Table 2). The coding scheme was based on Zhang and coworkers’ (2007) coding scheme; researchers further expanded the coding schemes based on research needs.

Table 2: Coding categories and definition

Label	Category	Definition
L-F	Unelaborated Fact (Refer to Zhang et al., 2007)	Posting a simple fact about a concept
L-EF	Elaborated Fact (Refer to Zhang et al., 2007)	Posting a fact with detailed information
L-E	Unelaborated Explanation (Refer to Zhang et al., 2007)	Posting a simple explanation about a concept
L-EE	Elaborated Explanation (Refer to Zhang et al., 2007)	Posting a concept with detailed and systematic explanations or mechanisms
L-Question Level 1	Question Level 1	Posting a brief question without providing the

L-Question Level 2	Question Level 2	context, specifying gaps of information, or suggesting possible ideas.
L-Resource 1	Resource Level 1	Posting a well-developed question(s) with context/directions of thinking
L-Resource 1	Resource Level 2	Posting a link lacks context, information, explanation
L-I	Insufficient Information	Posting links of resources with Explanation and Information
		Less than 3 words, not a sentence

The results suggest that the notes posted in the Super Talk have more Elaborated Explanations than the average ITM notes. This suggests the high quality of the content in the cross-classroom collaboration area (Figure 4).

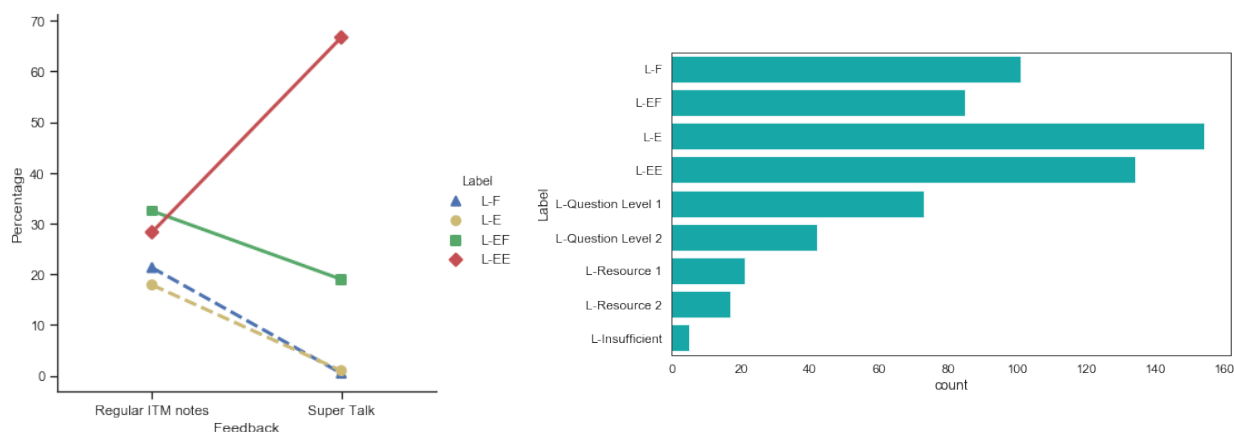


Figure 4. Compare of Idea Complexity between notes posted in the Super Note and Regular ITM threads (Left) The summary of the total 633 ITM regular notes with contribution types (Right).

Discussion and conclusion

The multi-level emergence design and the use of technology in this study tested how ideas emerge, rise above, and interact among communities. The design of this study attempted to address the research challenge of facilitating students' exploration in a tool that enables crisscrossing multi-level idea landscapes (Scardamalia & Bereiter, 2016). The force originating from the sharing and collaboration echoed to the creativity theories in the emergence paradigm, like open innovation which explains the phenomenon of companies making best use of external ideas and technologies in their own business and further letting unutilized internal ideas go outside to the field to be used by others (Chesbrough & Bogers, 2013). At the micro level, through the face-to-face discussion during the metacognitive meeting, students build on each other's ideas, identify the valuable insights and gaps in research. Although different classes may have similar research progress, without the designed cross-classroom interaction, students' ideas may remain in the concrete classroom walls. The two students' learning trajectory mentioned in the results section suggest that students' valuable ideas can disseminate through group discussions and cross-classroom collaboration to benefit others' learning. The Super Talk not only provides students an opportunity to address their urgent needs in investigating challenging questions at the macro-level, but also offers an opportunity for students like Kevin who didn't get much response and worked alone. However, the Super Talk brought a new chance for him to be able to pursue this research question, collaborate with others, and enable his valuable ideas shared through a broaden platform.

It is necessary to highlight the importance of the teacher's role in creating the classroom culture in embracing ideas from the cross-classroom collaboration, and actively making connections between the new ideas with the home class's understandings.

The results of the research question suggesting that ITM supported individual students' ideas emergence and sharing within and across the communities. The use of ITM shows the potential technology in bridging ideas through multiple scales which could not be fulfilled by face-to-face lecturing. Based on the results reported above, this study further demonstrated how key ideas developed through interaction with individuals with other group members, and further extended through the design of cross-community activities. The findings of ongoing cross-community space suggest a promising research design to increase the multi-level

interaction dynamics. By accumulating current years' members' insights synchronically in addressing challenge questions, the collaboration from the micro-level(individual) advanced the idea of diversity in the macro-level (community), the discussion results further produce feedback and provide learning materials at the micro-level.

This study sheds light on the possible designs and processes to enable collaborative knowledge building across a network of classrooms in a broader learning environment and ongoing learning process. The results may have several implications for conceptualizing and designing learning space for sustained Knowledge Building across communities.

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Symposia

Global Perspectives on Social Movement Collective Action as Learning

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Abstract: This session theorizes learning in social action for the learning sciences. Bringing together scholars of social movements across the globe, including migrant justice movements in Japan, public school teachers' strikes, educational justice in South Africa and Mexico, participatory budgeting in Chicago, and LGBTQ2S+ youth organizing in the Midwest USA. These contexts help us to understand what and how learning unfolds through collective action and offers the learning sciences new theoretical and analytic frameworks for theorizing learning that challenge normative ideologies, practices, and worldviews.

Learning politics and politicizing learning

Scholars in the Learning Sciences are increasingly attending to questions about the political and ethical dimensions of our designs and our scholarship – what is our work for, whom does it serve, and how might it advance democratic engagement for equity (Esmonde & Booker, 2016; *The Politics of Learning Collective*, 2017; Philip, Bang, & Jackson, 2018). Work from this perspective can help us develop critically engaged relationships with communities and tools that can further progressive social movements to respond to racism, settler colonialism, xenophobia, Islamophobia, anti-semitism, queerphobia, transphobia, ableism and other systems of injustice.

It is vitally important that we understand collective action—from Black Lives Matter to climate justice organizing to Indigenous resurgence to immigration fights—as locations of praxis where learning integrates insight and action. Social movements shape the political landscape and at their core they are collective learning processes (Choudry, 2015). From grievance construction to strategy setting to consciousness-raising and direct action, social movements enable and require participants to analyze, articulate, and act on the social world. Learning is foundational to social action (Curnow, 2013; Foley, 1999), and within the learning sciences, attention to learning in social movements and community organizing has increasingly begun to shape how we theorize power, politics, equity, and justice (Booker, 2017; Curnow, 2013; Curnow, Davis & Asher, 2019; Esmonde, Curnow & Riviere, 2014; Jurow & Shea, 2015; Kirshner, 2008; Meléndez, 2016; Philip, Gupta, Elby & Turpen, 2018; Teeters & Jurow, 2018; Uttamchandani, 2019; Vea, 2019, under review; Zavala, 2016). The papers in this symposium will illuminate and interrogate the learning processes in and across social movements. The papers in this session examine multiple scales of learning and action from contexts around the globe.

Authors will present papers for 10 minutes each, followed by commentary by our discussants. Time will be reserved for collective agenda setting to challenge the learning sciences to engage in theorization about learning and politics in service to a more just future. Questions include: How might the learning sciences centre the voices of social movement actors as educators and learners? How might these diverse movement contexts expand how the learning sciences analyzes learning or make us reconsider what counts as learning?

Expanding emplaced networks of (hidden) bodies toward collective agency

Miwa A. Takeuchi, University of Calgary, and Virgie Aquino Ishihara, Filipino Migrants Center

In recent years, social activism has started to be studied as a site for multi-layered learning wherein learners' identities, epistemological development, and social relations are intertwined (Curnow, Davis, & Asher, 2019;

Esmonde, Curnow & Riviere, 2014; Jurow, Teeters, Shea & Van Steenis, 2016). In amplifying this strand of research within the learning sciences, we shed light on the collective learning demonstrated by a transnational activist group (Filipino Migrants Center or FMC) whose mission was to combat violence against migrant women. Based on cultural-historical activity theory, learning in and through social activism can be conceptualized as an activity that disrupts and alters the contexts that are creating social and historical dilemmas (Engeström, 2014; Gutiérrez, 2016). As our findings demonstrate, within the context of an urban entertainment district, the migrant women gathered in a local community park during the day to make their hidden bodies visible to the dominant community. Our conceptualization of body is guided by queer theory that illuminates *othered* bodies or *unintelligible* bodies that can be tacitly excluded from the normative materialization (Butler, 1993), and hence be masked and hidden in public places. We use the term *hidden bodies* to account for the fact that the migrant women in this study were working during the night, were stigmatized by the imposed stereotype that they were entertainers from a Third World country, and also domestic violence was once taboo.

In this paper, we address the following research question: How was a locally significant place (i.e., the park where migrant women congregated daily) transformed over time through the collective learning enacted by a group of activists? The data analysed for this article includes 1) four video/audio recorded dialogues between Author 1 and Author 2 as a representative of the FMC (each of these four dialogues lasted 120 to 180 minutes: total 649 minutes) happened between 2012 and 2019, 2) ethnographic field notes taken on activities at the FMC, 3) ethnographic field notes and photos taken during the shared walk and dialogue between Author 1 and Author 2 within the entertainment district wherein the FMC office was located, 4) on-site ethnographic interviews with two other members of the FMC (total 175 minutes), 5) policy documents regarding immigration and domestic violence between 2000 and 2019, and 6) collectively-written reports issued by FMC members between 2000 and 2019.

In our findings, we show how the park was transformed by people, but also, the park served to gather people for a collective action during the 20 years of activism. In addressing these women's problems, the FMC came to be connected with more and more people: organizations including the municipal government office, a local non-profit women's shelter, medical professional volunteers, and pro bono lawyers. Our findings show that the park was a place wherein integration of Filipino migrants into the local community happened over time — the place that had “a power of gathering” (Casey, 1996, p.25), holding together disparate and conflictual people and things. Specifically, our ethnographic findings demonstrate how local Japanese residents gradually showed concern and care towards Filipino migrant communities. Similar to what Teeters and Jurow (2018) depicted as relationships *de confianza*, that undergirded the food justice movement, our findings also demonstrate that a support network between the FMC and a local Japanese neighbourhood association was growing in the park and that moved the activism forward. Centralizing the activism led by historically unseen bodies and by bringing forward localized gender and migration politics, focusing on the history of Filipina migration in Japan, we hope to expand the currently dominant geo-political terrain of scholarship in the learning sciences.

Movements within the poetic and the political: Stories of everyday collective action within *Tutoría* networked communities of learners

Meixi, University of Washington, Santiago Rincón Gallardo, Michael Fullan Consulting, and Miguel Morales Elox, Redes de Tutoría

Educators, young people, and families have long been organizing to reclaim schools to advance their rights to learn and teach in ways that matter to them (Anyon, 2014; Kirshner, 2015; Zavala, 2016). While school-based organizing has often focused on economic, environmental, and social concerns, this paper examines a pedagogical movement - the movement and everyday actions of teachers, students, and families to design and develop a pedagogy called *Tutoría* (Rincón-Gallardo & Elmore, 2012). *Tutoría* has been called a counter-hegemonic pedagogy as it intentionally challenges dominant power relations in schooling. Instead it emphasizes learning as dialogic, within a larger learning ecosystem and community of learners (Brown & Campione, 1998; Cámara et al., 2018). For example, students often work in pairs with an object of joint attention where sometimes adults serve as tutors of students, other times students tutor peers and even adults. We ask: How and why do *Tutoría* participants learn and sustain a counter-hegemonic practice in two Mexican states in light of institutional frictions? Through reflective stories from movement actors, this paper theorizes connections between *social poetic* experiences of learning (Shotter, 2010) and renewed political possibilities in public schooling.

Drawing from sociocultural understandings of learning, this paper examines the dynamic nature of collective action and meaning-making within microlevel interactions, movements within and across spaces, and macro-level systems of policies and beliefs as people shape, and are shaped by participating in situated and

historical constellations of cultural practices (Gutiérrez & Rogoff, 2003; Lee, 2008). Hence for purposes of this paper, *social poetics* refers to micro utterances-experiences that resonate with us, and draw us to respond; in our responding, close the distance between self and other as we further place us in our surroundings (Shotter, 2010; Bakhtin, 1990). We examine the Tutoría movement participants' narrated experiences of *social poetics* and its political implications for organizing learning at school.

This study comes from histories of collaborative work that has taken various forms since 2004 (Cámara et al, 2018). The stories gathered in this paper come from a larger study conducted in two states in Mexico. We draw from a subset of 93 semi-structured interview narratives from Tutoría movement actors - students, teachers, and educational leaders in two Mexican states to understand their experiences of social poetics and the possibilities such moments generated for them through the stories they told of their work. These stories span 14 school and communities, 11 in Zacatecas and 3 in Guanajuato, where the movement was relatively thriving while each state having distinct histories in the movement. All interviews were transcribed verbatim, then 3 members open-coded a batch of ten transcripts and collectively developed coding schemes through grounded theory (Charmaz, 2001).

Overall, we find that movement actor's stories focused on everyday poetic experiences in teaching and learning— and that these were both the substance and vehicle for renewed political possibilities at school. First, we find that it was both movement actor's social poetic experiences while teaching and learning and experiences of institutional friction that inspired desires for pedagogical change at school. Second, experiences of social poetics across a wide range of movement actors allowed for multidirectional re-mediation of power. Because social poetics was experienced by actors at multiple levels of the school system, students, teachers, and families were able to organize for collective action from within (1) microinteractions with each other, (2) classrooms, and (3) home-community-school relations. This paper offers theoretical contributions to how pedagogical movements to shift dominant relations of power are relationally maintained and scaled across multiple levels and places. It makes the case for a growing attunement to designs that re-organize power and expand political possibilities in public schooling (Vossoughi & Booker, 2017), and the importance of multilevel actors to sustain grassroots movements that restore, humanize, and reconfigure school and home spaces towards self-determination in locally consequential ways (Bang & Vossoughi, 2016; Gutiérrez & Jurow, 2016).

Latino immigrants in civil society: Addressing the double-bind of participation for expansive learning in participatory budgeting

José W. Meléndez, University of Oregon

This article focuses on a study of participatory budgeting (PB), a process through which community residents are given the responsibility of determining how municipal funds will be spent on improvement initiatives in their neighborhoods. The emergence of PB in Brazil in the 1980's aligns with three distinct social-political movements emerging over the last 50 years. Studying by-products, such as PB, of social movements offers learning scientists a unique opportunity to identify and theorize on the transformative learning that takes place in the context of such social movements (Jurow & Shea, 2015; Meléndez, 2016). The PB process that served as the centerpiece of this research took place in Chicago's 49th Ward, a highly diverse community situated in the northernmost part of the city.

This study framed the 49th Ward's PB process—or PB49—as a form of deliberative democracy (Young, 2010). Deliberative democratic practices are characterized by the contemplative space they provide in which all residents and ideas are positioned as equal, relying on rational arguments to make decisions. PB49 included the competing interests of several actors—namely the Ward 49 alderman and staff, community members, and the researcher—each with different objectives and perspectives on the purpose of the process, who should participate, and how participants should be engaged. Centering on two iterations of the PB49 process, this study investigated the tensions in democratic practices that played out *in situ* when a historically underrepresented group—Latin American immigrants who were predominantly Spanish-language speakers—became involved.

The research question guiding the study explored instances when engagement in PB49 practices created moments of tension that either challenged or supported the inclusion of Latino participants in the PB49 process. In this context, *practices* refer to the situated activities that participants must engage in using tools and language—or artifacts—in order to perform the actions and roles required by an activity (Lave & Wenger, 1991). Adopting Wortham and Reyes' (2015) discourse analysis method for learning over time and events, the researcher coded the recorded interactions of participants at public meetings. The study findings revealed emergent tensions resulting from the talk-in-interaction between Latino participants as they attempted to engage in the practices of PB49. The author argues that in their collective attempts to engage in practices, individuals'

talk-in-interaction involved the double-bind of diversifying who was participating. Resolving this double-bind including creating a new activity structure to support the agentic participation of Latinos through a Spanish-Language Committee.

The thick description presented in this paper illustrates the expansive learning processes (Greeno & Engeström, 2014) that took place at the collective level, evidenced by groups of participants exhibiting qualitative changes in their agency to engage in the practices of PB49. This collective change emerged when participants had the opportunity to engage in designing for praxis (Zavala, 2016) that related to solving the double-bind of participation. Meanwhile, system-level learning arose through changes in practices as mediated through new artifacts, activity structures, and greater incorporation of new participants that includes role remediation (Bang & Vossoughi, 2016). The research found evidence of these occurring as Latino participants not only sustained their involvement over an entire cycle of PB49, but also began to use language suggesting that they themselves had begun re-mediating their roles vis-a-vis others in PB49 and the community. This type of language included making claims (Abrego, 1996) in the public-sphere. The author argues that claim-making by Latino immigrants in the PB49 process was a new type of language that mediated their dispositions to become historical actors as their political imaginaries began to be activated; engaging in what could be characterized as praxis.

Shifting education reform movements towards anti-racist and intersectional visions of justice: A study of a teacher's pedagogies of organizing

Josephine H. Pham, California State University, Fullerton, and Thomas M. Philip, University of California, Berkeley

#RedForEd teacher activism and teacher social movements are driving U.S.-based education reform in unprecedented ways. Through organized membership, progressive teacher unions offer expanded possibilities for educational change while simultaneously addressing interrelated issues of injustice, such as fair wages and access to healthcare (Rottman, 2012). At the same time, hegemonic interests tend to take precedence when diffusely organized groups come together to take action at a larger scale (Turner, 2007). Through close analysis of micro-interactional processes that contributed to teacher-led social movement alongside 50,000 educators, students, families, community members, and laborers, we situate our study within the Los Angeles, California teacher strike in January 2019 to examine the following question: What are the pedagogies of organizing that support diverse groups' learning of social issues impacting their community and themselves, while sustaining the interests and participation of marginalized social movement actors?

Drawing from a larger research project conceived and conducted by Author 1, we purposefully focused on the experiences of Makario, a justice-oriented high school teacher and lead union organizer, as a case study to analyze how his pedagogies of organizing facilitated the conditions in which coalitions were seeded, nurtured, and reshaped. Situated within historical site conducive to union-community partnerships, his pedagogies of organizing were jointly informed by fifteen years of prior union organizing experiences with epistemological roots in ethnic studies, Filipino transnationalism, and third world feminism, as well as the rise of progressive leadership in the teacher union who advocated for racial justice in addition to #RedForEd broader demands for economic justice. Utilizing 32 hours of video recording, ethnographic field notes, artifacts, and informal interviews as data, we employed cross-cutting analyses from linguistic anthropology (Goodwin & Goodwin, 2004) and raciolinguistics (Alim, Rickford, & Ball, 2016) to examine how situated teacher activism constructs, maintains, and/or transforms race relations through everyday practices. Through a shared analytic lens of language, the body, and the material environment with deliberate attention to race and power, we examined pedagogies of organizing as a discursive, dynamic, and embodied process that influences—and is influenced by—*what* the goals of the social movement are, *how* coalitions are built, and *who* the social movement is for.

The pedagogies of organizing that Makario embodied and enacted catalyzed cross-generational and trans-ethnic collective action that simultaneously and jointly shifted the broader goals of #RedForEd social movement towards anti-racist and intersectional visions of justice. Specifically, he developed and sustained the learning and collective action of marginalized social movement actors by 1) tailoring larger political issues to human-centered needs, interests, and emotions; 2) organizing physical spaces for collective action with deliberate attention to intersectional participation, such as access to chairs for elderly, printed chant sheets in multiple languages, and anti-racist poster signs; and 3) enacting emergent strategies that orchestrated collective action built around shared identities as laborers, with acute attention to his situated positionality and embodied presence.

Contributing to the burgeoning body of research in the learning sciences that has expanded our notions of learning to include learning within the context of community organizing and social movements (Curnow, Davis, & Asher, 2018; Esmonde, Curnow, & Rivière, 2014; Jurow, Teeters, Shea, & Van Steenis, 2016; Vea, 2019), we contend that Makario's intentional everyday practices contributed significantly to the quality and trajectory of mobilizing teachers alongside other laborers. At the same time, his pedagogies of organizing is influenced and reshaped by—and simultaneously reshaping—education reform movements in a largely anti-union context. We argue that teachers are essential for policy reform (Milner, 2013) and that an expansive notion of justice-oriented teachers' work can offer new democratic possibilities for education reform.

Toward productive intergenerational learning ecologies: Lessons from a youth-led social movement in South Africa.

Tafadzwa Tivaringe, University of Colorado, Boulder, and Ben Kirshner, University of Colorado, Boulder

In this paper, I examine youth agency in the context of a youth-led social movement in South Africa, Equal Education. I consider the viability and effectiveness of Equal Education's equity-focused and youth-centric organizational model as an alternative to adult-centric ways in which the relations between educators and young learners are structured in formal school environments. This work responds to the growing calls for recognizing power in the learning sciences (Esmonde & Booker, 2017) by offering insights on how to structure youth-adult relations in ways that are consistent with equity goals (e.g., Kirshner, 2008; 2015; Watts & Flanagan, 2007), and providing a model for facilitating youth agency in ways that duly account for structural dynamics (Booker, 2017).

I draw on data from an ethnographic study of Equal Education, a youth-led intergenerational social movement that advocates for equality and quality in South Africa's education system (Erickson, 1992). From 2014 to 2016, I was a participant observer among members of EE as part of an international study that conducted research on organizing in six different cities. I administered surveys, conducted interviews, moderated focus groups, and recorded observational field notes. To show the utility of these data in providing insights on youth-adult relationships, I analyze these data using an adaptation of Evans' (1995) concept of embedded autonomy.

Equal Education is a "member-based mass democratic movement of learners, parents, teachers and community members striving for quality and equality in South Africa's education through activism and analysis" (Brockman, 2016). The group's membership is 7,035 activists, mostly black high school and post-high school youth residing in townships (low-income urban areas) and rural areas. In an effort to ensure that the organization was democratic and that core members – youth – had sufficient structural power to shape the organization's agenda, Equal Education adopted a democratically elected arm comprised of members from the organization's structures and bestowed this arm with the ultimate powers to make binding decisions on the organization's agenda and operations. The organization morphed from a non-profit operating in one province to a national movement with an organizational model that matches its claim as a mass democratic movement. Importantly, though, because Equal Education's youth members necessarily have to work collectively with the rest of the organization's adult community (parents, teachers, and staff) in advancing equality, the group's youth-adult alliance provides a rich case to understand the kind of organizational principles that facilitate young people's agency for a productive intergenerational learning environment.

I show that the movement's organizational model allows for youth to be relatively autonomous from adults while ensuring that learning goals for both adults and youth are embedded within the social ties. Regarding youth agency, this organizational model facilitates youth action in more structured and substantial ways than merely giving youth "voice" as much as become the norm in theorizing youth agency (McLeod, 2011). Moreover, I show how the degree of autonomy associated with this model has the potential to address adultism in formal school environments.

Given how such an organizational model has led to a social transformation of the capabilities and roles of youth within a policy process that conventionally privileges adults by shifting conceptions of expertise and learning identities, I argue that such a model has the potential to address challenges confronted by educators committed to acknowledging the role of learners in transforming learning ecologies and broader society (Booker, 2017; Valenzuela, 1999; Watts & Flanagan, 2007). Given its rich history of complex, yet successful youth-adult partnerships, the South African case offers a useful model of navigating challenging power dynamics within a global context such models largely remain elusive (Strong, 2018).

Educational intimacy, prefiguration, and learning towards social change: The case of an LGBTQ+ youth group

Suraj Uttamchandani, Indiana University

This study presents findings of a multi-year critical ethnography alongside Chroma (pseudonym), an LGBTQ+-themed community-based social group for youth ages 12–20 in the Midwestern USA. Chroma contains a Teaching Committee (TC), consisting of Chroma members who offer educative experiences for teachers and youth-serving professionals about working with LGBTQ+ youth. The TC formed in 2015 as Chroma Youth wanted to explicitly engage in advocacy to improve LGBTQ+ youth's lived experiences and to help teachers and other youth-serving professionals better understand issues relevant to LGBTQ+ youth. Since its founding, the TC has trained over 1,000 adults across local and regional platforms (Dennis et al., 2019). As an adult volunteer for the TC since 2016 and a researcher, I was an “unusually observant participant” (Erickson, 2012, p. 239) in the space. This study understands learning as organizing possible futures (Gutiérrez & Jurow, 2016). I ask what kinds of social relations developed in Chroma's TC and how did those relations become consequential for youth's future-shaping advocacy?

This ethnographic study drew on audio recordings of 26 TC committee meetings, six trainings, and four extended worktime sessions that took place between June 2018 and June 2019. In examining youth's conceptual practices and their consequentiality (Hall & Jurow, 2015), I also sought to avoid a “damage centered” conception of youth activists (Tuck, 2009) and instead offer a more complex understanding of how their collective learning unfolded.

Findings revealed that TC meetings contained significant youth reasoning about gender and sexuality as well as rhetoric. This reasoning, however, developed alongside and through humor, accountability, and facetious self-deprecation. This collection of sociodiscursive practices together foster what I term *educational intimacy*. Inspired by queer-theoretic perspectives on the learning sciences (McWilliams, 2016), educational intimacy describes the intimacy that exists between people who work together towards shared desired futures, that is, who are learning together. Educational intimacy is not always present in learning environments, particularly for LGBTQ+ learners who are tightly policed in school classrooms (Kosciw et al., 2018).

This study theorizes how educational intimacy is consequential for learning as it supports prefiguration (Yates, 2014; Curnow, Davis, & Asher, 2019), in which Chroma youth make Chroma TC meetings into the kinds of sometimes-joyous/sometimes-difficult spaces that are typically denied to LGBTQ+ youth in school classrooms (Kosciw et al., 2018) — that is, the kind of space Chroma youth seek to bring about through their trainings and activism. For learning scientists, then, educational intimacy offers a new perspective on peer collaboration and adult facilitation practices that allow for deeper engagement and meaning-making. From the perspective of learning as future-organizing, educational intimacy offers an answer to Vossoughi and Booker's (2017) questions, “What is the role of play in prefiguration? Of love?” (p. 228). This study helps characterize learning in community-based groups towards social transformation that learning scientists should take seriously.

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Multimodal Data Analytics for Assessing Collaborative Interactions

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Abstract: This symposium will discuss the current status of the research and development of multimodal data analytics (MDA) for the observation of collaboration. Five research groups will present their current work on MDA, each with a unique focus on different data sources and different approaches to the analysis and synthesis of multimodal data sets. A few themes emerge from these studies: i) the studies seek to examine collaborative behaviors as a process in ordinary settings, both formal and informal; ii) with MDA being in its early stage, manual and computational approaches are taken complementarily, also using human annotation as the ground truth for the computational approach; and iii) several different discipline-specific research and development lines contribute integrally to generating authentic measures of collaborative interactions *in situ*, making this line of research transdisciplinary.

Overview of symposium

In both formal and informal learning, in-person collaboration has typically been studied by human observers meticulously attending to interaction behaviors and taking notes while the collaboration is ongoing, then analyzing the observations a posteriori at the microgenetic level. Manual observations and analyses of the resulting rich and thick data demand tremendous amounts of resources and severely limit the scalability of the programs that support collaboration, and in turn the research progress. Emergent computational approaches to what is popularly referred to as “Big Data” can enable the automation of the collection, processing, and analysis of a wide range of collaborative behaviors in real time (Baker & Siemens, 2014; Martin & Sherin, 2013). Yet, it is unknown to what extent these computational approaches are being developed, tested, and used by the LS community for the authentic assessment of collaborative learning processes *in situ*. Also, theoretical and methodological perspectives and assumptions must be clarified to provide a solid grounding to the application of the new approaches.

This symposium brings together six studies (S1-S6) that employ multimodal sources of information to examine in-person or digitally connected collaborative behaviors. The studies are in different stages of development: some have the analysis results (e.g., S3, S4), and for others, data analyses are still in progress (e.g., S1, S2). Each of the studies is unique in their use of different modalities, different age groups of learners, varying task domains, and/or formal and informal learning contexts. The studies collected rich sets of individual’s collaborative behaviors in ordinary settings over time and analyzed them both manually and computationally. By discussing these research cases in the symposium, we will be able to jointly build the current knowledge base on the progress in multimodal assessment of collaborative learning processes. More importantly, in many technology-enhanced learning environments, students engage in collaborative problem solving in pairs or in groups. We give special attention to advanced computational approaches to automating the collection, analysis, and synthesis of multimodal collaborative behaviors. The guiding question for the presenters and the audience is, *in what ways and to what extent does multimodal data analytics help assess on-going collaborative interactions over time?* Specific questions include i) *What sources of multimodal behaviors are observed and analyzed?* ii) *What kind of information is derived from each source of multimodal behavior data?* iii) *What theoretical*

assumptions, conceptual frameworks, and/or methodological tools have been used and need to be further explored to analyze and synthesize the multimodal sources of information for assessing collaborative engagement?

The theme of this symposium will be a significant contribution to ICLS 2020 pinpointing the *interdisciplinarity of the learning sciences*. Multimodal data analytics of collaborative interactions requires multidisciplinary theories and expertise, inevitably involving teams of researchers from multiple disciplines, such as learning scientists, computer scientists, engineers, psychologists, and others. The symposium studies will exemplify how discipline-specific expertise works together to generate transdisciplinary knowledge and models to examine collaborative engagement authentically.

Studies (S1 - S6)

S-1. Speech-based multimodal analysis of collaboration

This section presents two case studies projects that implement a speech-based analysis of group collaboration using data from individual audio channels. Both cases build off of initial work that was developed within the Speech-Based Learning Analytics for Collaboration project (D'Angelo et al., 2019; Smith et al., 2016). This project utilized features derived from Speech Activity Detection (SAD) as well as manually coded indicators of collaborative behaviors to predict the quality of small-group collaboration among middle school students working on short mathematics problems. Individual audio channels (one for each student in a triad) were used to better understand individual and group contributions to the collaboration.

The data collection setup allowed students to speak freely, resulting in audio recordings with overlapping speech from the students in each group. SAD-based features were extracted that characterized either the individual student speech or the speech patterns of the group. These features capture information about the number, duration and location of the speech regions. Specifically, we extracted features that capture information about the overall speech duration and the “spurts” of speech. Spurts were defined as regions of speech that are at least 50ms long and were uninterrupted by pauses longer than 200ms. As students deal with the cognitive load of simultaneously solving problems and negotiating with their peers, they frequently interrupt each other or speak in short phrases.

We extracted these SAD-based features across the channels individually and in combination, taking into consideration speech activity from regions in which each individual student was the only speaker, when each student spoke, ignoring speaker overlap, when each pair of students spoke simultaneously, when all students were silent, or if all students spoke simultaneously. Duration-based features for individual and pairs of students were mapped to the group level using ratios and entropy statistics as described in Smith and colleagues (2016). These features capture information about the distribution of speech duration across the members of the group. The spurt-based features capture information about turn-taking and other features of the speaking style of the group.

Case 1: Engineering problem solving

This case is focused on small groups of undergraduate engineering students that worked collaboratively on tablet-based engineering problems. The teaching assistants (TAs) for this class are graduate and undergraduate students who do not have extensive teaching experience and need prompts and other support in order to successfully help students in their collaborative problem solving. This project involves working on analysis of speech data to aid in the prediction of problem-solving situations that need the help of a TA through a prompting system.

Data collection for this project, completed in Spring 2019, involved three groups of engineering students over the course of five weeks of instruction. Each class lasted approximately 50 minutes and students were engaged in collaborative problem solving for most of that time on synced tablets that allowed them to see each other's drawings and annotations of the problem. Individual and group audio was collected and synced with other modalities of data, including the tablet log data and video data.

Case 2: Medical problem-based learning

This case involves studying larger groups, ten medical students, engaged in collaborative problem solving with the assistance of a facilitator. The case combines multiple audio sources to look primarily at instructor versus group speech. Problem-Based Learning (PBL) is a popular student-based model of instruction in medical education and is guided by a facilitator who is expected to shape students' conversation so that it generates learning. Facilitators need to be deeply engaged in the conversations to coach students toward considering important aspects of the case they may not have identified and to promote engagement and thinking about target concepts. This role requires dynamic and real-time decisions about when to intervene and how to best do so in the context of a particular case at a particular point in time in the discussion.

Data collection for this project, completed in Summer 2019, used an individual audio channel for the facilitator and a group microphone for the students. Collecting 10 channels of audio data for individual students

was not feasible from a practical standpoint, and also would have been unlikely to capture much additional information. This project involves developing a process of visualizing features extracted from speech data from the PBL sessions that will enable the identification of patterns in speech frequency, proportion, duration, and speaker turns. These visualizations, along with a professional learning community, will allow facilitators to improve their implementation of these PBL sessions.

S-2. Video processing for the design of intuitive embodied interactions

This paper discusses approaches to the analysis of videos recorded during a series of formative user studies for a prototype interactive installation at Discovery Place, a science museum in Charlotte, NC. Our work focuses on the design of a specific class of embodied interaction: Human-Data Interaction (HDI) (Cafaro, 2012; Elmqvist, 2011). Designing HDI installations that can engage museum visitors is very challenging. HDI displays often compete with surrounding stimuli (other exhibits, people, signs, etc.). This limits the number of visitors who notice them, a phenomenon called display blindness (Cheung, Watson, Vermeulen, Hancock, & Scott, 2014). Also, museum visitors do not consult user manuals before interacting with an exhibit and often think that the system is broken if the installation does not respond to their signal quickly, a phenomenon called affordance blindness (Coenen, Claes, & Moere, 2017).

Museum visitors can use our installation to explore and compare two datasets. The visualization consists of two interactive globes, displayed on a 75" screen. Data are visualized at a country level, using color gradations (i.e., darker colors mean higher data values). Each globe visualizes one dataset expected to be thought-provoking for museum visitors and that illustrate issues such as gun violence, immigration, and unemployment.

This presentation discusses how to automatically identify the gestures and body movements that visitors typically make in front of an interactive installation. This is to develop techniques to move gesture elicitation studies (Wobbrock, Morris, & Wilson, 2009) out of research labs. The context of use has a profound impact on interactions in museum settings, and therefore researchers need to craft strategies for conducting elicitation studies *in situ*. We want to assess if observing the gestures and body movements of visitors in-situ will produce the gestures and body movements that are more intuitive and easily discovered. To achieve this goal, we need to design a tool that can track people's movements from video recordings and is able to identify the most common gestures and body movements. Also, an immediate use of this tool is to investigate if people perform different gestures and body movements when interacting alone with the screen, vs. when they collaboratively explore our data visualization in groups.

To explore different levels of engagement with our prototype, we conducted a manual analysis. Two researchers reviewed and coded the videos of the experimental sessions using a video annotation tool (Anvil). Because of the nature of our prototype (a large, interactive screen), visitors generally interacted with it in groups. The coding was structured using multiple tracks (to represent, for instance, the age range of the user, and the gestures that she/he used). In order to account for multiple users, we had to duplicate such tracks for each of the users who collaboratively interacted with our installation. This was challenging for the coding process: it forced us to decide a-priori the maximum number of visitors that we wanted to code, and it complicated our effort to ensure inter-coder reliability. We considered the segmentation agreement, i.e., whether the two coders agreed on the beginning and end time for a code, and the category agreement, i.e., whether the two coders agreed on the actual code on a segment of the video. In ongoing analysis, we are using a video analysis tool (OpenPose) that automatically labels gestures and body movements to explore collaborative interaction patterns. We will discuss the challenges that we encountered when crafting a dictionary of the gestures when tracking multiple people in collaboration.

S-3. Epistemic Network Analysis to connect affect and dialogue in collaboration

Distributed environments provide a unique opportunity for learners to work together across geographical boundaries. This work examines the collaboration of middle and high school age adolescents in afterschool clubs from different countries across four continents as they develop STEM content-focused media projects. They share ideas and provide feedback asynchronously through email or Slack (a cloud-based team messaging application) or synchronously through video conferences from two or more sites.

Video conferences are a key source of data, recording the interactions of students as they collaborate. Participants' conversations in the conferences were transcribed, followed by qualitative coding for constructs that emerged from the text. While this method provides a tangible analysis of the recorded data, it does not account for the emotional interactions of participants that video data can capture. Combined use of visual and spoken data provides genuine information about the collaboration dynamics but presents a complex challenge on how to integrate them meaningfully with methodological rigor.

Epistemic network analysis (ENA) provides a useful analytical tool for examining the relationships among constructs derived from multiple types of data (Lund et al., 2017). In this study, ENA was utilized to model the connections among group discourse and the affective states of individual participants within a recent temporal context. The use of the moving window allows for the model to capture the linkages that are created as participants respond to and build upon each other's utterances and emotional expressions.

To prepare the data for ENA, a qualitative coding approach was used for the transcribed dialogue. Coding for affect involved identifying the presence of positive or negative emotions demonstrated by each participant (Pekrun, 1992). Neutral emotional states were indicated as the absence of a positive or negative affect. The coding process became complex, depending on the number of participants and the length of the video conferences because the emotional state of each participant must be accounted for the entire duration of the online meeting both when they were speaking and when not speaking. Once the affective valence for each individual was coded, it was integrated alongside the coding of dialogue into the ENA webtool to examine connections between positive and negative affect with discourse constructs. Examples of this analysis can be seen in Figure 1 (Lee et al., 2020). The data used in this analysis were collected from a 30-minute online meeting held in November 2018 with learners from Kenya and the U.S. The models visualize the relationship among constructs in the group discourse and positive affect exhibited by a Kenyan and a U.S. student for the entire duration of the meeting even when they were not speaking.

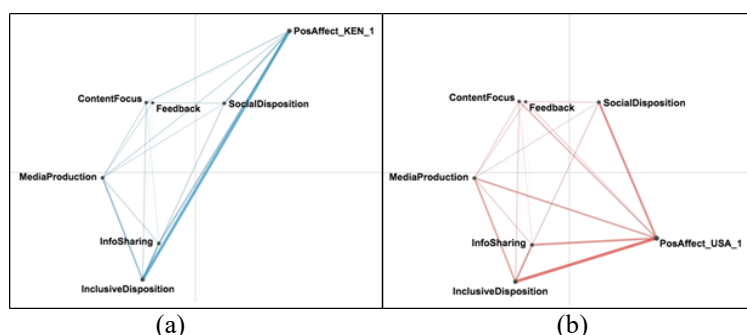


Figure 1. Sample ENA models for a Kenyan learner (a) and a USA learner (b).

While it provides an opportunity to integrate two sources of data, ENA also entails several challenges that will require further attention. The first issue was harmonizing different types of data into a single model, including determination of the appropriate segmentation and moving window size. While an utterance is often used to segment discourse data, researchers will need to consider if it can be applied for analyzing affective states within video data. Similarly, incorporating multiple types of data will require analysis of how recent temporal context is conceptualized and defined for each data type. Second, further work is needed to develop new approaches to handling simultaneous data within ENA. In the example above, the simultaneity of individual affect was modeled as separate constructs, which was feasible due to the small number of participants and constructs involved. Addressing this will promote broader application of ENA.

S-4. Information theory to assess engagement in robot-mediated collaboration

Studies 4 and 5 deal with designing robotic interactions to support equitable collaboration among young children. Collaboration is one of the key factors for young children's social and intellectual development as they start public schooling, and critical for their academic success. Leveraging social robots' appeal for young children, our project has introduced a humanoid robot as a collaboration mediator, instantiating an interaction triad of two children and a robot, where the children are encouraged to engage in collaborative conversations.

In this section, we report a study on children's engagement with each other and with the robot over time. In line with viewing engagement as a three-faceted phenomenon including behavioral, emotional, and cognitive engagement (Fredericks et al., 2004), children in our study expressed their collaborative engagement through talk, emotion, and body posture and gestures. We conducted a process analysis of these different expressions and their changes over time. Acknowledging that multimodal data analytics is in its infancy, we had four preliminary research questions: Q1) *How does a child's engagement progress over time?* Q2) *To what degree do the three multimodal data types correlate per child?* Q3) *To what degree is the robot's mediation related to the child's engagement?* And Q4) *To what degree does the engagement relationship of two children in a pair evolve over time?*

We explored a new approach to synthesizing multimodal datasets to assess children's collaborative engagement, guided by the aforementioned engagement theory and the information theoretic analysis of *mutual*

information (MI). We used data from two triads participating in three sessions, each taking 20 mins: children A&B and C&D. A total of 60-minute audio and video data were used for each triad, recorded using four directional and ambient microphones and two HD video recorders. Audio data were processed and analyzed by automatic speech recognition at 3-second intervals. Matching video data were annotated manually at the same interval for kinesics (body posture and gestures) and linguistic alignment (whether children respond to each other and/or the robot). The assessment phase came after the analyses of each of multimodal data sets were complete and also involved calculating the engagement values as a compound variable for each child. With the MI construct, we quantified the dependence among three time series of multimodal data: i) vocal pitch and intensity as evidence for emotional engagement, ii) kinesics for bodily engagement, and iii) linguistic alignment for cognitive engagement. Dependence was defined as shared information (variable I), with a value between 0 and 1 (perfect sharing). We computed collaborative engagement as the sum of bodily engagement (*Kinesics*), cognitive engagement (*Alignment in utterances*), and emotional engagement (*Intensity* and *Pitch*). Denoting these values at a time t , engagement, $E(t)$, was calculated as

$$E(t) = K(t) + A(t) + \frac{I(t) + P(t)}{2}$$

For Q1, Figure 2(a) depicts regression lines of child A's and C's engagement (y-axis) over time (x-axis). Similar trends are found for the children in the same group. Regression lines are best fits of all compound engagement values (blue dots) for 1-min intervals. Fit values are as high as .6, meaning that the lines adequately represent how engagement evolves. Also visible is engagement consistency of a child. Child C's values are clustered along the regression line (more consistent), but more dispersed for child A (less consistent). For Q2, we calculated means and *SDs* of normalized MI between data sources for each child over all sessions, finding that voice Intensity and Pitch correspond more with each other ($I > .75$ for all sessions) than Kinesics and Alignment ($I < 0.1$, for all sessions). Alignment conforms strongly with both Pitch and Intensity ($I > 0.6$), meaning that most of the children's speech is collaborative. We found no large variation between these values across sessions.

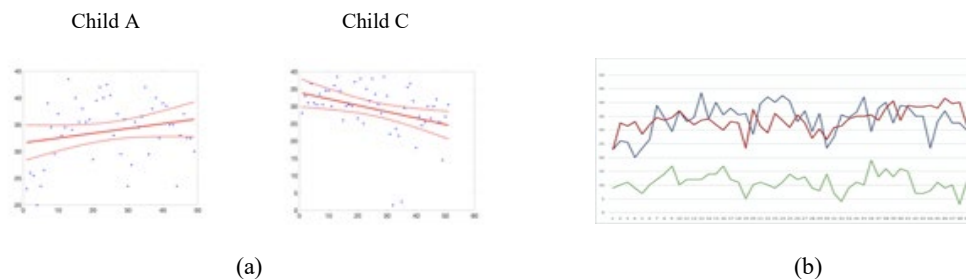


Figure 2. Regression lines of a child's Engagement over time (a) and trends of children and robot talk (b).

For Q3, the frequencies of engagement values and robot talk per 1-minute interval are presented in Figure 2(b). Trends in a child's Engagement and the robot's mediating talk over time correspond with each other, showing that their interactions were reciprocal. Correlations between child engagement and robot speech range between 0.57 and 0.76, confirming visual analysis. There were no statistical differences in this range. For Q4, we compared the engagement relationship of the two children in the same group over time. Means of normalized MI are .63 ($SD = .2$) for A & B and .51 ($SD = .23$) for C & D, showing a higher MI relationship for children A & B.

Through both theory- and data-based modeling, we were able to compute a compound variable of children's collaborative engagement. The strength of this approach was evident when we compare it with qualitative human observations on site. For example, the progression in engagement of child C in Figure 1(a) showed that her engagement decreased (even with no statistical significance); the on-site observations noted that her interest moved from the task at hand to the robot itself, so her collaborative engagement with child D decreased. Analyzing data dispersions, it is evident that some children's engagement is more consistent over time than others'. Thus, our approach allows the individual characterization of a child to be used for identifying intrinsic and extrinsic factors for those individual variations.

S-5. Automated video analysis of human vs. robot mediated collaboration

This section is a continuous effort to examine collaborative engagement of children in triadic interactions. For this study, we examined if there is any difference in children's engagement when they had a human mediator compared to when they had a robot mediator. A similar interaction triad of two children and a mediator were implemented, where the children are encouraged to engage in collaborative conversations. A new group of twenty-four children participated in both of two phases, one with a human mediator (the first two weeks) and the other with a robot (the second two weeks). The study has two primary goals: exploring AI-based techniques that could

lead to more automated methods of engagement measurement, and identifying the challenges involved in order to formulate structural recommendations for the community, to inform future study design and improve the likelihood of successful automated engagement measurement.

Towards these goals, the research team is now annotating the levels of overall engagement and more specific collaborative features, such as individual gaze targets and body orientation, at every three-second interval. Following this, we will leverage analysis techniques explored in a study of Superpower Glass, a wearable learning aid for children with autism. As part of the study's exploratory analysis, a number of automated techniques were applied to evaluate communication and engagement. Applying these approaches to the current study, neural network-based face detection provides locations of faces in the scene, as well as several landmark features representing salient features of each face (e.g. the shape of eyes, eyebrows and mouth).

As presented in Figure 3(a), combining this face detection (face locations shown as green boxes) with a customized object detection framework that identifies the robot's location (orange box) enables calculation of the learners' orientation towards the robot mediator. A convolutional pose machine (CMU's OpenPose) identifies key body pose features such as the head pose direction, hand and joint locations. As presented in Figure 3(b), this pose estimation is applied to further enable body orientation analysis and gauge kinetic aspects of engagement. Together these visual features will inform the construction of higher-level

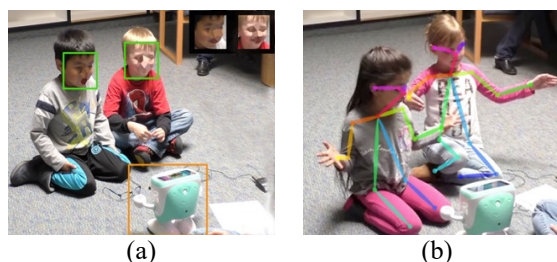


Figure 3. Examples of automated video analysis techniques.

engagement features, such as instances of gaze directed from a learner to their peer or the robot, and body orientation relative to the group. Convolutional neural network-based emotion recognition applied to detected faces will provide prediction of emotional state. We will then explore a number of approaches (from basic logistic regression to recurrent neural networks and three-dimensional convolutional neural networks) for using these features to predict the overall engagement level of a session as it progresses.

There are significant challenges in the automated analysis of collaborative engagement from video. Even when the structure of a common mediation narrative and a generally consistent locale are provided, comparing engagement between teams of children is extremely difficult due to a number of factors, such as heterogeneity of background activity (e.g. others present in the room), differences in camera location, relative starting alignment of the students to human vs. robot mediators, and individual differences in how learners express engagement. Identifying the effects of these variations on the techniques being explored will be critical for the goal of producing structural recommendations for future studies.

Additionally, some students may exhibit even more significantly different expressions of engagement, including those with learning challenges. Ensuring inclusion of such learners and a diverse representation of students overall in ongoing sessions will be a vital step towards developing more robust, broadly applicable and equitable methods for automated engagement analysis.

S-6. Collaboration Literacy Feedback Tool (CLiF)

Providing and receiving feedback about collaboration skills in real classrooms require a tool that is able to 1) capture synchronized multimedia signals from the environment, 2) automatically extract, analyze and fuse multimodal features from the recordings in real-time, and 3) provide multimodal feedback to students and instructors. This section will discuss our current advances in solving the technological and pedagogical challenges involved in creating this kind of tool, that we have named CLiF (Collaboration Literacy Feedback).

The first challenge was the ability to record synchronized multimedia signals of students' actions and interactions during collaborative learning activities in a way that is affordable and easy-to-use. We solved this by designing and building a low-cost sensor array consisting of a Raspberry Pi 3B microcomputer, a 6-microphone array and a 220-degree fisheye camera, as presented in Figure 4(a). A custom-made software system enables the synchronized use of several recorders at the same time with minimal training and setup. This system is able to capture video with a resolution of 1640x1232, a frame rate of 15 fps which is compressed using the high-quality profile of the H.264 codec. The captured audio is 6 channel, 16 bits, 16 KHz without compression. The system can be expanded to capture other media (digital pens, electro-dermal-activation) via external sensors through bluetooth connectivity. The approximate cost of each sensor is 150 USD.

Data extraction and analysis involves data capturing, a multi-level process, and AI techniques similar to the approaches described in various sections above. Lower-level features, such as body and head posture and speech content and speaker ID, will be used to create higher-level features that estimate relevant collaboration

constructs. For example, gaze direction coupled with speaker ID and speech content provides an estimation of the level of attention that a student pays to her/his teammates and uptake of ideas across speakers. The final step in the project is to explore new and innovative ways to provide feedback to students and teachers. The main challenge in this step is to develop technologies that could help us exploit the multimodal nature of human communication to provide feedback in a way that is not disruptive of the collaborative activity. Online feedback (during the activity) will be compared with offline feedback (after the activity). Also, different combinations of automated vs. human feedback will be explored to determine their cost/benefit ratio.

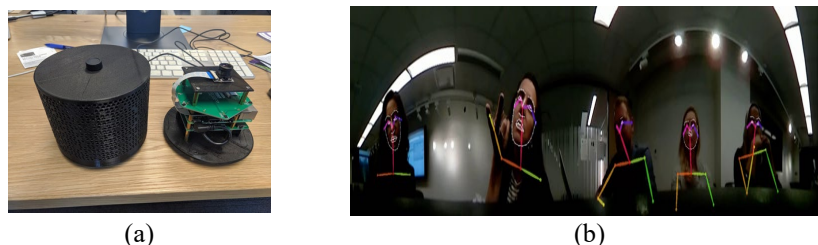


Figure 4. Collaboration recorder (a) and body posture and facial features extracted (b).

One distinctive aspect of CLiF is that has been designed to respect and protect the privacy of students and instructors. Data ownership and the right to override any algorithmic decision from data capture to feedback interfaces. is embedded in the design of the feedback system. For example, each student has the capability of removing her data from the analysis or to restrict who has access to the final analysis of the data. All the human-faced systems will be evaluated according to perceived usefulness and level of intrusiveness.

Discussion

The work presented demonstrates the ways in which multiple behavioral modalities were marshalled to derive synthetic accounts of collaborative learning processes. The studies addressed the research problems by using complementarily both manual and computational approaches to collecting and analyzing behavioral data ranging from audio (S1, S4, S6) to visual (S2, S3, S4, S5, & S6), to utterances (S4, S5), and to log data (S1). Common to all was that data were collected unobtrusively and in authentic settings. Multimodal data analytics are still evolving, and it is noteworthy that human annotations were warranted as the ground-truth for the development of computational models.

Overall, the studies sought to overcome challenges with the large amount of analytical work while analyzing and interpreting of collaborative processes data, and thus served as testbeds for research programs aiming to leverage the potential of Big Data in education research. The computational approaches that the studies used enabled the automatic analysis of multimodal data sets and the production of credible outcomes in a timely manner (even in real time). This significantly increases the scalability of the research examining individuals' and groups' collaborative processes authentically at both microgenetic and global levels and for an extended time span. It is also foreseeable that the programs proven effective locally for supporting collaboration can be scaled up.

A challenge common to all is the extraction of meaningful information from the data, i.e. identifying information in the data that is relevant to answering research questions and that is grounded in theories of learning. The significance of learning theories was evident in the studies. Relevant learning theories drive choices of the appropriate computational approaches and the selection of information in the ontological and temporal perspectives. Some studies relied on keeping temporal segmentation at a minimum (e.g., every 3 sec) so as to capture changes in behaviors thoroughly, through which inferences to affective dynamics (S3) and collaborative engagement (S4, S5) are made. S1 and S2 selected the data that were meaningful within a theoretical framework, through which inferences to learning processes were made. S4 exemplified how learning theories are operationalized into formalisms that validated computational analyses. This area should be further developed.

Linking learning theory to computational models requires close collaboration among experts from multiple disciplines, and the studies presented evidence for the effectiveness of this multidisciplinary collaboration. Learning scientists, behavioral scientists, interaction design researchers, and computer scientists were able to jointly create new conceptual, theoretical and methodological innovations, breaking new ground in the study of collaboration in authentic contexts.

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Bridging Research and Practice to Implement Change in Teaching and Learning at Scale

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Abstract: This symposium explores the challenges of applying research at scale through the consideration of a case study of a collaboration between a consortium of learning sciences researchers from five institutions and science education leaders from 10 US states. The case is the OpenSciEd Project, which is an initiative to create and disseminate a 3-year, middle school science program. The OpenSciEd project has the explicit goal of meeting three competing goals in order to have impact at scale: implementing findings from research (research-based), meeting the practical constraints of American public school classrooms (practicality), and creating products that will be widely adopted in the market place (marketability). In this symposium, we will discuss how these three competing goals have influenced the organization of the project, the design of instructional materials, the design of professional learning experiences for teachers, and the collection and analysis of data in field trials.

Symposium background

Learning Sciences researchers often aspire to having a large-scale impact on educational practice. Achieving impact can depend on much more than having relevant and robust research findings. Studies of research utilization suggest that there are multiple paths to impact: practitioners can take up findings to make decisions regarding policies and programs; they can use research concepts to inform thinking about persistent problems of practice; and they can use tools that reflect key principles derived from a body of research (Weiss & Buculavas, 1980; Penuel, et al., 2017). In this symposium, we focus on this last path, through the exploration of a project that is developing and disseminating tools derived from research. In this case, the tools take the form of instructional materials and resources for teacher professional learning. Well-designed tools can be a particularly powerful means to communicate and help practitioners take up instructional shifts, particularly when they provide models for how to change practice in significant ways (Ikemoto & Honig, 2010). Instructional materials are tools that teachers “participate with” (Remillard, 2005) to make changes to practice. As teachers use them, their classrooms transform, and they can come to see new possibilities for student learning. In this symposium, we consider the OpenSciEd project, a project to develop an open content (2) science curriculum for middle school designed to:

- Enable schools to achieve the goals of the Next Generation Science Standards (NGSS; NGSS Lead States, 2013),
- Provide equitable learning opportunities for students from populations that have historically been underserved,
- Be adopted and successfully implemented by a large number of schools across the U.S.

The OpenSciEd project was launched in 2017 by the Carnegie Corporation of New York, a private foundation, and Achieve, the organization that worked with 26 states to develop the NGSS. Their objective was to meet the need they observed for high quality instructional materials for the NGSS. Their idea was to bring researchers with the expertise and experience to create high quality materials together with state-level leaders in science education who could collaborate with researchers in the creation of materials that would be marketable and practical to implement. The Carnegie Corporation, who has since been joined by three other funders, selected a consortium of five organizations (the Developers Consortium) to develop the OpenSciEd program and recruited state science education leaders from 10 states (the State Steering Committee) to oversee the work of the developers and to facilitate the field testing of the materials in their states.

In this symposium, members of the Developers Consortium will describe challenges that we, as learning scientists, are experiencing in this attempt to translate research into instructional materials and professional learning programs with the goal of large-scale—both broad and deep—impact. We will focus on the challenges

of meeting the competing goals and constraints inherent in this work, including creating products that are:

- Research-based, remaining faithful to the richness and complexity of the research base supporting science learning in social contexts;
- Practical, ensuring that classroom and professional learning materials are feasible to implement across the diversity of classroom contexts found in American public schools; and
- Marketable, producing products and programs that are attractive to large numbers of schools and districts, and affordable for them to implement.

The four presentations in the symposium will describe how we have addressed these challenges in specific contexts: 1) the organization of the OpenSciEd project, 2) the design of instructional materials, 3) the design of professional learning programs for teachers, and 4) the collection and analysis of data in field.

Organization of the OpenSciEd project

Daniel C. Edelson, BSCS Science Learning

In many respects, the OpenSciEd project has been structured to expose and explicitly address the tensions between the three goals of being: research-based, practical, and marketable. The fact that the project founders selected researchers to lead the development reflects their commitment to creating a research-informed program. The fact that they sought out educational leaders from state educational agencies and educational service agencies to serve as a steering committee reflects their commitment to practicality and marketability. The commitments that they asked the members of both the Developers Consortium and the State Steering Committee to make and the decision-making structure that they put in place ensured that the goals and concerns of both researcher and practitioner perspectives would be carefully weighed in important decisions.

From its earliest stages, important decisions about the project have been negotiated by the members of the Developers Consortium and the State Steering Committee, with the objective of achieving compromise that would enable the project to achieve its end goal. This end goal was described in an early consensus document as:

A group of state education agencies, working with school districts, classroom educators, experienced science curriculum developers and the science education community, will create and field test a complete set of robust, research-based, open-source science instructional materials that are aligned to the Framework and NGSS and accessible to all students, while building demand for the materials and implementation supports in tandem. (OpenSciEd, 2018a)

The mechanism for making these decisions became the development of guiding documents for the project. In the first few months of the project, the State Steering Committee and the Developers Consortium jointly created six guiding documents:

1. State commitments, laying out the expectation for all state partners, including their participation in a steering committee and implementation of a field test in their state;
2. Guidelines and guiding principles for the Developers Consortium, a high-level description of the components to be developed;
3. Overview of program design specifications, describing the contents to be included in the program's specifications
4. Professional learning design principles, describing key attributes that the professional learning programs and resources for OpenSciEd must possess
5. Data collection sampling strategy, laying out the basic strategy for collecting data in field trials
6. Operations and governance functions, describing a new organization to be established to oversee the development of the OpenSciEd program and its dissemination.

What brought these state leaders and researchers together was two shared beliefs: (1) high-quality, low cost instructional materials are necessary to enable schools and teachers to achieve the goals of the NGSS, and (2) there was no other mechanism in place that would meet this need. What enabled them to achieve consensus on these foundational documents was their recognition of the need to compromise in order to achieve this shared

goal. State representatives were asked to represent the interests and concerns of their states but not to object to proposals based on the unique concerns of their states. Developers were asked to advocate for approaches that are supported by research evidence, but to recognize the need to compromise based on practical challenges of implementation across diverse public school contexts and the considerations of the marketplace.

Two early issues tested the willingness of participants to compromise and ultimately laid the foundation for the collaborative process that has played out over the subsequent years. The first issue required substantial concessions on the part of state representatives. This issue pitted practicality against marketability. In developing a scope and sequence for the program, the Developers Consortium analyzed the standards across the ten partner states and found that 4 of the 10 states specify grade levels at which specific standards are to be taught. (The NGSS does not specify a sequence for standards within the 3-year middle school grade band). We found that the likelihood that two states had assigned the same standard to the same grade was roughly 1 in 3. Recognizing that this marketability issue for their individual states could defeat the project before it even got started, all ten states agreed to collaborate with the developers to sequence instruction in a way that had the strongest justification in research on learning progressions.

The second issue forced a compromise by developers. It pitted the goal of being research-based against practical and market considerations. All state partners expressed a sense of urgency. They saw a limited window of opportunity to release these materials to the marketplace before schools and districts would be forced to adopt by policies in place. In fact, in November 2017 at the first convening of the partner states, they argued that the project would fail unless initial instructional materials could be in field testing within 12 months and released to the public within 24. For researchers with longstanding commitments to careful development of instructional materials and professional learning programs through co-design with teachers and multiple cycles of development, classroom testing, third-party review, and revision, this was a stunning request. However, recognizing the validity of the state partners' concerns, the developers agreed to a timeline that called for only one cycle of field trials and revision of each 6-week unit prior to public release. This timeline called for the release of the first three units within 18 months, followed by the release of three new units every 6 months over a three-year period.

These are only two of dozens of compromises that have been negotiated over the course of the project so far. They are the product of a structure designed to bring tensions to the surface, and they helped establish a culture that recognizes the need for compromise to achieve shared goals.

Design of OpenSciEd instructional materials

Brian J. Reiser, Northwestern University

Developing the program of instructional materials has involved two strands of work. First, we developed two foundational documents to guide design: a scope and sequence and a set of design specifications (OpenSciEd, 2019a, 2019b). The scope and sequence maps out how learning objectives are to be accomplished over the course of the three-year, 18-unit program. The design specifications provide instructional and usability guidelines for the materials. Second, using these foundational documents for guidance, we are developing the instructional units, conducting field trials, and revising them based on lessons learned from the trials. As of February 2020, we have developed and field tested twelve 3- to 6-week units, and we have revised and released five of them. Throughout, we have struggled with tensions being research-based, practical, and marketable. In this section, we focus on several challenges that emerge from tensions between the instructional shifts called for by the (research-based) reforms being targeted and established practices or policies (i.e., practicality and marketability).

Challenge 1: Develop a design approach backed on research synthesis rather than a single perspective

From its inception, the project has had the goal of creating a program that reflects the best available research. However, in contrast to many research-based educational programs that focus on implementing specific lines of research associated with its developers, state partners felt that the program should reflect research findings broadly and be synthetic, rather than parochial. As a result, the Developers Consortium is composed of multiple research and development groups and has been charged with engaging a broad research community in its work.

To achieve this goal, the development consortium proposed to recruit committees of experts representing multiple perspectives to develop program design specifications that would guide the work of the consortium. The consortium formed ten specification-writing teams, each focused on a key aspect of the materials. The specifications cover: the pedagogical approach to be used in the units (instructional model and classroom routines); strategies for embedding professional learning opportunities within the instructional materials; strategies for assessment; strategies for supporting equity and access; techniques for implementing particular aspects of the NGSS (e.g., individual science and engineering practices and crosscutting concepts); the integration

of English language arts and mathematics; and how to meet practical needs and constraints (e.g., cost of materials and use of technology). Each team was led by one or two researchers with expertise in the team's assigned area. Every team included both researchers and practitioners, including at least one teacher nominated by a partner state. The design specifications were reviewed by the Developers Consortium and the State Steering Committee, and were revised, prior to formal approval by the Steering Committee. The specifications have been released to the public as a product of the OpenSciEd project (OpenSciEd, 2019b).

Challenge 2: Draw on research but include the practitioner voice in all aspects of design work

For the development of instructional materials, all our teams have been staffed with researchers, developers, and classroom teachers. Teams often worked with partner teachers to pilot candidate anchoring phenomena and solicit feedback on directions. Field trials enabled us to bring in perspectives of hundreds of teachers from the ten partner states, beginning with their feedback in professional learning, and most importantly through data collected from them and their students while they enacted the units. Additionally, we established a design process that included a series of meetings with State Steering Committee members at multiple points of the development timeline. Following field trials of that unit, the design team reviewed all feedback from student and teacher data from field trials and a review of the unit from Achieve on its alignment with NGSS and developed a revision plan. The design team then presented the revision plan to the State Steering Committee for feedback before implementing their revisions.

Challenge 3: Support the instructional shifts of NGSS but avoid creating materials that teachers perceive as too foreign or feel unprepared to enact

The partner states vary in how far along they were in their NGSS implementation. Several states had been early adopters of the standards and had offered several years of professional learning for large numbers of teachers. Others were more recent adopters or had not been able to implement much professional learning. Furthermore, the goal of the state partners was to fully test the usability of the project's instructional materials at scale, and therefore not to restrict participants in field trials to only experienced "early adopter" teachers. Indeed, following four days of professional learning on the pedagogical approach and the specifics of the units they were preparing to teach, field trials teachers reported the materials posed challenging shifts for their current pedagogical practice.

The core commitments of the pedagogical approach, as outlined in the design specifications, reflected the key shifts in the reforms (e.g., Windschitl & Stroupe, 2017). The Framework and NGSS advocate for a shift from "learning about" science that others have established to "figuring out" the science by building the knowledge as a learning community (Schwarz, Passmore, & Reiser, 2017). This necessitates engagement in science and engineering practices as a fundamental approach for building science knowledge, by making sense of phenomena and solving problems. Second, engaging learners in knowledge building practices means that students should see their science work as addressing questions and problems they have identified, rather than simply following instructions from teachers or textbooks. Thus, each lesson needs to be coherent from the students' perspective, rather than solely motivated because teachers and curriculum designers know the lesson would be useful (Reiser, Novak, & McGill, 2017). Addressing these shifts is ambitious. However, we needed to avoid developing materials that required teachers to be already familiar with and bought-in to the new pedagogical approaches, or that would require professional learning beyond what the state partners said was reasonable to expect. We aimed to develop materials that would support teachers in making the incremental shifts needed to make progress on these goals. To accomplish this, we pursued several strategies to attempt to balance innovations in pedagogy with broad usability.

First, we realized we needed to address the interacting issues of classroom climate, classroom discourse, and instructional design in both curriculum materials design and professional learning. The systemic nature of the pedagogical shifts meant teachers needed to work on discourse moves that would support the shifts in task design that gave students more agency in developing questions, engaging in argumentation, and developing and revising models. We identified a limited set of classroom routines that we have used consistently across all units. We have emphasized them in both instructional materials and professional learning. We also incorporated educative features into the teacher materials to call out these general routines and help teachers apply them in context.

Second, we placed an emphasis on guidance for assessment in the instructional materials and professional learning. Recognizing that teachers are often subject to school or district policies governing assessments and grading, we provide guidance on how to use students' work throughout the unit as formative assessment opportunities, and we organized working sessions during professional learning to work with peers on assessment and grading strategies using the instructional materials. These strategies focused on using assessment to support the NGSS instructional shifts reflected in the materials, rather than in ways that might be in tension.

A third approach to helping teachers take on these materials as incremental steps toward shifting their practice involved striking a balance between being responsive to student ideas and expecting teachers to improvise based on the particular student ideas in their classroom. Engaging students in knowledge building that meaningfully addresses their own questions requires skill in cultivating student questions and careful listening to students' ideas (Windschitl et al., 2017). However, it can be challenging for teachers to weave together what they hear from students with what they know is the sequence of phenomena and investigations planned in the instructional materials. While having students feel like their own questions are driving their investigations may be an ideal which some teachers succeed in supporting (Reiser, Novak, & McGill, 2017), the goal in the OpenSciEd pedagogy is somewhat more modest. The instructional materials ask teachers to elicit student questions, and then play a more directed role in helping students understand where they need to go next to investigate them. In general, while the instructional materials provide ample opportunity for students to engage in practices to develop knowledge, we attempted to provide sufficient supports for teachers to enact more scaffolded versions of these practices than explored in some smaller scale design-based research studies.

Design of OpenSciEd professional learning

Katherine L. McNeill and Renée Affolter, Boston College

Teachers are central to classroom learning, yet learning sciences research has paid less attention to teachers than to students and other stakeholders (Fishman, Davis, & Chan, 2014). In the context of science, the shifts in learning called for by the NGSS requires teachers to take on new roles (Windschitl & Stroupe, 2017). Teachers need professional learning experiences to support those changes (National Academies, 2015). Teachers, instructional leaders and other stakeholders in the K-12 education system may not recognize the teacher changes that need to occur, such as supporting sensemaking from the student perspective. Yet the adoption of new curriculum materials can create the need, space or resources for professional learning opportunities for teachers. Teachers may ask for support around the new curriculum materials. Furthermore, previous research suggests that the strongest student outcomes occur when teachers receive both new curriculum materials and professional learning (PL) (Lynch et al., 2019).

We use the *practical* needs of teachers for curriculum-based professional learning as an on ramp for PL that also addresses the professional learning needs of the teachers implementing *research-based* shifts in practice. Furthermore, we have attended to the challenges of *marketability* for a program that requires professional learning by attempting to meet school and district policies and norms for professional learning as much as possible. For example, one of the most challenging constraints for practicality and marketability is the amount of time that is available for teachers to participate in face-to-face PL. Although research suggests that PL is most effective when it is sustained over extensive time (Desimone, 2009), teachers and schools have limited time available for it. These design constraints have resulted in the Professional Learning Design Framework that guides our development of professional learning programs and resources for the OpenSciEd program (see Table 1).

Table 1: OpenSciEd Professional Learning Design Framework

Professional Learning Element	Description
1. Focus on equitable sensemaking	Threaded across all of the professional learning experiences is a focus on more equitable learning in science in which all students are known, heard and supported with access and opportunities for learning.
2. Frame experiences with a problem of practice	Each professional learning session begins with a “problem of practice” that frames the multi-day experience. These problems are grounded in challenges currently being experienced by the field test teachers in order to address an area of need.
3. Provide images of classroom instruction	Classroom videos and student artifacts are used when in the PL to illustrate classroom instruction with a range of students. These images highlight both what is possible and challenges that can arise that teachers can draw from for their own classrooms.
4. Offer the student perspective	Teachers are asked to experience 3D science instruction in “student hat”, such as developing models and participating in sensemaking discussions. These experiences support teachers’ understanding of the instructional model and increase their empathy for their students.

5. Engage teachers to collaborate and reflect with peers	All of the professional learning activities occur in a collaborative environment in which teachers work together to better understand the curricular innovation and to reflect on implications for their own classrooms.
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In this section, we focus on Element 2 - *Frame Experiences with a problem of practice* – which directly targets the practical needs of teachers and schools. Table 2 presents a transcript from the four-day introductory professional learning workshop in which middle school teachers were learning about their first OpenSciEd unit, *How do things inside our bodies work together to make us feel the way we do?* The unit explores the case of M’Kenna who is having health issues and the students work to figure out what is causing those issues. The teachers had just completed an investigation from the student perspective in which they explored how dialysis tubing has properties that are similar to the surface of the small intestine. The teachers were then asked in “student hat” to share out what they had figured out so far about what is causing M’Kenna’s health issues. In sharing out, one participant in “student hat” uses the word “absorbed” as part of their explanation. Another teacher (Participant 4) responds moving out of “student hat” to their own “teacher hat” stating “Yeah I can never assume that my kids have learned that,” which is the beginning of the transcript below.

Table 2: Transcript from professional learning

Facilitator:	Yep. So let's assume not so how could we write it without the word "absorbed"?
Participant 1:	There's more glucose and complex carbohydrates in M'Kenna than the healthy person.
Participant 5:	Leftover or, or still there.
Participant 2:	Still in the intestines. Not in the middle.
Participant 1:	And should we all be writing this down in what we figure out?
Facilitator:	In a moment, like see how I crossed it out. 'Cause kids don't want to erase right? There's more glucose and complex carbs left in M'Kenna's small intestine than the healthy person. Is that okay?

In this section of the transcript, the participants work together to construct language that they think may align with what one of their students might say as they explain the phenomenon. The facilitator supports them in building this conceptual understanding without focusing on the scientific language. This move supports teachers in thinking about how to increase access to more students using the resources they bring rather than prioritizing academic language. This aligns with research suggesting the importance of students figuring out phenomena from their own perspective in order to support greater student coherence and epistemic agency (Zivic, et al., 2018). Yet about three minutes later in the same conversation we see another teacher push back on this suggesting they needed to use the word “absorb” because of practical needs. Participant 6 states

So my pushback in using that word is it, it is a 6th grade standard. And I do think that we should. If we're driving. If we're preparing them for 9th grade, 10th grade, preparing them for the [state test], I do think it's an appropriate time...I do think it's an appropriate time to start to scaffold up, put a little rigor in here, and use appropriate vocabulary. Like we can't just like shy away from like, we have to really start to do that. It's in preparation for bigger things to come.

We see Participant 6 concerned about preparing middle school students for the state test and for high school so that it is important to “scaffold up” the academic or scientific language. This example illustrates a tension we see at times during the PL. The practical needs or perceived needs of teachers can be in conflict with research about student learning. In the professional learning design, we try to balance those tensions in order to continue to move teachers forward on their own learning trajectory while being aware of the practical influences on their classroom instruction.

Collection and analysis of data

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Quality implementation has long been cited in the learning sciences as critical to the success of any instructional intervention (e.g., Cobb & Jackson, 2012). To understand implementation and to inform the revision of instructional materials and professional learning opportunities more broadly, OpenSciEd organized an overarching field test based that draws on implementation science (IS) and quality improvement (QI) approaches (Bryk, Gomez, Grunow, & LeMahieu, 2015; Nilsen, 2015). While stemming from different intellectual traditions, IS and QI address a common concern when compared against more traditional research and evaluation: IS and QI are about making innovations work in specific contexts as opposed to determining whether an innovation can or does work (Grunow, Hough, Park, Willis, & Krausen, 2018).

The purpose of the OpenSciEd field test is not to support generalizable research claims or provide a high-stakes evaluation of materials of learning opportunities (Solberg, Mosser, & McDonald, 1997). Instead, the goal is to continuously improve materials and identify the types of capabilities needed by both teachers and schools to use the materials well (Peurach, 2016). One implication of this purpose is that the role of participants is different from a traditional research study. In a traditional research study, participants are kept at arm's length and are not active co-designers (Penuel & Gallagher, 2009). Another implication is for the instruments used to collect data (Yeager, Bryk, Muhich, Hausman, & Morales, 2013). In a traditional study or evaluation, instruments must adhere to disciplinary standards of validity and reliability for the claims that researchers want to make (e.g., broadly generalizable or high stakes). Given the stage of development for the instructional materials, the field test team privileged instruments that could be used easily *in practice*, *about practice*, and *by* educators that could generate data that was useful to developers and state leaders in serving multiple purposes. We used data collection instruments that were practical to administer to students and that were aligned with the instructional model used in the curriculum materials. Practicality was important because teachers were not offered a reward for providing data, and because we wanted teachers to focus their attention on implementation, not data collection. Aligning data collection to the instructional model could inform re-design in ways that general fidelity or stages of concern approaches to the study of implementation could not, because model-specific data could explicitly address elements of the instructional materials that developers conjectured were important to learning.

Therefore, the field test was shaped by multiple constituencies: developers (curriculum and professional learning) and state science leads. State leaders had “symbolic” uses for data generated through the field test that entailed helping stakeholders in a given state buy-in to the process; state leaders also had a “conceptual” use that involved helping to shift district and school leaders’ thinking about quality science instructional materials. Developers, on the other hand, had more “instrumental” uses that entailed informing redesign of materials, teacher tools / guides, and professional learning opportunities (Weiss & Buculavas, 1980).

Early in 2018, members of the field test team proposed five principles by which the field test would operate, which were reviewed and modified by developers and state leads prior to their formal adoption for the project. These principles were informed by the field test team’s prior work along with tools and processes from QI and IS. They were: (1) *Minimize burden*: Collect only data that is needed by someone, for a purpose agreed upon as important by different stakeholder groups. (2) *Foreground equity*: Address questions about students’ access to prepared teachers, challenging activities, and experiences of the classroom. (3) *Support learning*: Learn from the pilot to improve equitable implementation and outcomes for all. (4) *Instrument practice*: Collect data directly from practice. (5) *Be meaningful and actionable to end user*: Who will be working with the data and what will they do with it? Given the improvement and implementation focus of the field test, the consortium paid particular attention to the burdensomeness of data collection approaches (see principle 1, above). The field test team worked with state leads to identify that the appropriate amount of time for interviews and surveys was 30 and 15 minutes, respectively. To further attend to burden, we only asked to teachers of multiple sections to collect data in one section, and we distributed data collection tasks across teachers so individual teachers did not have to conduct all data collection tasks.

There is evidence that developers have made use of data from the field test to inform both unit-level and specific lesson revisions. A recent survey (n = 7) of writers indicated that they used survey data to focus more effort on developing assessments teachers said they needed, provide more tips for sustaining student interest throughout units, and support engagement in science practices and crosscutting concepts. They relied heavily on student artifacts to make more specific changes to lessons. Among the changes they reported making were to clarify confusing directions, modify pacing guidance, and removing activities teachers found did not reliably work. These survey data provide some preliminary evidence of one key aim of data collection, namely to inform improvements to materials.

Endnotes

(1) Authors are listed in order they will present in the symposium.

- (2) The term *open content* describes a work that is released to the public under a license that allows anyone to freely use, distribute, and modify the work.

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Preparing Researchers to Participate in Collaborative Research

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Abstract: This symposium offers new insights into how graduate programs can better prepare researchers to work collaboratively with practice and community partners toward educational equity and improvement. Each presentation shares key takeaways from a recent convening in Semiahmoo, Washington that focused on this topic, hosted by the National Center for Research in Policy and Practice (NCRPP). The aim of this session is to (a) share the results of the Semiahmoo workshop on expanding the use of collaborative research as a methodology across the learning sciences and colleges of education; and (b) invite the broader learning sciences community to participate in advancing changes to graduate education that are needed to make collaborative research a core methodology for the field. We summarize the role of collaborative research in achieving impact locally, sustainably, and at scale, as well as the role of schools of education in preparing researchers to engage in collaborative research.

Keywords: collaborative research, graduate education, partnership, methods, networks

Overall focus of the symposium

This symposium offers new insights into how graduate programs can better prepare researchers to work collaboratively with practice and community partners toward educational equity, improvement, and transformation. Each presentation shares key takeaways from a recent convening in Semiahmoo, Washington that focused on this topic, hosted by the National Center for Research in Policy and Practice (NCRPP). The workshop included deans, faculty members, and graduate students from six schools of education with several long-term partnerships with practice and community organizations; individual researchers with expertise in collaborative research; practice and community partners; and funders. Together, we surfaced specific aspects of graduate education needed to prepare researchers to participate effectively and equitably in various approaches to collaborative research.

The location of the convening in Semiahmoo, Washington, as the land of the Semiahmoo Nation, intentionally grounded our aims in advancing collaborative research centered in equity, justice, and recognition for the importance of historical knowledge and perspectives in locally-focused work. We held space for multiple epistemologies and forms of collaboration grounded in equity while at the same time uncovering aspects of collaborative research that could be scaled to improve preparation for this work for interested students in graduate programs across the country.

The aim of this symposium is to (a) share the results of the Semiahmoo workshop on expanding the use of collaborative research as a methodology across the learning sciences and colleges of education; and (b) invite the broader learning sciences community to participate in advancing changes to graduate education that are needed to make collaborative research a core methodology for the field.

We introduce this symposium by summarizing the role of collaborative research in achieving impact locally, sustainably, and at scale, as well as the role of schools of education in preparing researchers to engage in collaborative research. Each of the four presentations, led by members of five different universities, then synthesizes workshop participants' contributions focused on: (1) the dispositions, knowledge and skills, and experiences that researchers need to participate effectively in collaborative research; (2) strategies to embed collaborative research preparation in graduate programs; (3) building institutional capacity for collaborative

research; and (4) building networks to sustain and scale collaborative research practices beyond an individual institution.

The session will open with four short presentations that report the takeaways from the convening, based on documentation and content analysis of each workshop session. We will follow this with discussant remarks and questions that critique and extend the perspectives presented. We will then move into facilitated break-out groups for critique and contributions related to key takeaways, with participants invited to extend the findings from the workshop. Our goal is to expand the network of scholars working in collaborative research.

Major issues addressed and points illustrated by the collective work

Because collaborative research is focused on local problems of practice in partnership with stakeholders, it is uniquely situated to attend to partners' social, cultural, political and historical perspectives in designing strategies to advance educational equity, improvement, and transformation. At the same time, there is a need to scale core principles and practices of collaborative research across local contexts to ensure that researchers engage effectively and equitably with practice and community partners. In other words, the enactment of collaborative research must be sensitive to local needs, but core principles need to be shared field-wide.

Because traditional research is geared more toward contributions to knowledge, it does not always impact practice, especially in sustainable ways. Collaborative research, on the other hand, is designed to address issues of practice through multiple perspectives and forms of knowledge, leading to changes in practice and policy that “do real work” for and with practice and community partners, and thus are more likely to be sustained. Graduate schools of education importantly prepare students for traditional research methods, but often lack the coursework, mentoring, apprenticeship experiences, funding support, and institutional capacity that students need to participate effectively in collaborative research methods.

This symposium offers new avenues for changes to graduate programs that can better prepare researchers who aim to work collaboratively with practice and community partners toward sustainable educational change.

How the collective presentations contribute towards the issues or points raised

Together, the symposium presentations share multiple aspects of systemically working to advance collaborative research. Improvements to graduate preparation will require attention to each area presented here—cultivating key dispositions, knowledge and skills, and experiences; offering course pathways and mentoring; building institutional capacity; and expanding participation through connections to networks. At the same time, each aspect requires focused attention in order to develop and scale these aims.

The presentations further bring together advanced and junior scholars, including graduate students, across multiple universities as we begin to create an ecosystem for collaborative research. Symposium attendees interested in participating in these efforts to improve preparation for collaborative research can connect with the growing national network of junior and advanced scholars that emerged from the Semiahmoo workshop.

Significance of the contributions

While the primary purpose of education research is to contribute to educational transformation, educators have reported that traditional methods of conducting research and disseminating findings are limited in their accessibility, timeliness, and relevance to pressing problems of practice (Penuel et al., 2016). In contrast to traditional practices that do research *on* or *for* others, collaborative research builds on the tradition of engaged work *with* partners in real settings that is a hallmark of learning sciences research.

A shift to viewing research as something done *with* those most impacted by it is at the heart of a growing interest in collaborative research in education (Philip, Bang, & Jackson, 2018). Collaborative research, as we present it here, can take a variety of forms that include what are commonly considered research-practice partnerships (RPPs), research alliances, networked improvement communities (NICs), design-based research, and community-based collaborations. These partnerships in turn can take a variety of forms and approaches. “Research partners” based at universities or other research organizations collaborate with “practice partners” in state education departments, school districts, schools, social service agencies, libraries, or museums, or with “community partners” in community organizations or local communities. Most centrally, partnership members jointly decide to focus on a problem of interest to the practice or community partner, and decide on the working relationship and research methods best suited to address the problem.

Many future—and current—researchers aren't aware of the forms that such partnerships can take, or how to go about forming, funding, pursuing, and sustaining a partnership. Right now, this work is happening in pockets, with some schools of education offering more extensive opportunities for interested students. Some are lucky

enough to apprentice with faculty members who have established partnerships. However, apprenticing interested students to work in this way can be taxing on the relatively few faculty members with partnerships in place, and more importantly, on the local practice or community partners.

We therefore need sustained efforts to expand this work to more graduate programs and geographic areas, with special consideration for the potential to work with practice and community partners who have not been offered opportunities to benefit from participating in collaborative research. As collaborative research practices grow and show promise in education, it is important that we draw on increasing knowledge about them to better prepare researchers to work effectively and equitably with practice and community partners.

Offering learning opportunities to support graduate students in collaborate research further offers opportunities at the institutional level to move beyond the traditional role of universities to produce and transfer knowledge toward models for researchers and practice or community partners to engage in expansive learning together (Kerosuo & Toiviainen, 2011). This can shift institutional perspectives of what's important in producing and sharing knowledge to one that deeply considers "by, how, and for what and whom" knowledge is created and shared (Philip et al., 2018). In this way, programs that include preparation for collaborative research can contribute to renegotiating the relationship of higher education with broader society toward one of public engagement.

Dispositions, knowledge and skills, and experiences that researchers need to participate in collaborative research

Kristen L. Davidson and Robbin Riedy, University of Colorado Boulder

We asked Semiahmoo workshop participants to first share the dispositions—that is, the habits of mind, characteristics, or temperaments—that are most conducive to working in partnerships. While some people may be inclined toward these dispositions, participants felt they could be cultivated or deepened among those who are interested in collaborative research, current and future researchers alike. Importantly, these dispositions were informed by practice and community partners' perspectives (at the workshop and beyond) regarding what they report needing from researchers in order to advance mutual aims of educational equity and improvement.

To work collaboratively with practice and community partners, researchers need to own a shared responsibility for outcomes—especially with regard to students' lives—by being invested in the work and persevering through challenges. Practice partners especially emphasized this core aim, and noted that researchers' commitments to making a difference in students' lives were key to building trust and working jointly together. Just as the focal areas of partnerships often attend to advancing equity in education, researchers need to be equity-focused in their approach to working side-by-side with partners, with intercultural sensibilities and respect. This can involve balancing the workload among partners, respecting differing demands, and valuing different types of knowledge and experiences that research and practice partners bring to the problem at hand. Given research and practice partners' differing priorities and timelines, researchers need to be continually open-minded, flexible, and understanding about partners' changing needs and contexts. In order to counter historical imbalances of power and status among research and practice roles, it is especially important that researchers are humble, self-aware, reflective, and intentional in their own presence and actions, positioning themselves as active and deep listeners and empathetic sources of support.

In addition to these dispositions, participants named specific knowledge and skills that researchers need to develop for partnership work. Many noted the need for graduate students to be involved from the beginning of the formation of a partnership in order to experience the process of forming initial relationships and jointly deciding on partnership aims. At the beginning stages and beyond, researchers need to develop skills in how to enter spaces with potential and current partners, including learning about the partners' organizational or community context, having a sense of respectful norms of interaction, and developing strong communication and facilitation skills. It is important that graduate students are able to build trusting relationships with partners, and that practice and community partners are able to trust graduate students in their work together. As the partnership proceeds, graduate students need to develop skills to navigate challenges that may arise due to shifts in timelines and aims, turnover, and more. Students can learn from tools and routines that help to negotiate partners' roles and balance the work. At a basic level, researchers need project management skills—such as securing funding and other resources, budgeting, setting goals and establishing routines, managing data, navigating different timelines, managing teams, and so on—that often are not part of graduate preparation.

The research skills that students develop in graduate programs are also valuable to partnership work. Because research partners often are expected to bring expertise in research methods, they should be ready to co-develop a theory or plan of action with their partners, specify plans for collaboration, and shepherd the research process. Throughout the process, partnership members need collaborative problem solving and sensemaking skills in order to co-create new knowledge and design new solutions based on the partnership's work on the problem of

focus. In synthesizing findings from a project, research partners should be sensitive to the potential implications of those findings, and have clear, collaborative processes among partnership members for engaging in the interpretation of findings and for preparing to share them. Researchers then need skills to be able to share findings through multiple platforms that are accessible, relevant, and useful for their practice or community partners and beyond. For example, partners might present at conferences together, produce reports or briefs, create videos, blogs, or other multimedia presentations, co-develop curricula or professional development, and so on (Farrell et al., 2018).

As the partnership matures, researchers need particular types of knowledge and skills to sustain partnerships through multiple strong relationships, ongoing funding and resources, support from organizational leadership (on both sides of the partnership), and continued support for implementation of solutions developed by the partnership.

Lastly, participants described the kinds of experiences that researchers need to develop these dispositions, knowledge and skills, especially in terms of opportunities to actively practice these through coursework, mentoring, and apprenticing with experienced faculty members, which the next presentation more fully describes. The dispositions, knowledge, and skills outlined here offer new aims for the content and structure of graduate programs that can better prepare students—and further develop faculty members—for collaborative research approaches that can contribute to the kinds of educational change that initially motivate many students to pursue doctoral training.

Embedding collaborative research preparation in graduate programs

Caitlin C. Farrell, University of Colorado Boulder and Jennifer Russell, University of Pittsburgh

Graduate programs serve as an important training ground for people who want to engage in collaborative research efforts. In addition to developing expertise in research methods and specific content areas, graduate students need intentional learning opportunities to develop competencies in building relationships, co-developing a research agenda that meets local needs, and sensemaking around findings. However, graduate programs in schools of education often are criticized as resistant to change. Those programs that do have initiatives in place to support collaborative research are few and far between, without a shared understanding of how to best embed collaborative research preparation in graduate programs.

Background

There are key characteristics of effective learning opportunities to support graduate students in collaborative research preparation. First, students should have opportunities to engage in the theoretical and historical traditions of collaborative models of research. Graduate coursework can provide foundational experiences where students are exposed to core principles of collaborative research, such as what it means to ensure mutual benefit for partners and researchers, that create mental models and schema which are a resource when students later engage in apprenticed partnership work.

Second, learning about collaborative research should be active and embedded in partnership work. Students need opportunities to directly design or try out collaborative research strategies. For instance, within the context of a partnership, graduate students may engage with co-developed research questions, successful funding proposals, examples of data displays and guides for moderating collaborate sensemaking around findings. This approach moves away from traditional learning models that are entirely lecture based toward embedded, contextualized practice.

Third, learning about collaborative research practice involves coaching, expert support, reflection, and focused reflection directly on graduate students' individual needs. Programs require built-in time for students to think about, receive input on, and make changes to their collaborative research practices. Feedback and reflection help students to thoughtfully move toward the expert visions of collaborative research practice. Further, close mentoring ensures that graduate students engage with practice and community partners in ways that align with their expectations of the partnership.

All of these learning opportunities need to be offered systematically in graduate programs, so that all students can access them, and not only those who have a certain advisor. Therefore, any learning opportunities need to consider the potential barriers or supports necessary to support equitable access and participation.

Strategies and examples

At the Semiahmoo workshop, participants envisioned three broad strategies that graduate programs could adopt that embody these learning principles. In some circumstances, a program could design a new program or practice,

while in other cases, it may involve altering or adjusting practices already in place. These strategies include: foundational coursework; apprenticeship experiences; and mentoring structures and practices.

Coursework provides a focused time to build foundational knowledge for collaborative research. A collaborative research course can be a complement to existing methods sequences in graduate education research preparation programs, focusing on the core principles of these approaches, their theoretical traditions, and practical methods for engaging in productive partnerships. Alternatively, coursework can be organized as stackable modules or micro-credentials composed of discrete learning units focused on issues such as: project management skills; communicating with multiple research audiences; and building relationships and entering spaces.

Another consideration for graduate programs is ensuring apprenticeship experiences in which graduate students can learn how to conduct collaborative research by doing it with more experienced faculty members and practice or community partners. These experiences typically happen as students work with faculty on their research projects. However, relying solely on this model can have limitations. For example, students may not get opportunities to see the early phases of partnership development if they enter a project that represents a long-term collaborative arrangement. In addition, these opportunities may be limited at a given institution.

Ideally, students would get opportunities to engage in collaborative projects from start to finish, with strong mentoring structures and practices in place. Some graduate programs have created innovative mechanisms to enact this kind of mentored engagement in collaborative research by developing durable partnerships with sites of practice, such as school districts, and then creating a mechanism for students to propose, negotiate, and engage in a bounded project from start to finish, under the mentorship of faculty and practice partners. Mentorship is critical in this model when students are taking greater ownership of project; yet creating effective mentorship structures can be challenging to coordinate given that these are not faculty projects. Ideally there would be dedicated mentors from both the graduate program and site of practice to provide students with ongoing feedback as they engage in their collaborative projects, while attending to balance in roles and workload (Ghiso, Campano, Schwab, Asaah, & Rusoja, 2019).

In this presentation, we offer these considerations and strategies with examples of ongoing and developing work in several schools of education. In the discussion, we will invite session attendees to share further examples of structures in place or in development in their own institutions, and to connect to a growing network of scholars who are shifting graduate preparation in these ways.

Building institutional capacity for collaborative research

Barry Fishman, University of Michigan

“Public engagement” is frequently listed as a high priority for universities, especially in an age where the U.S. public has begun to question the value of higher education. At the Semiahmoo workshop, we proposed that collaborative research can serve as a powerful vehicle for renegotiating the relationship of higher education to broader society. Schools, colleges, and departments of education are natural places for innovation in collaborative research. Much scholarship and professional training in education is, after all, dependent on maintaining strong relationships with K-12 organizations. If schools of education have good reason to focus on the development of collaborative research *internally*, they also have good reason to focus *externally* on the rest of the institutions and communities where they live. Many universities have multiple points of contact with the publics they serve, or the communities where they are located.

The dominant model of scholarship in higher education—and also in schools of education—is defined by singly-authored research studies in which scholars are rewarded for the *specificity* of their focus. “High quality” research is designed to reduce variation and noise in order to isolate variables of interest. Research approaches featured in the learning sciences, including design-based research, have worked against this model by emphasizing scholarship conducted in real-world contexts, especially classrooms and other common settings for learning. But even in design-based research, sustainability and scalability can be limited by a range of factors, especially when the genesis of the research comes more from the research side of the partnership than from the practice side (Penuel, Fishman, Cheng, & Sabelli, 2011). Collaborative research is an opportunity to change this equation, though accomplishing this means overcoming a number of institutional constraints.

The *infrastructures* that shape higher education are a key barrier to the growth of collaborative research. We use the term “infrastructure” in the way that Susan Leigh Star used it; to denote structures and systems that are embedded, transparent, linked with conventions of practice, and embodied in standards and conventions (Star & Ruhleder, 1996). Infrastructures in research institutions that can present constraints to advancing collaborative research include things such as: tenure and promotion norms, funding opportunities, publication norms, student

recruitment, and graduation requirements. Supporting collaborative research within schools of education requires changes in these kinds of structures.

For instance, institution leaders might shift to valuing multiple types of research products and recognize that the time it takes to develop partnerships can result in reduced pre-tenure publication rates in comparison to more traditional forms of scholarship. Some institutions, including the University of Michigan, have moved to establish units or organizations that coordinate partnerships between community organizations and a range of researchers across campus, helping to coordinate and sustain collaborative partnerships and enabling a greater range of researchers to engage productively. We encouraged workshop participants to work on addressing capacity at their own institutions with their Provost, other units on their campus with natural connections to the public (e.g., social work, public health), their research offices, outreach organizations, and of course, their existing off-campus partners and collaborators.

This presentation will share specific strategies toward institutional change that support collaborative research and allow time in the discussion for attendees to consider the barriers and supports to these shifts specific to their own institutional contexts.

Networks to build field capacity for collaborative research

Adam Bell, University of Washington, Carlos Sandoval, University of California Irvine, Chris Wegemer, University of California Irvine, and Tiffany Clark, University of Colorado Boulder

In addition to capacity building for collaborative research within institutions, there is an important potential to leverage and build field capacity across institutional settings. Drawing from successes in the LIFE network for junior scholars in STEM education, one aim of the convening was to establish a cross-institutional network of emerging scholars that could facilitate the professional success of graduate students and postdoctoral researchers. In this presentation, we share the reasoning behind a network structure to advance collaborative research as well as the aims and practices of the emerging scholars network that we have established.

How networks can build field capacity

Networks can provide increased access to material, ideational, and relational resources that may be limited in graduate students' and postdoctoral scholars' home institutions. Because social capital is embedded in relationships (Lin, 2000), increased socialization *across* institutions can enable, graduate students are able to engage in "processes through which individuals gain the knowledge, skills, and values necessary for successful entry into a professional career" (Weidman, Twale, & Stein, 2001, p. 5)—in this case, a profession based in the relatively new field of collaborative research.

Graduate students' increased involvement in professional development networks, national organizations, and institutional practices positively influences their socialization into professional roles of scholarship and research (Gardner & Barnes, 2007). Opportunities to collectively share problems of practice can help members draw on the distributed expertise across institutions and apply skills to local contexts alongside a broader domain of practice (Corley, Boardman, & Bozeman, 2006). Relational development across a network promotes a learning environment that supports alternative forms of training by centering core principles of collaborative research that may not be emphasized in traditional academic approaches (e.g., doing research *with*, rather than *on*, communities). Moreover, network relationships contribute directly to graduate students' senses of relational agency and belonging within their domains of practice (Pyhältö & Keskinen, 2012). Professional development opportunities organized by the network can target skills that emerging scholars may not otherwise access. Graduate students and postdoctoral researchers have begun to organize a network and design activities to fulfill these aspirations.

A collaborative research network for graduate students and postdoctoral scholars can provide increased learning for emerging scholars across institutions by enabling participants to learn across institutions and broadening access to people, ideas, and other resources. The network can expand the social capital of emerging scholars by providing opportunities to interact with more experienced researchers, educators, and community members. These experiences elevate the work of emerging scholars, and can provide leadership opportunities for participants as the network grows and becomes more recognized. Additionally, an early career network serves as an organizational structure that can seek funding for network activities to support a broader reach of scholars (e.g., in-person convening, speaker series). During dedicated time at the Semiahmoo meeting, graduate students and postdoctoral scholars developed a cross-institutional network to support their collaborative research experiences.

Current activities and future plans for the network

The group established routines for a monthly meeting for all collaborative research-focused graduate students and postdoctoral scholars from the six core institutions represented at the conference (including those not present at the conference) and weekly meetings for a smaller visioning committee. In addition to norms, roles, and responsibilities, five goals of the network were identified: (1) To build a community of emergent collaborative research scholars and practitioners who support one another in their personal and professional endeavors; (2) To surface career opportunities for emergent collaborative research scholars and practitioners, including networking and sharing our work with senior scholars, practitioners, and the public; (3) To build a repository of resources around engagement in collaborative research work for emergent scholars and practitioners; (4) To provide opportunities for collaboration among emergent collaborative research scholars and practitioners; (5) To build a network of scholars that are committed to and enact anti-racist, equitable and transformative community-driven partnerships. These goals reflected the personal values and professional resources that graduate students believed would facilitate their success as collaborative researchers.

Subsequent digital meetings refined the activities and purpose of the network, which currently consists of about three dozen junior scholars. Collectively, the group created and refined a logic model to structure collaborative activities. Three emergent sub-groups formed to take the lead on specific tasks on behalf of the collective. First, a design politic group conceptualized a foundation for the network's shared intellectual work by making values and principles explicit; importantly, this included establishing the meaning of partnerships in education in relation to justice-oriented theories and systems of oppression. This process opened up possibilities for "remediating normative axiological assumptions" (Bang, Faber, Gurneau, Marin, & Soto, 2015, p. 3) about what is valued in partnership research projects. By establishing a design politic, the network participants will continue to grow their understanding of the dispositions, knowledge, and skills, and experiences required for building impactful partnerships. This will support the development of innovative and transformative practices.

Second, a professional development group organized several activities aimed to facilitate future professional successes of its members. This involved creating processes to share job opportunities across institutions, organizing a digital symposium where graduate students could share their work, and collecting topics of interest across all members to facilitate collaboration on publications. In the future, this will increasingly include opportunities to connect with (and learn from) established collaborative research scholars, potentially facilitating mentorship relationships.

Third, a community-building group planned activities for the group to interact, including organizing a meetup session at future professional meetings for graduate students interested in collaborative research and setting up a system for graduate students to share their planned presentations at conferences so others could attend. These activities represent an organizational expression of what graduate students would like to see in their own collaborative research experiences. This session will offer an opportunity for a group of interested junior scholars to attend and grow this network among scholars in the learning sciences.

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Short Papers

Scaling High School AP Computer Science: Access and Outcomes From Chicago Public Schools

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Abstract: To understand student access and success in advanced coursework in computer science (CS), we investigated AP computer science participation and outcomes in Chicago Public Schools, where efforts are underway to broaden participation by scaling CS pathways to all schools across the district. We focus particular attention on the recently introduced AP Computer Science Principles course, which was created with the explicit goal to broaden participation among underrepresented students. We found that the district is making progress toward equitable access to AP CS courses and that inequalities persist in terms of effectively preparing underrepresented students for AP coursework.

Introduction

Efforts to scale computer science education (CS) across the U.S. have gained momentum in the past decade. Building on progress in states and cities, in 2016, President Obama announced the “Computer Science for All” initiative, which brought together organizations to scale CS nationally and ensure equal access to high-quality CS for all students (Smith, 2016). Similarly, in recent years there have been initiatives across the country to increase participation in Advanced Placement (AP) computer science, with a particular emphasis on traditionally underrepresented demographics. In 2012, the National Science Foundation partnered with the College Board to develop a second AP CS course with the purposeful goal of introducing CS to a broader range of high school students (the existing course, AP Computer Science A or CS-A, focuses on programming in Java and has historically served students already interested in programming as a career). The new exam, AP Computer Science Principles (CS-P), was first administered in the 2016-17 academic year and has grown substantially in subsequent years. By 2018-19, the national volume for CS-P exceeded CS-A by over 25,000 exams (College Board, 2019).

Across the nation, AP CS participation is growing dramatically, with the biggest gains among females and underrepresented student groups. Much of this growth has been attributed to the launch of CS-P, which resulted in a substantial increase in the number and percentage of AP CS exams taken by female, low-income, and underrepresented students (Code.org, 2019). However, even with these gains, participation remains unbalanced and performance gaps persist (College Board, 2018).

In 2016, Chicago Public Schools (CPS) established computer science as a high school graduation requirement as part of the district’s Computer Science 4 All initiative, which aims to develop a computer science education “defined by equity, empowerment, and opportunity” (Office of Computer Science, n.d.). The graduation requirement is primarily fulfilled through the *Exploring Computer Science* (ECS) curriculum and professional development. Previous research on CS in Chicago has shown that participation in ECS represents equitable access to ECS as well as equitable course outcomes (McGee et al., 2018). As part of the ongoing work to scale up CS and develop K-12 CS pathways, the district is now focusing on expanding access to AP CS courses.

This expansion fits into the CPS strategic goal of growing the number of early college credits earned by high school students (through AP or dual credit courses). To encourage high schools to increase AP enrollments, the district includes an AP performance indicator as part of the School Quality Rating Policy (SQRP). Since 2011, the number of students taking AP courses has increased by 53%, despite gradual yearly declines in overall student enrollment in the district (Chicago Public Schools, 2018). However, similar to the national challenge, CPS also has substantial racial and gender gaps in AP participation (Emmanuel, 2019). This research seeks to understand the current state of access and effectiveness of AP CS in Chicago, which is a necessary first step to develop strategies to prepare and support students from underrepresented groups to succeed in computer science pathways.

Theoretical framing

In a recent review of scholarship on the AP program, Kolluri (2018) examined the program in terms of two dimensions: equitable access and course effectiveness. A focus on equitable access entails an examination of the availability of AP course offerings at schools serving primarily students of color and low-income students as well

as the distribution of AP participation by student subgroups within schools. Course effectiveness relates to the goal of AP courses to build college-level skills and help prepare students to succeed in college. Kolluri concluded that the AP program continues to struggle with the challenges of access and effectiveness. Additionally, among all AP subject areas, AP CS had particularly concerning racial inequities. The review offers three possible hypotheses to explain the continued struggle to achieve equitable access and effectiveness: 1) “Most underrepresented AP students cannot benefit from the program,” 2) “AP curricula are being ineffectively taught to underrepresented students,” and 3) “AP is a component of social reproduction.”

We use the hypotheses from Kolluri (2018) as a theoretical framework for developing research questions that can be explored using data from AP CS in CPS. Given the recent introduction of the AP CS-P course and its emphasis on broadening participation, a particular focus of the analysis is student access and outcomes in that course. This paper describes the analysis and findings from the following research questions: To what extent is the district successfully broadening participation in AP CS? Are underrepresented AP CS students prepared for rigorous coursework and benefitting from the program? Is AP contributing to social reproduction?

Methods

To address our research questions, we analyzed student-level data for all students enrolled in AP CS courses in CPS. The first analytic step sought to identify patterns of access among underrepresented student groups and involved analyzing descriptive statistics using 2018-19 data on AP CS students in the district, along with national data on AP CS students. The second analytic step sought to examine the relationship between scores on the CS-P exam and student and teacher characteristics. We developed dimensions for each type of characteristic by grouping theoretically relevant measures and estimated a multilevel linear model to test the effect of student characteristics on AP exam score while controlling for teacher factors. For example, we hypothesized that math GPA, attendance rate, enrollment in a selective school, and grade level (when taking CS-P) all contribute to student preparation. The model used two years of data (2017-18 and 2018-19) to understand the relationship between student and teacher characteristics and CS-P scores.

Broadening access to AP CS

For the 2018-19 school year, the CPS dataset included 1277 AP students and 24 teachers from 18 different high schools in the district, including 7 selective enrollment schools (defined as providing “academically advanced high school students with a challenging and enriched college preparatory experience” (Chicago Public Schools, 2019)) and 11 non-selective schools. About 73% of the students in the dataset were from selective schools and the remaining 27% were from non-selective schools. The majority of AP CS students in the district (79%) were enrolled in the recently introduced CS-P course. Twelve of 18 schools offered only CS-P, two schools offered only CS-A, and four schools offered both CS-A and CS-P.

Overall, AP CS courses in Chicago are more equitable in terms of access for underrepresented students than AP CS courses nationally. Higher percentages of African American and Hispanic/Latino students participated in AP CS courses in CPS than AP courses nationally (see Table 1). Access to CS-P, in particular, was notably higher for underrepresented groups, suggesting that the district is progressing toward achieving its stated goal of broadening participation in CS through the implementation of CS-P.

Table 1: AP CS-P and CS-A Participation, 2019

Race/ethnicity	AP CS-A			AP CS-P		
	National %	CPS %	Difference	National %	CPS %	Difference
African American	3.9%	12.5%	8.6%	7.0%	15.0%	8.1%
Asian	33.1%	23.5%	-9.5%	21.5%	14.9%	-6.6%
Hispanic/Latino	12.0%	29.4%	17.4%	19.7%	39.5%	19.8%
White	43.4%	28.3%	-15.1%	44.6%	26.4%	-18.2%

However, comparisons to national averages may be less important than understanding the extent to which schools offering AP CS are representative of the district and whether AP participation within these schools is evenly distributed. Table 2 shows that the district schools offering AP CS are not representative of CPS high schools overall in terms of racial and ethnic composition. Schools offering AP CS have substantially lower percentages of African American students and higher percentages of Asian, Hispanic/Latino, and White students. Asian and White students, in particular, are highly overrepresented in AP schools compared to district averages. There is a similar pattern within AP CS schools. Specifically, there are lower percentages of African American and Hispanic/Latino students in CS courses compared to the overall student percentages in those schools.

Given the explicit focus of AP CS-P to increase participation rates for underrepresented students, we might expect to see more equitable access in CS-P within the district. Our findings indicate that CS-P is more equitable than CS-A with respect to gender and racial/ethnic composition. In 2019, 46% of CS-P exam takers were female, compared to just 26% of CS-A exam takers. Participation in CS-P is also less inequitable in terms of race and ethnicity, although both CS-A and CS-P do not yet reflect the demographics of the district or of the schools that offer AP CS. Also, neither CS-A nor CS-P reflect district or AP school percentages of students eligible for free or reduced lunch (CPS overall: 77%; AP CS schools: 65%; CS-A: 51%; CS-P: 54%).

Table 2: AP CS Student Demographics in CPS

Race/ethnicity	Overall CPS HS %	AP CS Schools %	CS-P Participation %	CS-A Participation %
African American	37.1	16.5	15.0	12.5
Asian	4.1	9.4	14.9	23.5
Hispanic/Latino	48.0	50.0	39.5	29.4
White	8.8	20.1	26.4	28.3

Broadening success: Student achievement on AP CS-P

Mean scores on the CS-P exam, math GPA, and percentage free/reduced lunch for CS-P students in Chicago are reported in Table 3. The overall mean score in CPS was just above 3, which is the score needed to receive college credit. However, on average, both African American and Hispanic/Latino students earned an AP score below this cutoff. These student groups also had lower average math GPAs and higher percentages were low-income than Asian and White students.

Table 3: AP CS-P Scores, Math GPA, and Free/Reduced Lunch by Race/Ethnicity in CPS

	Mean AP CS-P	Math GPA	FRL %
Overall	3.2	3.1	55.3
African American	2.4	2.7	64.3
Asian	3.7	3.5	59.3
Hispanic/Latino	2.8	2.9	77.3
White	3.7	3.4	16.9

To further investigate student achievement, we developed a multilevel linear model to estimate performance on the CS-P exam (n=1262). In Table 4, we present the results of the model, which estimates the effect of AP student demographics and student preparation measures, controlling for teacher preparation factors that we hypothesized would be associated with performance. Teacher preparation factors included the year they participated in district CS professional development, number of CS courses taught, and whether they have a background (degree or license) in CS.

Table 4: AP CS-P Performance in Chicago Public Schools, Adjusting for Teacher Preparation Factors

		Coeff.	SE
	(Intercept)	-0.561*	(0.711)
<i>Demographics</i>	Female	-0.189***	(0.045)
	FRL	-0.088	(0.054)
	Asian	-0.005	(0.127)
	African American	-0.252	(0.138)
	Hispanic/Latino	-0.188	(0.124)
	White	-0.085	(0.121)
<i>Student Preparation</i>	Math GPA	0.637***	(0.037)
	Attendance Rate	0.759*	(0.387)
	Grade Level	0.024	(0.037)
	Selective School	0.986**	(0.315)
<i>Teacher Preparation</i>	CS Courses Taught	0.021	(0.033)
	CS PD Year	0.156**	(0.054)
	CS Background	-1.048*	(0.386)

Significance: *** = p<0.001; ** = p<0.01; * = p<0.05

The results of the modeling indicate that several of the variables were statistically significantly associated with CS-P exam score. For demographics, female students scored lower, even after controlling for student and teacher preparation measures. The finding that low-income students did not score significantly lower on the CS-P (after controlling for student and teacher preparation factors) provides some evidence that the hypothesis that AP contributes to social reproduction may not apply to CS-P.

All of the student preparation measures except grade level were significant and positively associated with exam score, including math GPA. Given the differences in math GPA by student race/ethnicity (Table 3), this finding provides evidence in support of the hypothesis that underrepresented students may not benefit from the program because they have not been provided with the necessary preparation to succeed. That is, preparation appears to be critically important for maintaining effectiveness as the program expands to underrepresented students. Attending a selective school was positively associated with CS-P performance, which may reflect that students' middle school GPAs are one of the factors in the admissions system for selective high schools and math GPA is a significant predictor of AP performance.

Regarding the hypothesis that AP courses are ineffectively taught to underrepresented students, we do not have good measures of course implementation quality to investigate this claim. Teachers having a background in CS was significant but negatively associated with CS-P performance. This unexpected finding will be explored in the next phase of our analysis. Further quantitative and qualitative research into instructional quality and teacher preparation is needed to better understand the relationship between these factors and AP CS outcomes.

Overall, the results of our analysis indicate that the district has made progress on broadening access but that substantial access challenges remain both in terms of continuing to scale up AP offerings across district schools and ensuring equitable access within schools. Challenges also remain for broadening success through CS-P. The findings point to several areas for further investigation and may be particularly beneficial for informing the development of strategies to effectively scale up AP CS in the district. In the next steps of our analysis, we plan to further refine our models by developing a composite score for AP performance and estimating additional multilevel models. These findings about access to AP CS courses and the student and teacher factors that are associated with CS-P performance provide insights that may benefit the ongoing work in Chicago and in other districts around the country to create CS pathways for high school students and the important role that AP CS courses have in building those pathways. It is critical to understand AP outcomes, and, specifically, differential outcomes for underrepresented groups of students, in order to create equitable pathways in CS.

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Scaling Just Like Experts Do: Results of an Expert Interview Study

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Abstract: Scaling innovations such as adaptive educational technologies into practice is a complex endeavor. It requires both an increase in the number of users and a deep change on different school levels. The goal of this study is thus to investigate enabling conditions and limiting factors of scale and specifically how these factors relate to each other by applying a data-driven approach. That is, conducting interviews with experts in the field of scaling-up adaptive educational technologies. By conducting expert interviews, we had access to their accumulated expertise about scaling factors and the interplay between these factors. For our analysis, we applied Epistemic Network Analysis. The analysis positioned collaboration between stakeholders at the core of the network and revealed the strongest connection between collaboration and teacher characteristics such as teacher concerns, competencies and professional development. We discuss our findings in light of existing scale approaches and draw implications for future scale efforts.

Keywords: Scaling innovations, Epistemic Network Analysis, educational technologies

Introduction

Scaling up an educational innovation refers to both an increase in the number of users and a deep change on different levels of the envisioned practice environment (Clark & Dede, 2009). For example on the learning and teaching level, due to the innovation students and teachers will probably have to learn new roles. At the system level, to enable teachers to act in new roles professional learning is required. And further, to prepare the envisioned innovation for local adoptions a flexible approach is needed (Cohen & Mehta, 2017). Both professional learning and local adoption in turn need a lot of communication across different school levels and between educational practice, administration and research, but lack according to Burkhardt (2018) from exactly that communication. Therefore, scaling is considered to be a multidimensional, resource-intensive and challenging endeavor (e.g., Cohen & Mehta, 2017). To address these issues, a number of scale approaches arose (often also termed as implementation or transfer process; e.g., Design-Based Implementation Research, DBIR, Fishman et al., 2013; Design-Based Research, DBR, Design-Based Research Collective, 2003 and many more). For example, DBR (Design-Based Research Collective, 2003) and DBIR (Fishman et al., 2013) deliver important impulses about scaling educational innovations such as to collaboratively and iteratively designing an innovation with practitioners and flexibly addressing local needs. Overall, these approaches represent valuable sources for conceptualizing scale but might lack empirical validation and a clear understanding about the interplay between different scale aspects. By making scale the object of inquiry and by applying a data-driven approach the present study aims to contribute to close this research gap. More precisely, we examine how different enabling conditions and limiting factors of scale relate to each other by conducting interviews with experts. The experts had profound experience in the field of scaling-up not just any innovation but a stellar example for a 21st century innovation. That is, adaptive educational technology (EdTech). This educational innovation allows for personalized and effective student learning (e.g., Pane et al., 2014) and requires a deep and wide change on different school levels. Thus, adaptive EdTech is seen as a suitable representative of a range of educational innovations and scale-related challenges.

Method

Sample and data collection: To examine how different scale aspects are connected, we recruited fifteen experts in the field of scaling-up adaptive EdTech. Experts were primarily researchers who had long-standing experience and profound expertise in a variety of EdTech development and scale projects. To get a broad variety of prior experiences both the experts' disciplinary background and role ranged from a) Computer Science, Learning Sciences, Science & Mathematics Education to Learning Assessment and from b) Principal Investigator, Co-Principal Investigator project manager, research associates to advisory board member. Interviews were conducted either personally or with a video conferencing tool and took between 41 to 96 minutes. The interviews were audiotaped with the experts' consent. *Interview Protocol:* For the interview protocol, we reviewed scale and EdTech related literature (see above and e.g., Puentedura, 2010) and identified categories of question. We then pilottested an initial protocol with an expert who was not included in later analyses and revised it accordingly.

The final protocol included 20 open-ended questions and covered the following broader themes: general experience with the scale process, collaboration with different stakeholders, technical implementation, use of EdTech in school, teacher competencies, mindsets, concerns with regard to EdTech, role of the curriculum. *Coding Scheme:* To code the transcribed interviews, we developed a coding scheme by combining a top-down and bottom-up approach: We again reviewed the scale and EdTech related literature and derived initial codes. For the bottom-up approach, we repeatedly reviewed the transcribed interviews and identified codes that were not yet touched by the aforementioned literature. Our final coding scheme covered six codes, namely *collaboration (C)*, *teacher (T)*, *resources (R)*, *technology characteristics (TC)*, *curriculum (CU)* and *else (E)*. For example, the code C was aligned to an expert's answer if the expert referred to any form of collaboration either within the same group of stakeholders or across different stakeholders. The unit of analysis were the experts' answers to a single question. Because our goal was to analyze dependencies between different scale aspects, more than a single code was applied to an answer. To code, two raters were intensively trained. Interrater reliability was assessed with a subset of three interviews. Across all six codes interrater reliability was very satisfactory (C: $\kappa=0.85$, T: $\kappa=0.86$, R: $\kappa=0.76$, TC: $\kappa=0.74$, CU: $\kappa=0.85$ and E: $\kappa=0.67$). Disagreements were resolved by discussions. *Data Analysis:* To investigate how different scale aspects relate to each other, we conducted Epistemic Network Analysis (ENA; e.g., Shaffer, Collier & Ruis, 2016). That is a method for quantifying connections between codes and for visualizing these connections in a network. While the network nodes represent the frequency of the code, the connecting lines between nodes represent the co-occurrence of codes within temporal or local proximity.

Results

Prior analyses

Across all 15 interviews we coded 534 answers with the codes C, T, R, TC, CU and E. Expressed in absolute frequencies the six codes occurred as follows: C occurred 349 times, T occurred 277 times, R occurred 162 times, TC occurred 145 times, E occurred 86 times and CU occurred 53 times. In line with Shaffer and colleagues (2016) our network had a strong goodness of fit as the co-registration correlations measured by both Pearson and Spearman across the first and second dimension of the network were extremely high $r > 0.9$ (1st dimension: Pearson's $r=0.94$ and Spearman's $r=0.93$; 2nd dimension: Pearson's $r=0.98$ and Spearman $r=0.97$).

Core of the network and connections between different scale aspects

As seen in Figure 1, the code C is at the core of the network. Across all interviews, we could distinguish between two different forms of collaboration: The first refers to interdisciplinary collaboration between (multidisciplinary) researchers and practitioners from all levels of the educational system and from all levels the school. Experts mentioned for example the following partners to be important during different stages of the scale process: *Policy makers, district leaders, super intendents, subject matter coaches and other professional developers, science coordinators, principals, senior administrative leaders, teachers, students, school boards, parents clubs and the broader school community*. Note that the italics (other than the italic codes) display paraphrased parts of experts' answers. The other form of collaboration that facilitates the wide use of an adaptive EdTech is collaboration amongst teachers. Experts spoke either of a *culture of collaboration* or *communities of practice*.

Given our six codes, the ENA revealed a network with 15 connections (see Figure 1). In the following, we concentrate on the three strongest connections. That is, connections clearly greater than 1.5 measured by the relative frequencies of codes' co-occurrence. These connections are between C-T with 2.53, C-R with 2.12, C-TC with 1.86. *C-T* forms the strongest connection. That is, a close collaboration between both is required to identify and address teacher mindsets, concerns, competencies and to provide for professional development and other forms of support. For example, expert B said the following about gaining teachers' trust and collaboration to facilitate a smooth scale process: "Yeah. I think we're talking indirectly about the questions you asked, but I think they all add up and add to the fact that if you have to work with teachers and be able to run studies in schools, that you have to be aware of all of these issues and try to address (...) because if you do that, I think you gain the teachers' trust and the confidence and they see the value in what you are doing and therefore are more welcoming." To understand the relationship between *C-T*, we further examined what kind of teacher mindsets, concerns, competencies and forms of professional support the experts mentioned. Depending on their specific form, these teacher characteristics either display enabling conditions or limiting factors. Across all interviews, experts described the following teacher mindsets to be important for enabling the scale-up process. Teachers would need to be *willing to adapt or adopt these technologies into their teaching processes, need to be willing to accept that change and be willing to spend some time and to continue learning*. In this context, it is also important to help teachers *see the need, perceive the (added) value and to perceive the technology as a solution to a given problem*. In addition, experts named a variety of teacher concerns that might display limiting factors. Teachers were

concerned about *the volume of work and time* that is required to work with an adaptive EdTech. That is, *not delivering the demanded content in time*. Teachers were further concerned about the extent to which the technology is aligned with curricular standards and the lesson plan and to which extent it prepares students for assessment (e.g., state tests). *Student privacy* (e.g., sharing and storing of data) and *equity* (e.g., access to computers beyond school) were two other major concerns. In terms of teacher competencies, the expert named the following as enabling conditions. They ranged from *basic tech skills, working knowledge of the system, knowledge about how to use the tool (translate data, to be able to interpret those results), TPACK – technological, pedagogical, content knowledge, ability to run experiments in classrooms, competence to work with constraints and have a Plan B as well as classroom management, teaching experience and knowledge about their student thinking*. There was consent across all experts that *professional development in form of trainings or workshops* is a key in the scale-up process.

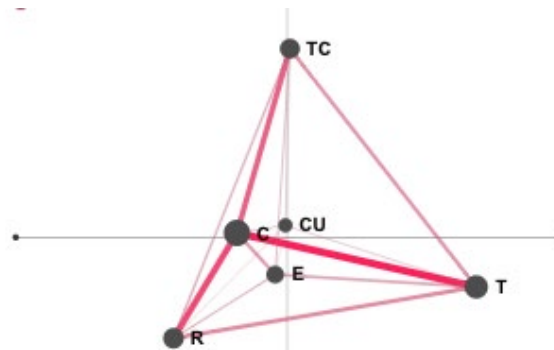


Figure 1. ENA across the codes collaboration (C), teacher (T), resources (R), technology characteristics (TC), curriculum (CU) and else (E).

The codes C and R form the second strongest connection within the network (C-R). That means, collaboration between researchers and practitioners and also a coordinated effort and high amount of communication amongst practitioners is required to identify and deal with (local) *resources*. In this context, expert B said: “Yeah, so increasingly, school districts have firewalls for what – and that prevents students and teachers in classrooms from accessing particular web sites or portals. And so oftentimes a district teachers or the science coordinator for the district will have to check with their IT department to make sure that they can actually get access to the portal. That’s not the case for the majority of schools [...]” Again to finer investigate the connection between collaboration and resources, across all interviews we identified what kind of resources the experts see as decisive for the scale process. For instance, they named *money, time, school infrastructure, availability and bandwidth of the school internet, availability of technical support (for maintenance of school computers) and the availability of technology and computers at students’ homes* as important. The actual use of the adaptive EdTech depends on the extent to which the resources are available in school and also to which extent solutions customized to local needs can be provided (e.g., small group work around limited number of computers, print out/ plan B for very limited number of computers).

The third strongest connection is established by C-TC. For example, expert D explained how collaboration helps in dealing with specific TCs: “Which would prepare them for the kinds of things that they would do. Often, the first – if a technology is particularly complex, like a particular project or subject matter, then a researcher would work closely with the teacher, sometimes even teach the class. You know, sort of model the teaching approach, and then allow the teacher to sort of gradually, maybe in a subsequent period, right, or maybe on a day’s delay they might, you know, do it with another class, following the example from the researcher.” To gain a better understanding of the C-TC relation, we identified a range of TCs (i.e., the domain, its purpose of use, the way it adapts to students’ performance and the extent to which it functions) to display important enabling conditions or limiting factors (or just neutral facts). In terms of the domain, experts named mostly STEM-related topics such as *science, earth science, environment science, math* but also *writing*. In terms of the adaptivity, they, for example described the underlying *algorithm of the technical component* of the EdTech. With regard to the purpose of use, experts named *science simulation, access to data and visualizations of data to teachers in science teaching, reading and writing, helping learners [...] develop their spoken English skills, helping students learn a specific aspect of math, getting the students to construct a model of scientific process, visualizations of complex system, automated scoring*. Specifically, in terms of the purpose of the technology use collaboration plays a crucial role to manage practitioners’ expectations, to co-design or to enable a shift in ownership.

Discussion

Scaling up educational innovations such as adaptive EdTechs is a complex endeavor. To address the complexity many scale approaches evolved but did not yet entirely unfold how different limiting factors and enabling conditions of scale are interwoven. Thus, we set out to investigate not only individual scale aspects but also how they relate to each other. In so doing, we applied a data-driven approach, conducted, transcribed and coded expert interviews and used ENA to account for dependencies between different scale aspects. Our ENA revealed one main finding: Collaboration is the most important enabling condition in scaling-up an educational innovation such as adaptive EdTech as seen by its central position in the network and by forming one part of the three strongest connections (C-T, C-R and C-TC). Collaboration here referred to both collaboration within the same group of persons (e.g., teachers) and collaboration between persons from different groups. For instance, collaboration between researchers and teachers is needed to understand teacher mindsets, concerns, competencies and professional development requirements (C-T) and to identify local resources (C-R), such as the availability of school computers or the availability of the IT-person at school. By identifying users' needs and local conditions in advance and throughout the innovation development process, the research team is able to consider a range of settings and to develop, iterate and redefine customized solutions (e.g., through modularizations) accordingly. Collaboration also played a crucial role with regard to technology characteristics (C-TC). That is, by enabling collaboration between researchers and practitioners technology characteristics can be re-defined. In this context, it is particularly important for the research team to transfer the (added) value of the technology for student learning or teacher work facilitation as highlighted in the Substitute-Augmentation-Modification-Redefinition Model (Puentedura, 2010). These findings are in line with key components of previous scale related literature (cf. DBR and DBIR) such as establishing a space for co-designing an innovation with practitioners or iteratively improving the innovation in diverse teams. With regard to the other form of collaboration (within the same group) experts highlighted the need for a culture of teacher collaboration. In such culture, teachers can identify different technology features and can discuss how the technology might fit into the broader lesson plan/ curriculum. Considering also the specific nature of the educational innovation at hand (i.e., adaptive EdTech) in the recent International Computer and Information Literacy Study (e.g., Eickelmann et al., 2019) teacher collaboration was an important enabling condition for using technologies in the classroom (not necessarily *adaptive* EdTechs).

In sum, we draw the following implications with regard to a smooth scale process: 1a) Collaborate early on in the development process, 2a) collaborate with a variety of stakeholders, 3a) through collaboration identify end users' needs and local resources and adapt to them and 4a) enable collaboration amongst teachers. To further integrate practitioners' perspective one of our next steps implies to conduct similar interviews with teachers and to identify the extent to which dependencies between different scale aspects differ across teachers and researchers.

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Scaling Up and Scaling Out Situative Design of Online/Hybrid Instruction and Assessment

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Abstract Extended design research yielded a situative approach to designing online instruction with some evidence and strong potential for scalability. This approach maximizes productive disciplinary engagement via public discussion of student “wikifolios” in threaded comments. Formative self-assessments and automated quizzes minimize grading and private instructor interaction with students while supporting and documenting achievement. This approach can be implemented in any modern learning management system or using Google tools. It was successfully used to scale up an online course for hundreds of open learners. But an extended partnership to scale out at a fully online high school revealed that educators who were unfamiliar and/or uncomfortable with sociocultural theory found the approach difficult to implement. In response, five design principles have been reframed as fourteen specific steps that do not require familiarity with sociocultural theory. This promises to help users learn how the approach works while designing, delivering, and scaling courses.

Keywords: Online learning, situativity, productive disciplinary engagement, expansive framing.

Three decades have passed since situative theories of learning emerged from extended efforts at the Institute for Research on Learning (e.g., Brown, Collins, & Duguid, 1989). For complex reasons, situative theories are less prescriptive for instruction than modern cognitive theories (Greeno, 1998). Nonetheless, numerous researchers have explored the practical implications of situative theories, typically using design-based research to generate design principles that are presented along with relevant aspects of the research contexts. Such contextualized principles contrast with more specific prescriptions from the range of applied cognitive research (e.g. van Merriënboer, Kirshner, & Kester, 2003; Duffy & Johnassen, 2013).

Some see the primary pedagogical implications of situative theories in approaches like Anchored Instruction (CTGV, 1990) and Problem-Based Learning (Hmelo-Silver, 2004). From our perspectives, such approaches are better characterized as “socio-constructivist” because they place individual learning and social interaction on a roughly equal footing. Our more resolute approach embraces Greeno’s (1998) “situative synthesis” whereby different forms of individual activity are treated as “special cases” of socially situated activity. We believe that (a) this offers a better starting point for addressing historical group-based educational inequities and countering deficit-based responses, (b) disciplinary discourse (rather than presumed cognitive engagement) is an ideal focus for iterative refinements, and (c) the situative synthesis can exploit the entire range of formative and summative assessments. Specifically, a range of informal, semi-formal, and formal assessments streamlines grading, allows instructors to focus on public discussion of student work, and gives refiners trustworthy evidence of impact.

The Participatory Learning and Assessment (PLA) framework and scalability

This new approach builds on principles from five other programs of DBR that insistently explored the implications of situativity. This included Randi Engle’s studies of *productive disciplinary engagement* (PDE, Engle & Conant, 2002) and *expansive framing* (Engle et al., 2012). Engle argued that learners should (a) “problematize” content from their own perspective, (b) find connections with people, places, topics, and times beyond the course, (c) hold themselves and peers accountable to disciplinary norms, and (d) be positioned as authors (rather than consumers) of disciplinary knowledge. We embedded these principles along with principles from situative studies of motivation (Filsecker & Hickey, 2014) within multiple levels of increasingly formal assessment (Hickey & Zuiker, 2012). This produced a new set of design principles deemed *Participatory Learning and Assessment* (PLA). Particularly when paired with *open badges* (Hickey & Schenke, 2019), PLA can support and recognize *generative learning* (i.e., likely to transfer to new educational, professional, and personal, contexts) while keeping instructor demands manageable.

In support of scalability, PLA only requires editable pages with threaded comments and online quizzes (in all modern LMSs and Google’s *Coursebuilder*, *Sites*, and *Docs & Forms*). Many PLA implementations rely partly or entirely on open educational resources, which further supports scalability. Some courses feature

conversational videos or podcasts where instructors or experts model the PDE with disciplinary knowledge and resources.

Scaling up in a Big Open Online Course (BOOC) on educational assessment

Many of the features used to implement PLA first emerged in a graduate course called *Assessment in Schools* taught by the first author since 2007 and moved online in 2009. In 2013, a grant from Google was used to scale up a big (but not massive) open online course (“BOOC”) using Google Coursebuilder. By enrolling enough for-credit students in each section of the “Assessment BOOC” and focusing instructor interaction on those learners, it was possible to include hundreds of non-credit open learners without requiring significantly more instructor time. The semester-long Assessment BOOC was implemented and refined annually from 2014 to 2016.

The grant supported a programmer and teaching assistants. This made it possible to iteratively streamline and ultimately automate most of the instructor/facilitator routines (Hickey, Kelly, & Shen, 2014). By the third year, the grant funds were exhausted and there were no teaching assistants. But hundreds of open learners were still able to complete their “wikifolios” and earn badges containing links to that work alongside enrolled students, while making almost no additional demands on the instructor (Hickey & Uttamchandani, 2019).

Scaling out in a Research Practice Partnership with a fully online high school

A multi-year research practice partnership (RPP, Coburn & Penuel, 2016) using design-based implementation research (DBIR, Penuel et al., 2011) was carried out to adapt PLA to the fully online Indiana University High School (IUHS). This RPP was led by the second author (a former high school English teacher) as doctoral research. The existing IUHS courses reflected the school’s history as a mail-based “correspondence school.” Students obtained a textbook, downloaded conventional assignments, and uploaded completed assignments for grading. When students felt prepared, they sought out a local proctor (e.g., a librarian) and completed a rigorous paper exam that the proctor mailed back for grading. These exams helped convince the NCAA to renew IUHS’ endorsement in 2014 after the NCAA stopped recognizing courses from most other online schools. However, many of the athletes who began flocking to IUHS for “credit recovery” courses were failing those exams. IUHS and NCAA agreed that students needed more meaningful opportunities to engage with teachers and content. The RPP aimed to provide this interaction to support success while remaining NCAA compliant by providing valid evidence of achievement.

The RPP worked with two existing teachers (biology and 9th grade English) and two new teachers (10th grade English and social studies) to adapt PLA and create four new courses. As documented in Itow (2018), the 10th grade English and social studies teachers had learned about sociocultural theories when completing their degrees. In contrast, the biology teacher had learned about cognitive learning theory, while the 9th grade English teacher had completed an alternative certification that did not include any learning theory. The 9th grade English teacher self-described as “politically and educationally conservative” and taught full time at a private church-affiliated school. From the start, the 9th grade English teacher worried PLA would undermine educators’ authority and ultimately left the partnership. Building on newfound expertise, the 10th grade English teacher quickly created the 9th grade course.

The 10th grade English teacher and social studies teacher were particularly engaged and were subsequently were hired full-time and given multiple courses. They refined the PLA framework over several years, with a focus on pacing. They ultimately gave students six months to complete self-paced courses. While this format increased completion rates, it also reduced peer-to-peer interaction that had previously peaked around weekly deadlines. Nonetheless, there was plenty of evidence that students were examining completed work of their peers and reading instructor comments on peer work; remarkably some students interacted with others who had already completed the course. The biology teacher initially struggled, but ultimately adapted PLA in a way that appears promising for STEM. All three teachers are continuing to teach their courses and student achievement is high.

A new step-by-step presentation of the PLA framework

In response to the difficulties some have had in implementing PLA, the five PLA design principles were recently reframed as fourteen more prescriptive steps, which include four optional steps. In particular, the first two principles in the PLA framework have been broken down into eight steps in which relevant experiences and examples from other courses are used to help newcomers who are unfamiliar with sociocultural theory. An article with a fully theorized description and examples from a range of courses is forthcoming elsewhere (Hickey, Chartrand, & Andrews, accepted). What follows is a summary of these “untheorized” steps that have also been presented in several recent workshops. These workshops have convinced us that this new presentation helps broad

audiences gradually come to understand (a) what it means to use expansive framing to support PDE, (b) how the same assessment can serve both summative and formative function, (c) how and why disciplinary engagement should be assessed carefully and separately from disciplinary knowledge, and (d) how and why multiple-choice tests can be used to estimate transfer to new contexts and to evaluate iterative refinements.

Step 1: Create a personalized framing activity. This crucial first curricular activity helps students define a personally relevant context where they can practice using the concepts of the course. Designers are reminded that (a) some first drafts can and will be incomplete or even inappropriate, (b) that students can and should look at peer examples and instructor feedback when drafting their initial frame, and (c) that students should refine their characterization across activities as their understanding of their context expands.

Step 2: Define an introductory engagement routine. This initial routine gently introduces expansive framing with relatively simple course content. In most of our courses, this is accomplished in the very first assignment, (sometimes before students define their framing context) and simply has students introduce themselves to explaining which course objective is most relevant to their personal and career goals.

Step 3: Define primary engagement routines. Create routines that engage students productively with manageable “chunks” of disciplinary knowledge. In most assignments, students (1) summarize the relevance of curated elements that make up those chunks, (2) reorder those summaries in order of relevance to their framing context, and (3) justify those rankings (e.g., explaining why the first is most relevant and the last is least relevant).

Step 4: Define secondary engagement routines. Introduce more advanced concept in secondary routines that (a) build on the concrete artifacts and insights generated in the primary routines, (b) may or may not employ the ranking strategy described above, and (c) are introduced further on in assignments and/or courses.

Step 5: Define collaborative engagement routines (optional). We suggest including collaborative “team-based” activities judiciously, if at all. This is because PLA supports extensive social interaction around individually completed work; collaborative activities can also call for synchronous engagement that many online students find difficult to manage. Of course, we defer if collaboration is elemental to disciplinary practices being learned.

Step 6: Define obligatory engagement routines (as needed). In our experience, some courses in some disciplines will include some content that most learners can’t frame expansively. Put differently, we sometimes find that courses have some content that is necessary but that learners find difficult to generate a framing context. Some courses have had students frame engagement from their college major or by viewing introductory OERs.

Step 7: Define student engagement expectations and routines. PLA assumes that students will examine and discuss peer work and interact with the instructor via threaded comments directly on student work. This helps students hold each other accountable to peers and to disciplinary norms, and position students as an audience for their peer authors. But such interaction should not be graded or formally evaluated; in contrast to more abstract discussion forums, we find that most students are usually quite enthusiastic about discussing their own work.

Step 8: Define instructor engagement expectations and routines. Instructors should model and encourage PDE, but they needn’t participate in every threaded exchange. We also suggest instructors prioritize helping students define and refine their framing contexts and introducing more advanced concepts within discussion threads.

Step 9: Create public informal assessments of engagement. These reflections formatively assess understanding while summatively assessing prior engagement. They are used for awarding completion points, “repositioning” (Agarwal and Sengupta-Irving, 2009) minoritized students, and surfacing sociopolitical issues. We currently use prompts for *contextual*, *collaborative*, *consequential*, *conceptual*, and *cultural* engagement.

Step 10: Create private semi-formal self-assessments of understanding. These are private open-ended items featuring known-answer questions about key concepts in each assignment. They are intended to summatively assess prior understanding of those concepts while formatively assessing achievement in advance of achievement tests.

Step 11: Create automated formal tests of achievement. We suggest including private, multiple-choice test for clusters of assignments (i.e., “modules” in many LMSs) that are automatically scored. These should include challenging “best answer” items that can’t be searched when time is limited (perhaps two minutes per item). While the contents of the tests should be “aligned” with the assignments and formative assessments, the actual items should not drive instruction and the specific associations in test items should not be directly presented in advance.

Step 12: Create model wikifolios, podcasts, or videos (optional). We suggest that designers consider creating a model wikifolio for students to refer to the first time the course is offered. In larger courses, it may be worthwhile to create videos or podcasts for each assignment. Rather than delivering content (which is challenging to do well), these recordings are more conversational, whereby more advanced professionals and/or experts model the forms of engagement expected of students, explaining relative relevance in their own context.

Step 13: Create microcredentials (optional). The public nature of student engagement in these courses is ideally suited for web-enabled digital badges. The wikifolios and threaded discussions (which the badges can link to) facilitate recognition of “21st Century” competencies like collaboration, creativity, and critical thinking.

Step 14: Design homepage, submission, and grading systems. Depending on the platform, it will likely be necessary to create a course homepage so that students and instructors can more readily access wikifolios, a routine for letting instructor know when wikifolios have been completed, whatever grading or point scheme to be used, and a gradebook that provides FERPA-protected grades and private feedback.

Next steps

Having defended her dissertation, the second author was hired as the Principal of IUHS. We are now laying the groundwork to expand the use of the PLA across the school using this new step-by-step presentation. We expect that this new presentation will help all of the teachers and course designers develop and teach new cooperative courses and further refine and streamline the existing cooperative courses.

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Building Capacity Via Facilitator Agency: Tensions in Implementing an Adaptive Model of Professional Development

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Abstract: One approach to offering sustained professional development at scale is to prepare school-based facilitators to implement a professional development program at their school sites. In implementing a given program, especially one designed to be highly adaptive, facilitators will undoubtedly modify the program. Few studies, however, have examined such adaptations. In this study, we examined the adaptations made by mathematics teacher leaders to a highly-adaptive program of professional development. We considered how teacher leaders modified, omitted, and created activities, focusing questions, and other aspects of the program. We found that facilitators made modifications to address local priorities, yet also omitted core program activities as the project progressed. Our study illustrates a tension encountered by developers of adaptive PD programs between wanting a program to be adaptable enough that facilitators will continue to implement it as their priorities shift and keeping core aspects of the program intact.

A common approach to implementing professional development (PD) is for the developers of a PD program to facilitate the program with teachers themselves (Borko, 2004). While this approach can ensure that the program is implemented as conceived, it typically does not allow for the program's sustained implementation at scale.

One way of sustaining a PD program at scale is for the developers to build the capacity of others to implement it. For example, PD developers can support teacher leaders or other facilitators in developing the knowledge, skills, and vision required to implement the program (Borko, Jacobs, Koellner, & Swackhamer, 2015; Jackson, et al., 2015). After building facilitators' capacity, support from the developers may become unnecessary.

In implementing a PD program, facilitators are likely to make adaptations. Such adaptations have recently become the focus of scholarly inquiry. For example, Jacobs, Seago, and Koellner (2017) examined the adaptations made by a single PD facilitator to a highly specified PD program comprised of a set of "predetermined goals, activities, and resources" (p. 2). Studies of this nature remain rare, however, and few to date have examined the adaptations made by facilitators to highly adaptive PD programs. As facilitators are likely to have more leeway in modifying activities and structures in adaptive programs, the adaptations they make could be both more numerous and more substantive than those made by facilitators of more specified PD programs. Whether or not this is the case, however, is unknown and worth examining, as such adaptations have implications for the scalability and sustainability of adaptive PD.

In this study, we examined adaptations made by facilitators to a highly adaptive PD program known as the Problem-Solving Cycle. We investigated the following questions:

1. In what ways did PD facilitators adapt components of a highly adaptive program of mathematics teacher professional development?
 - a. What types of adaptations did the PD facilitators make?
 - b. What were the rationales underlying these adaptations?

Study context

This study is part of a research-practice partnership (RPP) focused on building the capacity of a school district to establish and sustain a PD program. We focus, in particular, on middle school mathematics. The ongoing RPP is between the Urban Unified School District (pseudonym UUSD) and a university. As with other RPPs, central to ours is long-term collaboration (Coburn & Penuel, 2016).

The partnership was founded on commitments from both sides. UUSD was implementing two new policies aimed at ensuring that every student would have access to high-quality teaching and learning: 1) a re-designed task-based mathematics curriculum and 2) district-developed, interdisciplinary Dimensions of Teaching and Learning. The curriculum was aligned with UUSD's mission to offer rigorous and meaningful mathematics to all students. The Dimensions described visions of equitable teaching and learning around three main components: a) agency, authority, and identity; b) access to content; and c) assessment. The university contributed two structures with UUSD's policy goals in mind: 1) the Problem-Solving Cycle (PSC) model of PD workshops,

which were designed to support teachers' learning of mathematics, student learning, and instruction through the analysis of tasks (Do The Math, workshop 1 in a PSC cycle) and video-based discussions (VBDs, workshops 2 and 3); and 2) the Teacher Leadership Preparation (TLP) model, which is intended to prepare teacher leaders to lead PSC workshops with mathematics teachers at their own schools. During project planning meetings, the RPP leadership team made initial adaptations to the PSC and TLP models to support the curriculum and Dimensions. For example, rather than use a single mathematics task for each iteration of the PSC, as is typically the case (Borko, Jacobs, Koellner, & Swackhamer, 2015), we used three tasks from the UUSD curriculum - one per grade level. Using a DBIR model (Penuel, Fishman, Cheng, & Sabelli, 2011), adaptations were made on an ongoing basis to ensure sustainability and sensitivity to the learning goals of the district and individual school sites.

Conceptual framework

Highly specified and highly adaptive programs of professional development

Programs of professional development can be thought to exist along a continuum from highly specified to highly adaptive (Koellner & Jacobs, 2015). Highly specified PD programs are designed to be implemented in a way that closely mirrors how they were conceived by the developers (e.g., Jacobs, Seago, & Koellner, 2017). By contrast, highly adaptive PD programs (e.g., Borko, Jacobs, Koellner, & Swackhamer, 2015) are more flexible and provide facilitators greater latitude with regard to how they choose to implement the program.

Agency and sustainability

Facilitators asked to implement a highly adaptive PD program are positioned with greater agency than those asked to implement a highly specified program. Agency is present when one has the power to make decisions, exercise choice, and act at their discretion (Pickering, 1995). In implementing a highly specified PD program, facilitators have less agency, as choices about what to do and how to do it are largely predetermined by the program itself. On the other hand, those implementing a highly adaptive PD program can make choices throughout the implementation process regarding the particular way in which they would like to enact the program.

Positioning facilitators with agency is likely to both encourage and diminish the sustainability of a PD program. Highly adaptive PD programs position facilitators with the agency to decide how to implement the program, affording them the opportunity to continually adapt the program to suit their changing needs, interests, and priorities. As such, the model may remain relevant over the years and continue to be used. This agency, however, may also result in such substantial modifications that, over time, the PD model bears little resemblance to how it was originally conceived by its developers.

Adaptations to professional development programs

The adaptations facilitators make to a PD program differ in type, number, and rationale. Leufer and colleagues (2019) proposed the following typology of adaptations PD facilitators may make: a) follow (use as designed), b) modify (change), c) create (develop something new), d) omit (drop entirely), or e) sort (change the order).

Although little work has examined the rationales underlying PD facilitators' adaptations to PD programs, studies of teachers' adaptations of curricula show that the modifications they make are often rooted in sound rationales and factors such as teachers' pedagogical content knowledge, prior teaching experience, or input from colleagues (Davis, Beyer, Forbes, & Stevens, 2011). With regards to PD facilitation, Mumme, Seago, Driscoll, and DiMatteo (2010) argued that adaptations facilitators make to PD programs can be attributed to their knowledge and beliefs, but also to external factors beyond a facilitator's control.

Methods

Participants for this study consisted of mathematics teacher leaders (TLs) from nine UUSD middle schools. Most schools were involved for all three years of the project. TLs took part in six TLP meetings per year. During the TLPs, activities central to the PSC were modeled for TLs to then facilitate in their own site-based PSC workshops.

Videos of TLP meetings and PSC workshops were collected over the three years of the project, resulting in eighteen TLP videos and a maximum of eighteen PSC videos per school site. After video collection, a researcher viewed and created content logs for both TLP and PSC videos. The research team then engaged in three phases of analysis. During phase one, we used the content logs to create a table identifying the main features of each TLP meeting and corresponding PSC workshop at each school site. In phase two, we drew upon this table to compare TLPs to corresponding PSCs, identifying parallels and divergences. During phase three, we coded these parallels and divergences to determine the types of adaptations made (see Table 1).

Table 1: Adaptation Codes Modified from Leufer, Prediger, Mahns, and Kortenkamp (2019)

Follow	Follow the structure of an activity as originally modeled during the TLP.
Sort	Re-order workshop activities differently than modeled during the TLP.
Modify	Make a change in the activity or portion of an activity to the extent that a difference is noted, but similarity exists between it and what was originally modeled in the TLP.
Create	Develop a new activity or portion of an activity that is different from what was originally modeled during the TLP.
Omit	Eliminate an activity or portion of an activity from that which was originally modeled during the TLP.

In this paper, we focus on the modify, create, and omit codes because they were generally representative of the facilitators acting agentially. After coding all adaptations, we selected instances illustrative of each type of adaptation TLs made at their PSC workshops. We took this approach to feature particular intentional adaptations so as to highlight the ways in which TLs were acting agentially in planning and facilitating their school site PD.

Findings

Analyses comparing an individual TLP to corresponding PSC workshops revealed that the PSCs conducted at different school sites were adapted differently.

Modifications were the most frequent adaptation made during PSC workshops. They varied in nature, and often were seen in how language was purposefully adapted, analytical lenses were shifted, and supplemental resources were intentionally integrated. For example, in year 1, TLs at School 9 modified the focal question for the Do The Math activity. During the Do The Math activity modeled at the preceding TLP, the focal question asked was, “What are the advantages and disadvantages of the various representations used to solve [the focal task]?” However, TLs Kevin and Frank (self-selected pseudonyms) explained that their department at School 9 had been discussing math practices, so they wanted to focus instead on the math practice of *Making Sense of Problems and Persevering in Solving Them* (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). The TLs thus shifted their focal questions for the Do The Math activity at their workshop to, “What evidence do we see of students making sense and persevering?” The School 9 TL team made a purposeful choice to modify the nature of the focal question in order to address site-specific goals.

Creations. Activities within the PSC workshops were often created when additional topics or needs arose within the school site context. At a TLP in year one, the modeled Do The Math activity utilized adult-created student work. At School 5, TL Kitty chose to compile authentic student work samples from her classroom. She purposefully selected particular representations from specific subgroup populations so as to capture the variety of student work teachers may encounter when teaching the focal task. She noted that she curated this new collection of authentic student work for the PD because the adult-created work did not capture all the patterns that often arise in teaching the task. Teacher leaders also created new activities and incorporated them into the agendas of the PSCs they facilitated. At School 8, TL Mara projected state test questions, querying participating teachers on how to modify the questions to make them group-worthy (Lotan, 2003). This type of question modification task was a new activity structure that was not modeled in a TLP. At School 2, there was also a discussion of state tests, yet in this case, it was an administrator who introduced an activity in which participants discussed state testing, which limited the time TLs had to enact other activity structures they had planned to implement.

Omissions were more frequent both at the end of academic years and in year three. Core PSC activity structures (i.e., Do The Math and Video-Based Discussions [VBDs]) were sometimes omitted. Even when activities were done, particular components of the activities were sometimes omitted. For instance, across multiple years, we observed school sites omitting the sharing of norms in a VBD and the explicit naming of focal questions to ground discussions in both Do The Math activities and VBDs. Across several school sites, focal questions and norms, which are important components of the structure of these activities, were increasingly omitted over time.

Discussion

We found ample evidence of teacher leaders making adaptations to a highly-adaptive PD program. We also found empirical support for our argument that the adaptability of a highly adaptive program can both contribute to and diminish the sustainability of the program. In the outset of this paper, we argued that the adaptive nature of the Problem-Solving Cycle PD program could keep the model continually relevant even as priorities shift, thereby enhancing its sustainability. We also argued that this adaptability could result in changes so substantial that the PD program may, over time, appear less and less like the program as originally conceived. This study lends empirical support to both arguments. Over the course of this project, teacher leaders modified the PD program to address their local priorities and interests (e.g., using core activities of the program to address colleagues’ interest

in mathematical practices), so that the program remained relevant. However, over time, the adaptations we observed increasingly consisted of omissions, including omissions of core features of the model (e.g., Video-Based Discussions). There is thus a tension in preparing facilitators to implement an adaptive PD program between wanting the program to be adaptable enough that facilitators continue to implement it as priorities shift and striving to keep core aspects of the program intact and in use. How to navigate this tension remains an open question.

Agency and adaptations

Although facilitators of a highly adaptive PD program have notable agency, there are limits on this agency. District personnel who facilitated the TLPs encouraged TLs to adapt the PSC workshops to address their schools' priorities, yet our data reveal that, in some cases, the TLs' agency to make such adaptations was hamstrung by external constraints (Mumme, Seago, Driscoll, & DiMatteo, 2010). For instance, at one of School 2's PSC workshops, an administrator took time to discuss state tests, which reduced the time left for other activities. Hence, in a highly adaptive PD program, facilitators may be simultaneously positioned with agency and a lack thereof by various actors. This presents another tension to navigate in preparing facilitators to implement adaptive PD.

Future directions

We plan to build on the analyses presented here by examining both how *modify, create, and omit* adaptations change in frequency within individual school sites and how the grain size of these adaptations changes over time.

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A Video Club in a Networked Improvement Community: Coupling C- and B-Level Activities to Access A-Level Expertise.

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This paper examines how a video club activity in the context of a Networked Improvement Community supported participants in converting their practice-based expertise into a resource for improvement across the network. NICs are an increasingly popular model of a research-practice partnership that relies on practitioner insight to improve the design of solutions. Therefore understanding how NIC activities generate the kinds of insight needed for network-level learning is critical to understanding the implementation of the model. Drawing on qualitative data collected during the initiation of a NIC, I show how a video club activity provided a way for educators to generate, select, and integrate improvement ideas into a subsequent design task. The analysis provides insight into how the features and sequence of activities can be organized to support problem-solving in a NIC.

Problem statement

Networked Improvement Communities (NICs) are a type of research-practice partnership that bring practitioners and experts together from different contexts to solve a common problem (Coburn, Penuel, & Geil, 2013). NICs use a social strategy of reorganizing research and development activities. This reorganization brings together groups with diverse expertise that are tasked with the iterative testing and scaling of interventions to identify what works, for whom, and under what conditions (Bryk et al., 2015). This collaborative design strategy requires a “reconsideration of when and how in the arc of problem solving this diversity of expertise is best exploited” (Bryk, Gomez, & Grunow, 2011, p.4). Therefore a key task for NIC leaders and researchers is to consider who participates, when, how, and to what effect in solving their common problem.

The question this paper addresses is, *how can NIC activities be organized to create the conditions that transform researcher expertise into a resource for improvement?* The paper draws on qualitative data collected throughout the initiation of PiPNIC, the Personalization in Practice - Networked Improvement Community, that brought together 21 educators from 5 schools around a common challenge in implementing personalized learning. The initial stages of the NIC were organized by the 90-day cycle (Park & Takahashi, 2013), which included four Saturday meetings. The analysis focuses on the features of two activities on the first Saturday meeting, a video club and design task, and the generation, selection, and integration of new ideas for improvement.

The first finding is that the networked video club activity sparked educators to share what they noticed about their own and other schools’ practices. These “noticings” became a resource for the improvement at other schools across the network when they completed a subsequent design task. The second finding is that coupling the networked activity with a design task provided a way for educators to leverage practice-level insights into improvement. These two findings locate when, where, by whom, and how improvement ideas were generated and integrated into solutions. In understanding the NIC as three nested layers of activity (Engelbart, 1992), these findings suggest that network, or C-level, change was motivated by providing access to local, or A-level, practice. These findings affirm the improvement science principle of gaining a deep understanding of local practice and conditions to motivate systems level change (Bryk et al., 2015). In this way, this paper explicates how the improvement structures of a NIC can work to get new ideas into action.

Theoretical framework

This case study relies on three constructs to understand the problem solving process: conferring in personalized learning, video clubs, and the improvement infrastructure of a Networked Improvement Community.

Conferring in personalized learning

Personalized learning is a pedagogical approach that combines new technologies and student-led learning by building flexible learning pathways around learners’ interests, goals, strengths, and needs (Rickabaugh, 2016). One strategy for educators to support these personalized pathways is a practice called “conferring,” which is a regular, data-informed conversation between an educator and student, during which educators capture information about student learning, record and document progress, and co-construct a pathway with the student (Halverson et al., 2015). Educators across different types of PL implementations consistently placed importance on conferring, yet they found little research to support this in a PL context. In the initiation of PiPNIC, the research team selected

the design and testing of conferring protocols as a common problem of practice. When the educators came together for the initiation of PiPNIC, they had limited knowledge of each other's practices or contexts.

Video club activity

To support participants in learning about each other's conferring practices, the first PiPNIC meeting was organized as a modified video club activity. In video clubs, educators share recent videos of their practice then discuss what they notice (Sherin & van Es, 2009), building a shared language of practice as a pathway to improvement (Frederiksen et al., 1998). Video clubs focused on mathematics teaching have been shown to support teacher learning, particularly in what they notice about students' thinking (van Es & Sherin, 2008). But where most video clubs focus bring together colleagues from the same school, we hypothesized that a networked video club design would provide a pathway for educators to learn from other participants in the NIC as they worked to improve the collective impact of conferring.

Improvement infrastructure

NICs combine individual problem solving with an intentional infrastructure to support collective impact, where infrastructure refers to the practices and technologies that support actions. The term "networked improvement community" comes from Douglas Engelbart's idea of learning at three organizational levels, where A-level is the core work of the organization, B-level is work that improves A, and C-level is work that improves B-level work (Engelbart, 1992). As an improvement infrastructure, the A, B, and C levels provide configurations that support the problem-solving tasks. In the context of PiPNIC, A-level activity is focused on the student-teacher interaction in a conferring meeting; B-level activity includes the actions of the school team to improve, such as reflective conversations amongst educators to align their conferring practices; and C-level supports the school team at getting better at how they improve conferring.

Research design

This paper is a design-based case study that draws on a range of data to explore a single phenomenon (the arc of problem solving for the Irving school team) within the design of the partnership (PiPNIC).

Partnership design

On the first day of the 90-day cycle, NIC participants shared videos of their current conferring practice with educators from other schools in a networked video club activity. Participants (21 educators and 10 researchers) were assigned to watch the videos of conferring in four small groups with at least one educator from each school. Having one person from each school in each group was meant to foster cross-school interactions and prevent one person from becoming the de facto spokesperson for their school.

One researcher facilitated each group. First, participants were asked to script the conferring session by writing down what they saw happen, second-by-second, in the conferring meeting. The researcher prompted participants to observe, rather than interpret, what they saw in the video. Researchers then guided subsequent discussion with two open-ended questions: (1) What is the goal of this session? (2) What are the parts of this session, and how long did each part last? The researchers recorded the answers to these questions on their facilitator's sheet. The observers' scripts and facilitator sheets were passed on to the school team to support the following design activity.

Next, each school met with their team to accomplish the design task of how they wanted to improve their conferring. Each team had one researcher to facilitate this conversation with three questions and record their answers on another facilitator sheet: (1) What did we learn from others observing us? (2) What did we learn from observing others' videos? (3) What would we like to do to improve? These questions begin with reflection then task the team with identifying a direction for improvement.

Data collection and analytic approach

PiP researchers, who were designers, facilitators, and participant observers, collected a wide range of data throughout PiPNIC. For this paper, I selected a subset of artifacts to focus on the video club activity and subsequent school team meeting. For the video club, artifacts included 131 pages of scripts (about 20 pages per school) generated in the video club activity and 20 pages (4 per school) of facilitator documentation on the discussion of each video. For the school team meeting, artifacts included 5 pages (1 per school) of facilitator documentation. I also selected relevant portions of the 95 pages of case memos (1 for each school and 1 for PiPNIC) that were written at the conclusion of the 90-day cycle, at which time they were cross-checked with members of the research team. The details of design decisions were verified with participating educators in preparing co-presentations of conferring protocols for three regional conferences.

The analysis looked at this subset of artifacts from two perspectives: locating the generation, selection, and integration of ideas about conferring and identifying the hypotheses embedded in the design of NIC activities. For the ideas, I used inductive coding of the scripts to identify what aspects educators noticed about other schools' conferring videos and triangulated this with what the researcher documented of the discussion. By locating the generation of ideas in the scripts, this supports that the ideas were generated in the context of the video activity, rather than being preconceived. For the features of the NIC activities, I attended to structures that impacted who participated, when, how, and to what effect. Inextricable from these design features is that I both co-designed the organization of activities and managed the data collection during the partnership. Thus an articulation of PiPNIC features is intertwined with my own actions, beliefs, and interpretations. For this reason, I use the theoretical framing of problem solving in NICs to consider features that organize the who, when, how, and to what effect of the NIC activities and ground the analysis in the artifacts generated by participating educators and researchers.

Findings

This section is organized into how the networked video club activity generated A-level insights and how the B-level activity supported the integration of these insights into design decisions. The analysis draws in particular on the actions of educators from Irving School District. Irving is a small, rural district where personalized learning is district-wide, standards-driven reform. The noticing and design decisions of the Irving educators is framed by a district focus on standards and traditional measures of academic achievement.

The first finding is that the networked video activity supported access to A-level, practice-based expertise. For example, when educators from Irving watched the Franklin video, they noticed that the Franklin teachers spoke more than the students. Several educators across video groups brought up the balance of educator and student talk as a rough indicator of student participation. This prompted research team discussions throughout the 90-day cycle about the ratio of educator to student talk as a potential practical measure of conferring. Irving educators noticed in the Lewis video how the high school student led the organization of the conferring meeting, with the Lewis educators primarily asking probing questions. This insight highlighted the conversational moves educators and students make as an indicator of student ownership of the conversation and, by extension, of their own learning process. Irving educators noticed that in their own videos, the teacher dominated conversation prompts in the kindergarten and third grade meetings, but in the middle school conferring meeting, the student was identifying her own areas of struggle and asking for feedback. In this way, the A-level insights were sparked from watching the conferring meetings at other schools in the network.

The second finding is that educators integrated these A-level insights into B-level design decisions during the subsequent design task. Using Irving again as an example of how this played out, Irving educators met with their researcher to reflect on what they and others had noticed about their conferring practice. First, educators from other schools noticed that conferring at Irving was driven by standards-based performance assessments and that educators dominated the initiation and structure of the meeting. They noticed that the Irving teachers would occasionally interrupt the students or even answer the questions for the students. Educators from other schools suggested that Irving educators should “help guide students to discovery,” rather than provide answers; that students should do more of the talking; and that teachers should not “take over” the conversation. The Irving educators reflected on the contrast with Jackson High School’s focus on conferring as a time for reflection with their students.

When prompted to decide their direction for improving conferring, Irving educators began to envision a goal of a K-12 continuum of conferring, where students would have more voice and choice as they got to high school. They decided they wanted to spend more time “digging deeper into student’s thoughts,” as one educator described. As their conversation turned to what they would be interested to improve, several different ideas emerged: older students could create their own agenda for conferring; younger students could identify what they wanted to confer about or what came next in their learning pathway; educators for upper elementary and middle school students could integrate reflective questions. The team began to tie these ideas together around a common thread of student ownership of their learning process, and, as students got older, an expectation for students to make more of the decisions about their learning, supported by gradual release of control over the organization of conferring sessions. The A-level insights from the video club directly informed their B-level design decisions.

Discussion

The features of the NIC activities had consequences for Irving educators in generating, selecting, and integrating ideas into the direction for improving conferring. First, the networked configurations of the video club activity and open-ended discussions sparked ideas for improving practice. Notably absent were signs of professional defensiveness when sharing and receiving critique of one’s practice (Argyris, 1991). Second, the design task that immediately followed provided a context for considering others’ insights, reflecting on their own vision for their

school, and deciding a common direction. From the perspective of the design of the activities themselves, the intentional coupling of these C- and B-Level activities provided a sequence of generating ideas with the networked groups then considering and integrating those ideas with school teams. The integration of ideas from across the network into individual schools' designs legitimates the insights that were generated. In this way, the coupling of the activities leveraged the improvement infrastructure to generate insights as a resource for improvement.

These features have implications for the study and design of NICs more broadly. The use of a networked video club activity provided a strategy to generate practice-based insights; however, it was the *coupling* of this C-level activity with the school team design task that supported schools in generating, selecting, and integrating A-level insights for the subsequent design task. This suggests that attending to the *sequence of activities* of a NIC may itself a critical feature of the reorganization of the problem-solving process.

One limitation of this analysis stems from the use of Irving as an instrumental case. While elements of the Irving case were observed across all five schools, the Irving case provided the most complete case. The presentation of this case thus allows the exploration of the processes involved, though does not intend to argue that this was true for all participating schools nor for any NIC using a video club. The focus on design features of the NIC in analyzing the Irving case aims to identify how particular kinds of actions were encouraged, not determined. Finally, a future question to consider is how problem solving in NICs relies on the interactions of participants from different contexts. Whereas some NICs have been formed with educators from a single district, the analysis here suggests that the networked dimension of the video club was critical for generating new perspectives on current practices.

Conclusion

The question this paper addresses is, *how can NIC activities be organized to create the conditions that transform practitioner expertise into a resource for improvement?* By analyzing when, by whom, and how new change ideas were generated, selected, and integrated into proposed solutions, the paper identifies the organization of NIC activities, specifically the coupling of B- and C-level activities, as providing an improvement infrastructure to support educators in sharing their expertise with each other in a way that was useful in the design of proposed solutions.

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Using Machine Learning to Understand Students' Learning Patterns in Simulations

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Abstract: This study explores how unsupervised machine learning (ML) techniques can identify productive learning patterns as students conduct virtual experiments using a simulation. The log data from 52 pairs of eighth-grade students were analyzed using two ML techniques, Finite Mixture Model (FMM) and Sequential Pattern Mining (SPM). The results show four levels of learning patterns (i.e., Low Activity, Random Interaction, High Analysis, Tasked Exploration), each of which have unique, sequential actions. This study shows the potential value of unsupervised ML for understanding which types of interactions with simulations could facilitate students' understanding of complex scientific phenomena.

Keywords: machine learning, simulation, log data, learning patterns

Introduction

The Next Generation Science Standards (NGSS; NGSS Lead States, 2013) require students to understand complex scientific phenomena through science practices, such as carrying out investigations, collecting and analyzing data, and engaging in argument from evidence. Computer simulations can create such learning opportunities by allowing students to design virtual experiments by manipulating variables and displaying the outcomes in multiple forms, including molecular animations and dynamic graphs (e.g., Plass et al., 2012). During their experiments, students can also collect and analyze different types of data to identify relations among the variables and deepen their understanding of complex scientific systems (Stieff, 2011).

However, research has shown that students often struggle with how to conduct scientific investigations using simulations, which can lead to an incomplete understanding of scientific phenomena (Scalise et al., 2011). For instance, students may run too few or too many trials when testing hypotheses (Gobert et al., 2012). Some students also randomly change variables, rather than carefully designing their experiments (McElhaney & Linn, 2011). Even after successful trials, some students may not know how to interpret multiple sources of evidence to make sense of the underlying mechanism (Kanari & Millar, 2004).

Research has shown that productive learning patterns can be identified from log data using unsupervised machine learning (ML) techniques that can uncover hidden patterns in raw or unlabeled data (Amershi & Conati, 2009; Khalid & Prieto-Alhambra, 2019; Qiao & Jiao, 2018). For example, Shih, Koedinger, and Scheines (2010) used unsupervised Hidden Markov Models to discover student learning tactics while incorporating student-level outcome data. Bernardini and Conati (2010) used Class Association Rule Mining to automatically identify common interaction behaviors.

In particular, recent studies have shown the value of Finite Mixture Model (FMM) and Sequential Pattern Mining (SPM) for finding patterns within complex datasets (e.g., interactions in simulations collected during science inquiry instruction) (e.g., Baker & Inventado, 2014; McLachlan & Peel, 2000). For example, FMM can handle high-dimensional low sample size (HDLSS) datasets (i.e., # of observation is much smaller than # of variables) and model multivariate data from populations suspected to include separate subpopulations (Melnykov & Maitra, 2010). SPM can discover important learning subsequences that appear in the same relative order but not necessarily contiguous (e.g., $\langle a(bc)dc \rangle$ is a subsequence of $\langle a(abc)(ac)d(cf) \rangle$) (Zaki, 2001).

Using these two unsupervised ML techniques can determine distinct learning categories in log data and provide further insight into subsequential learning patterns within each category. Given the limited research on the use of FMM and SPM in the field of education, this study explores how these two techniques can identify productive interaction patterns that can enhance eighth-grade students' science learning within a simulation.

Methods

As part of a larger NSF project, 52 pairs of eighth-grade students from a low-income middle school completed a web-based inquiry project on photosynthesis for three to four days. During the project, pairs used a simulation to explore what happens to energy, matter, and plant growth during photosynthesis by conducting virtual

experiments (see Figure 1). Before and after using the simulation, pairs answered identical prediction and reflection questions about the target concepts. The simulation provided scaffolded prompts to engage them in making a hypothesis, designing an experiment, collecting data, and analyzing data to draw a conclusion. All pairs' actions with the simulation (e.g., a sequence of hyperlink and button clicks, students' responses to a data table) were logged with time-stamps. During the study, at least one researcher was present in each classroom to observe student interactions with the simulation and videotape selected pairs.

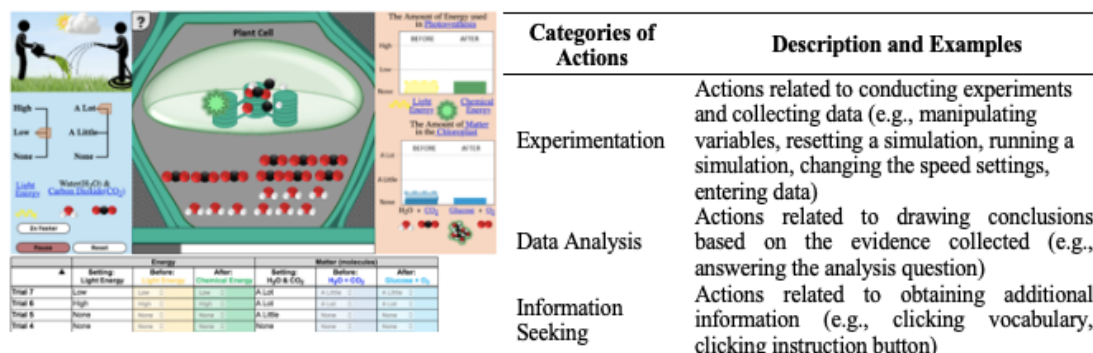


Figure 1. Simulation interface and student actions.

Analysis methods

Student responses to the prediction and reflection questions were scored using a seven-scale rubric that rewarded elaborated connections between multiple key concepts. Student actions from the log data were analyzed using the following three steps. First, we used exploratory factor analysis to consolidate the large number of actions into a smaller set of latent factors. As a result, 48 actions were grouped into three categories (see Table 1). Second, we used FMM with the Expectation-Maximization (EM) algorithm to approximate complex probability densities which present multimodality, skewness, and heavy tails of log data. Third, we explored how student sequential interaction patterns vary across the identified levels using SPM.

Results

Using FMM with the EM algorithm, the results show four levels of learning patterns based on the frequency of actions and learning gains (see Table 1). The Low Activity group is characterized by the lowest amounts of actions in all three categories (experimentation, analysis, and information seeking), as well as the lowest learning gains from the prediction to the reflection questions. The results suggest that this group may have been distracted or may have misunderstood how to use the simulation.

Table 1: Description of learning pattern levels

Level	Group	Pair Proportion	Actions			Learning Gains
			Experimentation	Data Analysis	Information Seeking	
1	Low Activity	67% (N=35)	Low	Moderate	Low	Low
2	Random Interaction	15% (N=8)	High	Moderate	High	Low
3	High Analysis	13% (N=7)	Moderate	High	Low	Moderate
4	Tasked Exploration	3% (N=2)	Low	Moderate	High	High

In contrast, the Random Interaction group is characterized by its high number of experimental runs and low learning gains (see Figure 2). Our preliminary findings from video and classroom observations reveal that this group appeared to make random actions with the simulation, such as running the simulation multiple times without changing the required variables, rather than carefully designing their experiments toward the learning goals of the activity. Consistent with the findings from previous research (e.g., McElhaney & Linn, 2011), such actions led to low improvement in their understanding of the target concepts.

The High Analysis group is characterized by its high frequency of analysis actions, moderate experimentation runs, and moderate learning gains. The results indicate that as students repeatedly analyze data

collected, they might have more opportunities to reflect on the key scientific ideas and revise their initial understanding of the concepts. Such processes could have helped them develop a better understanding of the abstract concepts of energy and matter in photosynthesis.

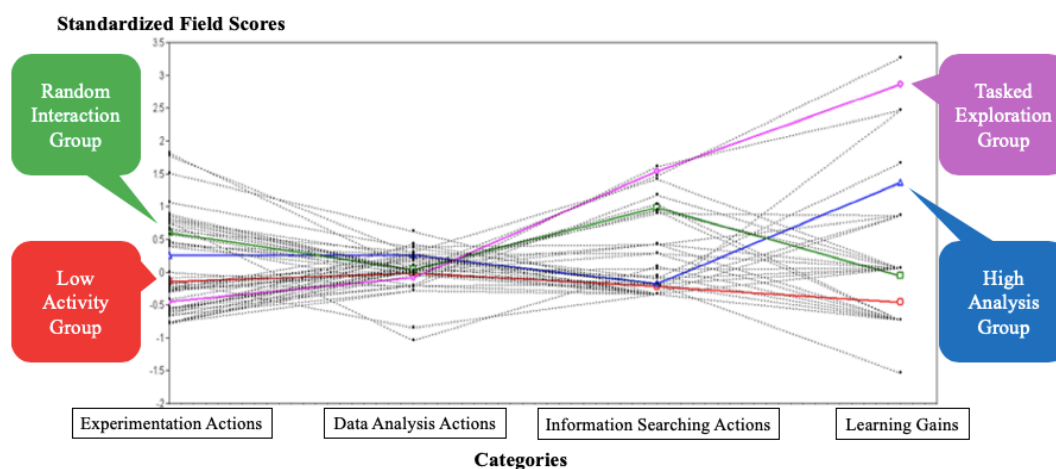


Figure 2. Groups of action frequencies for three categories related to learning gains.

The Tasked Exploration group is characterized by its low experiment runs, high frequency of information seeking, and high learning gains. Although they show less frequent experimentation actions than the High Analysis group, they appear to engage in purposeful investigations by manipulating the key variables required to answer a targeted hypothesis. It is possible that as they obtain additional information about scientific terms (e.g., light energy) and how to navigate the simulation, they developed more effective strategies to successfully complete their investigations.

Furthermore, the SPM analysis reveals unique sequential action patterns within each group (see Table 2). While the Low Activity and the High Analysis group demonstrate patterns of consistent experiment runs, the Random Interaction group only shows patterns of basic necessary functions to complete the task, such as reading the instructions and submitting the analysis response (e.g., IH, Sa, and S). Compared to other groups, the Low Activity and High Analysis groups appear to be more inclined towards utilizing the default variable settings for their experiment runs. However, the SPM analysis shows that the High Analysis group continues running experiments, while the Low Activity group immediately attempts to reach analysis.

Table 2: Sequential pattern mining in groups

Action (Detailed)		Group	Sequence	Support*
IH	Beginning: Instruction and Hypothesis	Low activity group	IH → 1S	0.916
R(XX)	Experiment (Energy Setting, Matter Setting) (e.g., R(LL) – (Low Sunlight, Low # Reactants)		IH → 1S → S	
R(a)	After experiment, ready to analyze		IH → R(LL)a → 1S	0.833
R(f)	Run experiment fast	Random interaction group	IH → 1S → S	
R(m)	Pause and continue animation during experiment run		IH → Sa → S	
Re	Reset experiment		IH → 1S → Sa → S	
1S	First submission before analysis	High analysis group	IH → S	1
Sa	Saving analysis		IH → 1S → S	
S	Submitting analysis		R(LL) → S	0.875
			IH → 1S → Sa → S	
			IH → Sa → S	
		IH → B → S		

*Note: The support's lower confidence bound is 0.8.

Conclusions and implications

This study shows the value of FMM and SPM to identify both productive and unproductive interaction patterns when eighth-grade students conduct experiments using a simulation. Although these unsupervised ML

techniques are widely used in the fields of statistics and computer science, they have not been used to explore middle school students' learning patterns within simulation environments. The findings of this study show that FMM can categorize students into different learning groups based on the frequency of actions in the simulation, as well as the improvement in their understanding of scientific phenomena. When supported by SPM, unique subsequential patterns of each group can even be detected. Such findings can inform how to design tailored scaffolding for engaging students in effective interactions using simulations.

Given the exploratory nature of this study, there are several limitations to be addressed in future research. First, given that our study analyzed log data from only 52 pairs and FMM is sensitive to parameters of selected models (Melnykov & Maitra, 2010), future research should involve a larger number of students to obtain stable clustering results. Second, the simulation used in our study provided carefully designed scaffolding to help pairs engage in science practices while exploring the concepts of energy and matter in photosynthesis. Students may have different interaction patterns when using more open-ended simulations with limited scaffolding or when exploring different scientific phenomena (e.g., physics). Future research should investigate different types of simulations with varying levels of scaffolding, variables, interactivity, and scientific concepts.

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Application of AutoML in the Automated Coding of Educational Discourse Data

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Abstract: This paper examines the potential for using AutoML techniques to develop automated classification models for coding educational discourse data. In particular, it provides a direct comparison between automated classifiers developed through rule-based and AutoML approaches. Through a presentation of an applied example, the paper offers insights on the challenges and strategies associated with utilizing AutoML in the automation of discourse coding. Results indicate sufficient levels of reliability and validity for classification models developed through both approaches. These findings suggest that AutoML approaches can perform at a level similar to rule-based approaches in the automated coding of discourse data.

Introduction

Discourse data that capture the communication and interaction of students can provide crucial insights about collaborative learning processes. However, coding remains a key challenge for analyzing large sets of textual data due to the time-intensive nature of the manual coding process. As such, using automated coding techniques can enable researchers to carry out qualitative analyses at scale. Numerous efforts have been made to facilitate the automatic coding of discourse data, including through the application of natural language processing techniques (Mu, van Aalst, Chan, & Fu, 2014).

Researchers have also utilized machine learning (ML) approaches to the automated classification of discourse data from collaborative learning contexts. Using preclassified data, Rosé et al. (2008) applied three ML algorithms—naive Bayes, support vector machines, and decision tree—to create customized text classification models. Despite promising results, there has yet to be a wider adoption of ML methodologies for automated coding. One of the reasons for this is that ML techniques require a high-level of expertise, particularly in the development of customized models (Lee, Macke, et al., 2019). In addition, the rapid advances in the field of artificial intelligence and machine learning, including the increasing application of neural networks, have further raised the already high barrier to entry, as the creation of effective ML models is contingent on the iterative process of selecting the most appropriate algorithm, architecture and parameters (Mendoza et al., 2019).

More recently, automated machine learning (AutoML) has gained attention for its potential to facilitate the utilization of ML techniques by a broader set of users. AutoML systems designed for specific tasks, such as the prediction of an outcome variable, can automatically go through the multitude of available options related to algorithms and hyperparameters to develop the optimal model for a given dataset (Mendoza et al., 2019). While some contend that AutoML-produced models can perform at a level that is comparable or even better than models generated by human experts, others argue that the lack of user control and interpretability can pose problems for contexts that are exploratory or require the user’s domain expertise (Lee, Macke, et al., 2019).

In this context, this paper examines the potential for using AutoML techniques to develop automated classification models for coding educational discourse data. In particular, it provides a direct comparison between automated classifiers developed through rule-based and AutoML approaches. Through a presentation of an applied example, the paper offers insights on the challenges and strategies associated with utilizing AutoML to the automation of discourse coding.

Methods

Data

The discourse data used in this paper comes from synchronous video conference sessions—referred to as meet-ups—involving adolescent participants from fifteen digital makerspace clubs located in Africa, Europe, and North America. During the meet-ups, the participants work collaboratively to create media artifacts on STEM-related topics. The construct selected for automation was Social Disposition, which was coded when an utterance demonstrates pro-social tendencies of the speaker, especially in expressing appreciation, acknowledgement or validation. Examples of utterances coded for Social Disposition include: *“I just really look forward to working with you and everybody else and to meet all of you too”* and *“That was a wonderful video. I really like the way you have done it.”* The unit of analysis was defined to be one utterance, or turn of talk. The analysis utilized

preclassified datasets, consisting of a total of 944 lines from the five meet-ups. The data was coded separately by two human raters for Social Disposition. Final agreement on the coding of each line was reached through a process of social moderation (Herrenkohl & Cornelius, 2013). The training set included data from four meet-ups (776 lines) and the hold-out validation set contained data from one meet-up (168 lines). Finally, a test set of 40 lines was derived from a previously uncoded meet-up consisting of 167 lines.

Interrater reliability measures

Interrater reliability (IRR) was measured using two measures: Cohen's kappa and Shaffer's rho (Shaffer, 2017). The kappa value was used to calculate the level of agreement between two raters, including the coding done by the automated classifiers. In addition, the Shaffer's rho statistic, which estimates the probability of Type I error for a given IRR measure, was used to statistically test for its generalizability (Eagan et al., 2017). Kappa and rho statistics were used at all stages of the automation process, with thresholds of $\kappa > 0.65$ and $\rho < 0.05$, to assess the effectiveness and generalizability of each model classifying the data.

Automated coding approaches

Two common approaches used in the automatic coding of discourse data are: 1) use of text patterns to search for specific characteristics in the discourse; and 2) application of ML techniques to generate predictive models for classification (Law, Yuen, Wong, & Leng, 2011). Building on previous work on the use of training, validation and test sets in the development of automated classifiers for discourse data (Lee, Gui, Manquen, & Hamilton, 2019), this paper aimed to compare the effectiveness and efficiency in the automated coding of the Social Disposition construct using these two approaches. Regular expressions (regex) were used to identify matching text patterns in the first rule-based approach, while the custom ML models in the second approach were created using Google Cloud Platform's AutoML Natural Language Text Classification tool.

Rule-based approach

The rule-based approach aimed to develop regex lists that can automatically identify the presence of the construct in the data. Based on the training set, researchers manually developed a preliminary regex list by searching for patterns in words, phrases and sentence structures. Each regex list was then used to automatically code the training set. Kappa and rho values were calculated to assess the interrater reliability between the computer-coded dataset and the codes in the training set. This process was undertaken in several iterations to further fine-tune the regex list until the researchers determined qualitatively that further adjustments would negatively affect the generalizability of the automated classifier.

During the validation stage, select regex lists meeting IRR thresholds ($\kappa > 0.65$, $\rho < 0.05$) were used to automatically code the hold-out set. Based on the IRR measures, the regex list that resulted in the highest kappa and lowest rho values was then chosen for the next stage. If none of the regex lists met the IRR thresholds, the process was returned to the training stage. In the testing stage, the final regex list was used to code 40 lines of previously uncoded data. The baserate of the test set was inflated to 0.2, meaning that at least 20% (or 8 lines) had been identified by the final regex list as having Social Disposition present utterance. After the test set was individually coded by two human raters, the kappa and rho statistics were computed for each pair of raters, i.e. Computer vs. Human 1, Computer vs. Human 2, Human 1 vs. Human 2. The automated classifier was considered to be valid and reliable for the construct if and only if the IRR thresholds were met for all three pairs of raters.

AutoML approach

The development of AutoML models for the automated classification of discourse data followed steps similar to the one described above in the rule-based approach. However, the training stage was simplified from the researcher's perspective, with the Google AutoML interface generating a custom model within approximately 3-4 hours after uploading the training data. In uploading the training data, the researcher is able to assign each line to three subsets (training subset, validation subset, test subset). If none are assigned by the researcher, then the system automatically parses the data, with each subset containing 80%, 10%, and 10% of the training data, respectively. Positively coded lines are distributed proportionally into each subset. The validation subset is used within AutoML to optimize the model by iteratively testing and selecting the most suitable options from the numerous algorithms and hyperparameter settings available. Once the model is developed, the test subset is used to evaluate the model. Google AutoML presents several performance metrics, including precision and recall values as well as a contingency matrix providing the breakdown of the true and false predictions made by the model against the test subset. While the evaluation metrics provided by the Google AutoML system is informative, they are based on a relatively small sample of the training data. As such, these measures were not used in this analysis for purposes of assessing the AutoML model's performance.

Once the AutoML model has been developed, it provides the predictive probability (value between 0 and 1) of the construct being present within a given utterance. Based on this value, the researcher needs to determine the classification threshold that will be used to assign a positive code. The precision and recall measures are sensitive to the classification threshold. Using higher classification thresholds results in greater precision but lower recall, and vice versa. The classification threshold of 0.5 was adopted for all AutoML models generated for this analysis, as the Google system balanced the precision and recall values at this threshold.

The AutoML model was used to automatically code the hold-out validation set. If the IRR thresholds were met, the model was moved onto the testing stage. However, if the kappa and rho levels were not reached, it was returned to the training stage. One of the disadvantages of the AutoML model is that it cannot be modified once it has been developed. This is because AutoML builds and deploys the best model based on the given training data. For this reason, any improvement of the model requires a new model to be built based on a more robust set of training data.

In order to minimize the amount of new data to be manually coded while maximizing the potential of the newly added lines to improve future models, a strategy was devised to utilize the failed model in the selection of the utterances for human coding. Because the model provides predictive probabilities for any given utterance, it is possible to assess the level of certainty that the model assigns to a particular prediction. As such, it is likely that the model will not be improved significantly from providing further examples of utterances in the training data for which it has a high level of certainty. Rather, it was posited that the model will benefit from gaining information on utterances it determines to be ambiguous. Based on this rationale, the strategy adopted for this paper was to hand code only those new lines that were determined to be “ambiguous” by the failed model. The model was used to predict previously uncoded data. Only utterances receiving a probability in the range of $0.05 < p < 0.95$ were identified for manual coding. The aim was to increase the training data size by 10% with such “ambiguous” lines at each iteration. These new lines were coded by two human raters, who then came together to agree on the final coding. The coded data was added to the training data to create a new ML model to be checked against the validation set. This iterative process was to be carried out until a model was found to have met the thresholds for agreement ($\text{kappa} > 0.65$) and generalizability ($\text{rho} < 0.05$). The testing stage for the AutoML model mirrored the process used in the rule-based approach.

Results

Table 1 presents the IRR measures associated with the training and validation stages of the two automation approaches. A total of four regex lists were developed during the training stage of the rule-based approach. By the third iteration, the kappa and rho values had already reached sufficient levels. However, an additional iteration was completed to qualitatively refine the regex list. The validation stage resulted in good IRR measures for both regex lists; however, the fourth iteration resulted in a higher kappa and lower rho values—meaning that the improvements made during the final iteration in the training stage were not wasteful. Based on this result, the regex list from Iteration #4 was used to selected as the final regex list for the testing stage.

For the AutoML approach, only two models were required to reach sufficient kappa and rho measures against the validation set. Following the failure of the first AutoML model to obtain good IRR measures, an additional 76 previously uncoded utterances (determined by the first model to be “ambiguous”) was manually coded and combined with the original training data. The second model produced after the inclusion of new training data performed much better against the validation set, resulting in kappa and rho values of 0.77 and 0.01, respectively.

Table 1: IRR measures of the training and validation stages for the two automation approaches

Iterations	Rule-based Approach (Regex List)				AutoML Approach	
	Training Stage		Validation Stage		Validation Stage	
	Kappa	Rho	Kappa	Rho	Kappa	Rho
# 1	0.55	0.45	--	--	0.60	0.26
# 2	0.61	0.15	--	--	0.77	0.01
# 3	0.80	0.00	0.72	0.03	--	--
# 4	0.82	0.00	0.73	0.02	--	--

Table 2 provides the results of the testing stage for the two automation approaches. The fourth iteration of the regex list and the second AutoML model were used to code the test set, which was also manually coded by two

human raters. Based on the high levels of agreement between all three pairs of raters for both approaches, it was concluded that the automated classifiers developed through both the rule-based and AutoML approaches were valid and reliable in coding the discourse data for Social Disposition.

Table 2: Results of the testing stage for the two automation approaches

Raters	Rule-based Approach (Regex List)		AutoML Approach	
	Kappa	Rho	Kappa	Rho
Computer & Human 1	0.81	0.04	0.81	0.03
Computer & Human 2	0.88	0.01	0.87	0.01
Human 1 & Human 2	0.94	0.00	0.94	0.00

Discussion

This paper aimed to present a proof of concept for utilizing AutoML techniques in the automation of coding text data. The results of this applied example suggest that AutoML approaches can perform at a level similar to rule-based approaches. However, a key element to consider in adopting AutoML for the automation of discourse coding is the issue of time and resource. While both approaches require human involvement (to manually develop regex lists or to hand code the training set), the AutoML process provided a significant savings in time when compared to the rule-based approach, which required extensive effort in creating and refining effective regex lists. The strategy of utilizing the unsuccessful AutoML model in the selection of “ambiguous” utterances for manual coding seems to have also contributed to the efficiency of the automation process. Nevertheless, given the limited and exploratory nature of this analysis, additional studies will be needed to further investigate the potential for applying AutoML approaches to automated coding of educational discourse data.

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Harnessing the Power of Research + Practice: Aggregating Knowledge About Implementation to Better Support Equity Outcomes in Systems

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Abstract: In this conceptual paper, we ask: How can we harness the power of research-practice collaborations and, in particular, how can we aggregate knowledge about educational systems in order to support implementation of new practices? With the goal of increasing teacher and student access to high-quality educational experiences and resources, we argue that there continues to be a need to systematically examine and learn across research-practice research and design efforts. To do so as a field necessitates the development of methodologies and infrastructure aimed at aggregating knowledge across partnerships. We aim to initiate conversation among learning scientists about the potential to systematically aggregate insights about how characteristics and dynamics of systems of practice interact with implementation efforts. In the long term, we hope this effort increases the prevalence and power of research-practice collaborations to better support equity outcomes across educational systems.

Grand challenge

In this short-form conceptual paper, we ask: How can we harness the power of research-practice (R+P) collaborations? Specifically, How can we aggregate knowledge about educational systems in order to support implementation of new practices? With the goal of increasing teacher and student access to high-quality educational experiences and resources, we have spent our careers in collaborative design efforts, research practice partnerships (RPPs), and participatory research; we argue that there is a need to systematically examine and learn across these efforts. Development of methodologies and infrastructure will be required to undertake and disseminate work aimed at aggregating knowledge across partnerships. Our immediate goal is to begin a conversation about this potential, including ways to gather and share methods and practices, and to systematically aggregate insights from RPPs. We point to the value of aggregating knowledge about how characteristics and dynamics of particular educational systems interact with implementation of efforts to impact outcomes of interest. In the long-term, we hope this effort increases the prevalence of R+P collaborations and harnesses their power to better support equity outcomes across educational systems.

Since the 1990s, collaborative efforts between researchers and practitioners have developed and tested designs for teaching and learning (Penuel, Fishman, Cheng, & Sabelli, 2011). Using various related research methodologies, efforts focus not only on the design for learning but also on the contextual variables that affect their implementation and outcomes. Now recognized as R+P initiatives, these efforts that take up the goals of implementation science have become more widespread in learning sciences. Examples of these genres of research include Design-Based Research with Co-design, Design-Based Implementation Research, RPPs, and Networked Improvement Communities (NICs) among others. Across these genres (and more) there is a translational, action-oriented, participatory lens. They share a methodological approach of unearthing characteristics and dynamics that define local contexts as they interact with implementation – all with the aim of ensuring that the innovation and outcomes of research will be useful and meaningful to those for whom it is designed.

Because RPPs are designed to attend to the local context and purposefully structure design to address the needs and conditions of the practitioner partners (Bryk, Gomez, & Grunow, 2011), outcomes from RPPs designs have great potential to improve learning and practice (Coburn & Penuel, 2016). Researchers have created and sustained mutually beneficial partnerships with practitioners, resulting in successful learning outcomes in local school districts and communities. *However, findings from these efforts are specific to and sometimes even unique to their settings. They are, on the whole, not developed to generalize across settings.* The MIST project, for example, is an ongoing partnership between university researchers and several large urban school districts in the United States focused on improving ambitious and equitable instructional practices in mathematics. MIST researchers have begun to identify key elements of a coherent system for instructional improvement; however, they call for additional studies that focus on large-scale instructional improvement in order to fully realize improvements in mathematics instruction *at scale* (Cobb, Jackson, Smith, & Henrick, 2017).

We echo and extend this call. Specifically, we reiterate the need for systematic inquiry of interventions across settings that attends to interactions of local context and patterns of implementation. We further argue that

a) the financial and human resources to conduct such studies are not commonly available, b) the methods to systematically gather and synthesize evidence across such a large-scale study of implementation have not been formally developed, and c) our field does not currently provide opportunities to disseminate large-scale, responsive research studies, including educative cases of partnership or implementation failures.

An opportunity: Aggregating knowledge to support scaling and equity

Despite the challenges we list above, we point to two imperatives that provide warrants for the work we suggest needs to be done. First is the continued failure in our field to produce interventions that scale (Lynch, Pyke, & Grafton, 2012). Second is the continued presence of equity disparities in learning settings, even as the field continues to expand participatory research efforts to address educational justice (Bang & Vossoughi, 2016).

Our proposal addresses two issues related to the challenge of scaling educational interventions. Penuel et al. (2011) argued that RPPs that consider local enablers and barriers to implementation as part of design of innovations could develop insights about what works, for whom, under what conditions. Among other funders, The National Science Foundation (NSF) named RPPs using DBIR and other approaches among those methods it sought to support, in light of the possibility that designing for adaptation to new contexts would increase the likelihood that the designs would continue to be useful and effective across contexts. Implicit in the call by Penuel and colleagues is the notion that individual research-practice teams, engaged in intensive design work, would need to contribute to and draw from the larger field (and adjacent fields like organization science) to build design and implementation knowledge that could account for context. Indeed, using research-practice approaches, the field has developed studies to understand the contexts of the specific RPPs in which the work was conducted. Yet, we still do not have broadly accessible theory, design principles, or best practices to support the field's understanding of interactions between local context and implementation, those that would arise from the study on implementation across multiple settings. Therefore, we repeat and extend the 2011 call; to more effectively provide evidence of what works for whom, under what conditions, we need methods to document 'conditions' and to aggregate knowledge about implementation.

The second issue of scale is the challenge to build capacity among RPP teams, a necessary and productive layer of RPP design and implementation work. Ideally, both researchers and practitioners experience professional development as part of participation on RPP teams; collaboration among experts from different fields and with varied backgrounds can produce innovative research and design (Carlile, 2004). Building capacity for design and implementation of novel interventions is also a key factor in scaling ideas and capabilities, both among individuals and among systems that must 'learn' to accommodate new practices. While there is increased sharing of capacity building practices happening over time (e.g., via publications, conferences, etc.), systematic analysis of these practices as a function of local context and the specific design/implementation work of these teams is still elusive.

We also point to the call to conduct R+P work as a means to ensure that educational experiences and resources are designed and implemented to be equitable for all students, their teachers, and other school system stakeholders. By incorporating the diversity of those whom partnerships serve and by addressing issues of equity as they play out in design and implementation, RPPs conduct the valuable work of surfacing the multiple dimensions through which equity may be addressed. With specific continuous improvement aims to address systemic inequities, RPP teams are well positioned to design innovations that productively alter systems (Bryk, 2017). Unfortunately, this short-form conceptual paper does not allow for a more comprehensive discussion of this issue; we look forward to engaging with others interested or involved with this work in other venues.

Theoretical perspectives

This paper draws from perspectives of participatory research (Reason & Bradbury, 2008) and work that has emerged from that tradition. One advantage of participatory research is that researchers and practitioners work collaboratively to understand local context and design innovations to address context-specific dynamics that influence equitable learning opportunities for youth. This research examines interactions among social, cultural, historical, and institutional aspects of contexts with the aim of improving practice. Taking a sociocultural approach, we look at contexts through the lens that participation is grounded in the individual experiences of people, current and historical, and based on institutionalized practices (Holland & Lave, 2009). We foreground this frame to describe critical aspects of partnerships; designing, implementing, sustaining, and scaling interventions involves coordination of people, policies, and materials, among other layers of practice (e.g., developing and harnessing human capacity from across a system). The sociocultural nature of RPP work implies that 'context' is a dynamic construct. This notion is reflected in research on the scaling of educational innovations which also cites the ever-changing contexts and needs of people, acknowledging the dynamic nature of scale will impact scaling strategies (Morel, Coburn, Catterson, & Higgs, 2019).

Knowledge aggregation exemplar: Enabling Conditions Collaboratory

The complexities of the sociocultural, dynamic nature of implementation contexts and the partnership work that occurs within them illustrate the need to share and aggregate experience and insights. Some synthesis efforts are happening behind the scenes in spaces like RPP consortia and funder-led grantee meetings focused on local problems of practice, but their intellectual work has yet to be broadly shared. We now turn to a discussion of an effort aimed at knowledge aggregation, and discuss the tools, structures, and cultural shifts used to access and aggregate knowledge within that community. That being said, without widely accessible, shared approaches to gather and synthesize this critical information, outside stakeholders and proximal communities will have (at best) limited access to processes and outcomes, let alone strategies to conduct future R+P work.

The Enabling Conditions Collaboratory (ECC) is a multi-project, cross-institution research investment by Lucas Education Research (LER), a division of the George Lucas Educational Foundation. LER's current research portfolio focuses on efforts to define rigorous project-based learning (PBL) in K-12. The ECC is working towards understanding the conditions that support high-quality PBL. Using Coburn's (2003) framework for reconceptualizing "scale", the ECC is examining depth, sustainability, spread, and shift in ownership within their PBL implementation efforts and collectively identifying ways to aggregate learning across projects to further investigate and better attend to these aspects of scale.

Participation in the ECC involves an added layer of project activity, separate but in support of each team's overall research goals. At least one junior research team member and one PI from each of the four projects participate in monthly virtual meetings. These meetings, facilitated by LER research advisors, are intentionally designed to support cross-team discussion and learning. Teams are encouraged to share protocols, nominate topics of common interest, and share findings, challenges, and feedback with one another. The monthly meetings also include opportunities for guest speakers to contribute additional perspectives on the work and build team capacity.

Approaches to support knowledge aggregation

Because the ECC shares a common goal of examining enabling conditions of high-quality PBL, the variation among the project implementation contexts is the object of inquiry, rather than a confound. In other collaboratives not focused on developing knowledge about interactions among local context and implementation, the variation of inquiry context must be examined *in addition* to the variation of intervention/change of interest and therefore requires additional work to unpack those interactions. Specifically, strategic comparisons may need to be coordinated in order to observe relevant dimensions of design and/or implementation. While the common problem of inquiry of the ECC grounds collaboration among the teams, this layer of work contributes to each project; each partnership defines their questions about enabling conditions by leveraging prior or ongoing data collection and extending current analytic strategies. In other words, within the common problem space, teams are still able to examine aspects of practice that are most relevant to their initial research questions. The common, but not limited or identical focus of the ECC teams' research is a key factor in the productivity of the collaboration. In future efforts, systematic examination of the functioning of collaboratives would illustrate tradeoffs of different forms and degrees of structure among teams, including shared research questions and approaches.

An important conceptual tool that can be used to leverage the common research space is a *systems perspective*. In the ECC, this perspective allows the teams to map the aspects of PBL practices that are involved in multiple teams' efforts and which are only studied in a small number of contexts. A shared systems map serves as a concrete representation of the components, interactions, and dynamics of systems of practice (stakeholders, resources, policies, etc.) and helps to ground cross-team conversations. The map has helped to surface opportunities for investigation to address specific questions about variations across systems/contexts.

In particular, the value of focusing on *social dynamics* of systems of practice are well documented (Reeves & Forde, 2004). Ensuring that a collaborative maintains a focus on sociocultural dimensions of practice when synthesizing evidence and insights across projects is paramount, but also introduces layers of complexity. Tracing the interactions between and among the sociocultural threads and technical components of systems of practice (i.e., changing practices of interest and related materials) that enable system or stakeholder change (e.g., increasing capacity) is a critical approach to knowledge building across research endeavors.

Building from a common understanding of the key components and dynamics of a socio-technical systems of practice, teams using design-based research methods can engage in *principled, iterative design* to extend their insights about systems of practice to scaffold ongoing efforts. This could include design of materials but also of institutional or social supports for various stakeholders and their interactions. Collaboratives that engage in design from the outset would be well-positioned to use both a (socio-technical) systems perspective and a principled design approach to structure their individual and shared work.

Finally, the importance of sociocultural aspects of the collaborative itself cannot be understated. A significant thread of the work of a collaborative is the establishment and maintenance of collaborative and

professional norms that equally benefit all participants. In the NIC partnership model, a hub or separate team takes on a facilitation role and in the LERs ECC, research advisors fulfill this role. Facilitators are critical for attending to relationship building, focusing on collaborative norms which sometimes conflict with professional incentives (e.g., authorship and recognized expertise).

Starting a conversation

Our purpose is to begin a conversation among the ISLS community about the potential of efforts to aggregate insights about how characteristics and dynamics of particular systems of practice interact with implementation efforts to impact outcomes of interest, including equitable learning opportunities. It is important to recognize that researchers are often incentivized to limit access to outcomes of their work prior to publication. There is a need to continue to shift the culture of research to more collaborative modes, including sharing research that is in progress or that has negative outcomes (e.g., implementation challenges). A challenge to this shift is institutional barriers including forms of professional advancement. Some funders clearly value the role of collaboratives including NSF whose use of program hubs are intended to produce cross-project collaboration. As research funding is a key element among professional advancement criteria, some shifts in professional norms may be on the horizon. It is also important to be realistic about the time and resources required to undertake the proposed work. It will also be crucial to understand practitioners' incentives to engage in this form of work, as a function of their professional processes, structures, and interests, in light of the time and resources it will require.

Despite these challenges, we are optimistic that the field is poised to take up tools and structures for knowledge aggregation and to address the challenge of harnessing the growing RPP efforts to learn about the role of context and enabling conditions in implementation research across settings in support of scaling. The increasing number of highly skilled and experienced R+P participants is a significant indication of the shifts underway. The number of funders supporting R+P work (and collaboratives) is an indicator that some policy stakeholders value this line of work. We are optimistic that should R+P teams engage in knowledge aggregation practices, we will be more likely to harness their potential and develop more equitable, scalable educational experiences for all.

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Posters

Collaborative and Emergent Regulation of Open-Ended Inquiry Through Semiotically Mediated Structures

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Abstract: Regulation of open-ended collaborative inquiry is an emergent, collective process. The study explores emergent regulation of knowledge building in a class of fourth graders inquiring light. The analysis traces knowledge building discourse and semiotic artifacts that enable a heterochronic link between actions occurred on different timescales.

Introduction

Effective collaborative knowledge building depends on student collective responsibility to jointly guide and control the trajectory of their work as it unfolds and deepens over time (Scardamalia, 2002). A challenging aspect is to understand how shared regulation can be maintained in minimally scripted environments and over extended periods of time, two features that typically characterize learning in open-ended collective inquiry and knowledge building (Zhang et al., 2018). Drawing on the theory of collaborative emergence (Sawyer, 2012) and on the notion of heterochrony (Lemke, 2000), regulation of collaborative inquiry can be explained as a collective bottom-up phenomenon whereby momentary actions of the participants grow, across interactional episodes, into intermediate collective structures, which have the potential to guide and delimit the inquiry trajectory. The moment-to-moment interaction is contingent not only on preceding circumstances but also on meanings of actions occurred in the past and that are recalled through the mediation of semiotic objects such as artifacts, individuals, etc. The purpose of this study is to examine critical moments of social emergence of a shared epistemic focus and determine how they add up to intermediate shared structures that frame and orient the ongoing inquiry work.

Method

The present study analyzes a group of 4th grade students participating in knowledge building on optical phenomena supported by Knowledge Forum (Scardamalia, 2002). It concentrates on the first two episodes of their three-month activity. Using an ethnographic perspective on discourse analysis, we analyzed a set of data including classroom interactions, teacher's reflection journal and online artifacts.

Findings

The data analysis focused on understanding the critical moments of social emergence of a shared focus on light, which guided the unfolding of the inquiry. A classroom discussion marked the beginning of the collective study, during which the initial topic "light" progressively evolved to investigate issues related to phenomena of reflection, absorption of light and colors on different types of surfaces. In this initial episode, the teacher showed notes the students wrote in a former view of Knowledge Forum (KF) when they were in Grade 1. One of these notes, in particular, contained a theory about how animals' fur color adapts to light. What follows is the teacher's journal note on this episode:

"...We looked at the "Adaptive Weirdos" view in the old Grade 1 database created by the current Grade four students. (...). The last note we opened (...) contained a theory about grey fur "reflecting" light away from his creatures' eyes so that it can see better. This note generated an interesting discussion on how light responds to color. (...). It also happened to be snowing outside after a few weeks of very mild spring weather. The discussion progressed to snow and the color white. We asked the question if there was a reason why snow was white. The students had many theories to share (...)"

In this initial episode, two critical moments of social emergence influenced the direction of the collective focus. The first one is when looking together at an old note in KF triggered a discussion about response of light to colors. Students started to develop and share initial theories about reflection and absorption of light on black surfaces. The second one is contingent on the snowing event outside, which unexpectedly stimulated an interest in observing how snow responds to light and redirected the attention to the connections between light, snow and color white. This emergent, collective focus became an intermediate structure that framed the subsequent inquiry activity. This structure is embedded in the new view called "Grey Fur and White Snow" that the teacher created

in KF. The view included portions of the original Grade 1 note that prompted students' discussion on light and colors.

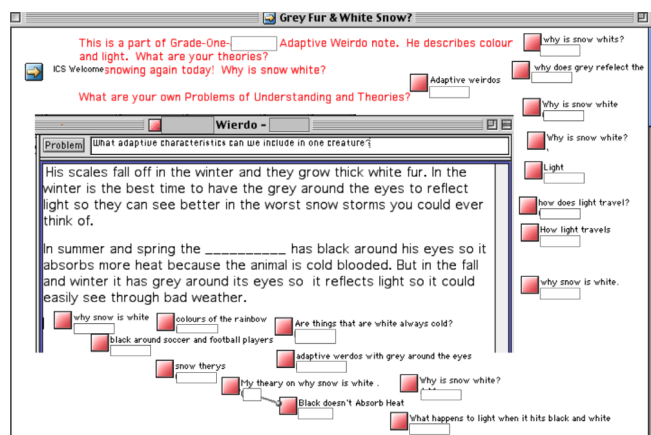


Figure 1. Knowledge Forum view called “Grey Fur and White Snow”.

The day after, the teacher was informed by Grade 1 teacher that during his absence students worked with great excitement in the new KF view. They seemed to “reconnect” with their former teacher as they shared with her their new problems of understanding and recalled experiments they performed with her in Grade 1. The following quote from a student was recorded in the teacher’s journal:

“I think snow is white because if the snow was black then it would melt faster. Since the snow is white, it is colder. At the courtyard center in Grade 1, we did an experiment where we put snow on black paper and on white paper, the black paper's snow melted faster”.

On this second day, students’ epistemic focus deepened towards a better understanding of light and color by comparing white and black and by including the notion of heat. Progression in the topic was associated with two socially emergent moments: Students became involved with the newly created view in KF and shared their new problems of understanding with their former teacher, recalling experiments done in Grade 1. The way the topic develops at the shorter timescale of these two episodes is an example of collaborative emergence (Sawyer, 2012). It is not scripted by the teacher nor can be predicted in advance. It is characterized by moment-to-moment contingency on concomitant events. Yet, if we take a longer timescale perspective, we start to see that the emergent unfolding of a shared epistemic focus is influenced by objects and events belonging to the past and creating a heterochronic link between the ongoing activity and a longer timescale process. Students and teachers interacted not only with each other in the here-and-now situation but also with semiotic elements – old KF notes, Grade 1 teacher, snowing outside – which triggered memories of actions occurred long time before and whose meanings became relevant to the emergence of a shared inquiry focus. These symbolic objects constrained subsequent actions and sustained a deepening focus.

This study suggests that shared regulation is a process emerging from the spontaneous flow of group interaction but with symbol-mediated linkages running on a longer timescale. Future work needs to examine emergent patterns of organizing the inquiry work through longer strands of classroom episodes.

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Visualising the Field: Reviewing Trends in Educational Design Research in Mathematics

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Abstract: This paper will use methods drawn from the digital humanities and social sciences to undertake a meta-study of recent EDR research in the domain of mathematics education. The findings suggest that much of the work presented as EDR might be better characterised as implementation studies as they contain only limited commitment to theoretical development capable of supporting the scaling of innovation.

Keywords: Educational Design Research, meta-study, theory development, mathematics education, Design based research

Introduction

Emerging in the 1990s the approach to taking educational research out of the lab and into the “real world” that has been known variously as design based research, design experiments, and educational design research (EDR) is the “signature” approach of the Learning Sciences (LS, Yoon & Hmelo-Silver, 2017). EDR is increasingly being taken seriously beyond LS, and its potential to scaffold changes in teacher professional practice is being recognised in places such as the policy world of the OECD (Paniagua & Istance, 2018). As the EDR framework is adopted beyond the confines of the LS community it seems more important than ever to interrogate the gaps and blind spots that are still evident its implementation. This paper contributes to such an interrogation through a meta-study of recent EDR studies in mathematics education. It does so making use of tools emerging from the digital humanities and social sciences to visualise trends in the literature.

Method

This paper provides findings from a meta-study of EDR in the domain of mathematics education published in outlets indexed in the ERIC database. The full method and inclusion criteria are set out in the technical paper (see Fowler, Leonard, & Fiedler, 2020). The 174 papers used in the study were investigated using automated content analysis with reference to the categories of theory development offered by diSessa and Cobb (2004). diSessa and Cobb’s five categories included *Grand Theories* (abstract drivers of action), *Orientating frameworks* (unfalsifiable prescriptions of pedagogical practice), *Domain Specific Instructional Theories* (action based testable theories often based on formulating, testing and revising learning trajectories) and *Ontological innovation* (the development of theoretical constructs that help us view learning differently and recategorize out current understandings).

Results

The content analysis shown in figure 1 shows some instructive gaps when the goals of EDR are considered. Context for instance is present as a theme, but context of the mathematical problems to be solved rather than the context of the learning. Theory development is notable as it is entirely absent as a concept. On the whole, the studies are focussed on improving the effectiveness of interventions, how students use the interventions, and how teachers can learn from being involved in the research. Where theory development has been prioritised the interest is almost entirely on domain specific instructional theories and the work remains focused on evaluating the usability of a new design within its own context (see Fowler et al., 2020 for further detail). Notable in its absence is theory development on how the results of the studies can be scaled or applied to other contexts

Vocabulary Models of Informal Language Production in Reddit

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Abstract: In this work, we present an analysis of word choice data within several sub-communities of the social media website reddit.com. We examine how the notion of a community member’s “veterancy” within the community affects their language production.

Introduction

Social media makes it easier for learners to find and interact with experts in a wide variety of fields, and social networks enable us to acquire and analyze discourse data on a vast scale. Participation in informal online communities has been examined through a variety of lenses, but there remain open questions around how participation affects the language learners use in these spaces. Word choice is a convenient level of analysis, as vocabulary is easily encodable and parseable. In this poster, we apply machine learning (ML) and natural language processing (NLP) tools in a novel domain, exploring the impact of veterancy on word choice in three informal language communities within the social network Reddit (reddit.com). This work is significant because it demonstrates that relatively rudimentary ML and NLP methods can be used to characterize the developing expertise of users. We used the following research question to guide our work: in communities with multiple “types” of participation, does (and how does) veteran vocabulary differ from the other types’ vocabularies?

Prior work

Computational sociolinguistics includes a significant body of work which blurs the lines between online personas and offline identities. In their survey of the field, Nguyen et al describe this subset of work as analysis of online language production to “automatically infer social variables from text” (2016).

We extend this body of literature by considering language production through the lens of *veterancy* within the community. We define a veteran in an online community loosely as someone whom a member of the community might consider by virtue of experience to be an authority on the community. Quantity of participation is thus a symptom of veterancy. Veterancy itself is not a totally novel demographic in this field: Fields et al (2017) consider length and frequency of membership in their analysis of programming patterns in the Scratch online community. Veterancy is similar to expertise, examined in the Scratch online community by Huang and Pepler (2019), but whereas an expert is presumed to be objectively better at some relevant task, veterancy does not include this connotation.

Methods

We addressed our research question through vocabulary classification via a recurrent neural network, trained unsupervised on a randomly selected half of two or more given post corpi. It considers each post using a “bag of words” model that entirely removes any order information, and removes the repetition of words. We generate our bag of words using the Natural Language ToolKit (NLTK) default word tokenizer, which conducts a number of small optimizations such as separating common contractions into their component words (Bird et al, 2009).

In binary classification settings, we calculate the “receiver operating characteristic area under the curve” (ROC-AUC) for our input sets. This provides a measure of true positives (correct guesses by the classifier) in comparison to false positives (incorrect guesses). We calculate this score for both the test set and the training set. Higher ROC-AUC values above 0.5 indicate more success separating the languages of the input sets. A ROC-AUC value on the test set comparable to that on the training set indicates that we avoided overfitting to features present specifically in the randomly selected training set posts.

In classification settings with more than two input sets, we use a subset of the test set to plot a “confusion matrix” indicating the true source of each post and the provenance that our classifier guessed for that post. Heavy concentrations along the main diagonal (where the post really was from source A and the classifier guessed source A) indicate successful classification. Heavy concentrations along a vertical line indicate that the classifier mistook posts from many different sources as being part of the same language, and therefore from the same source. As in the binary classification case, we compare a test set confusion matrix against a training set confusion matrix, with significant differences between the two indicating overfitting.

With a default veterancy threshold of 10 posts (a parameter we adjusted throughout our experiments without noticeable effect), we divide a given subreddit’s posts into a veteran set, a novice set, and a tourist set.

We measured confusion between these three sets for each of our chosen subreddits. We then repeated the classification process with a binary classification focusing on the pair of groups which the confusion measure suggested were most different to get an ROC-AUC approximation of how different the vocabulary distributions were.

Results and discussion

In *r/ArtFundamentals*, tourists and novices were not distinguishable from each-other, but veterans were with a true positive rate >0.8 and low false positive rates. In Figure 1 below, we report the confusion of our classifier for each subreddit. Each row indicates the true source of a post, and the column indicates the guess that the classifier made. Thus, we can see in *r/productivity* that the majority of all posts were guessed to be novice posts, indicating a failure of the classifier to learn the difference between categories. A similar pattern is displayed in *r/vim*, where most posts were guessed to be tourist posts. Rerunning the categories in pairs produced ROC-AUCs of 0.59 for novices vs tourists, 0.53 for novices vs veterans, and 0.47 for tourists vs veterans in *r/productivity*; in *r/vim* we found ROC-AUC scores of 0.55 for novices vs tourists, 0.52 for novices vs veterans, and 0.55 for tourists vs veterans.

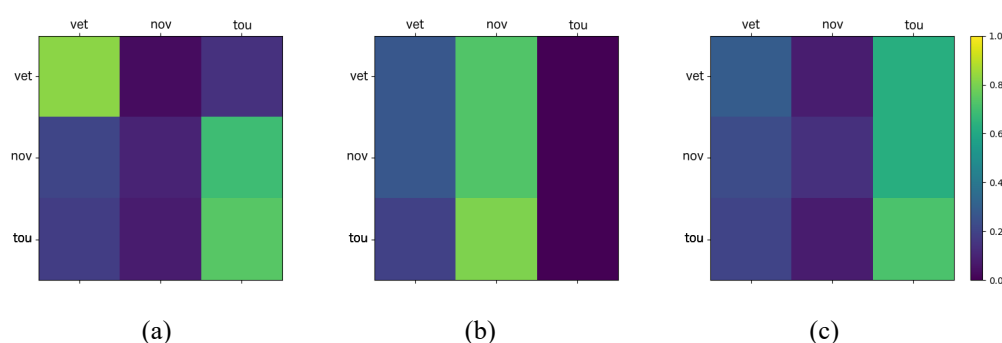


Figure 1. Confusion matrices for veteran posts, novice posts, and tourist posts in *r/ArtFundamentals* (a), *r/productivity* (b), and *r/vim* (c).

The significantly higher distinguishability measurements for veterans in *r/ArtFundamentals* suggest a meaningful distinction between veteran and non-veteran members of that community. This distinction, and the lack of detectable difference in *r/productivity* and *r/vim*, could be attributable to the teaching and learning focus of the *r/ArtFundamentals* community, with community members learning to produce vocabulary in a distinct distribution as they gained veterancy. Our results highlight how structurally similar communities (in our case three sub-communities within the same social media website) may exhibit distinct patterns of language change as members participate in these communities. Our work provides an example of how those patterns in language change can be measured quantitatively, paving the way for future research on the sources of variation across these communities.

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The Possibilities and Limitations of Infrastructuring with a No-Excuses Charter Network

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Abstract: This design-based study details the infrastructuring efforts of a no-excuses charter network and university partners to support the implementation of physics instruction aligned with the *Next Generation Science Standards*. A team of teachers, administrators, researchers, and curriculum developers worked in partnership to redesign the network's Instructional Guidance Infrastructures (IGIs) to better reflect instructional improvement goals. We found that some components of IGIs were more mutable than others.

Introduction

As a solution for improving the academic outcomes of students from historically marginalized communities, no-excuses charter networks have been particularly controversial. Proponents have praised no-excuses networks for their high academic standards, coherent instructional model, and orderly classrooms, while critiques have argued that these features contribute to the usage of didactic instructional practices that do not prepare students for participation in a complex, democratic society. Although some no-excuses networks are attempting to reform their instruction in response to critiques (e.g. Fine, 2017), there have been few attempts by researchers to aid, document, or analyze these improvement efforts. Our design-based study contributes to this work by describing preliminary findings from a multi-year infrastructuring effort of a no-excuses charter network, which we name as College for All, and a university-based team of researchers and curriculum developers. Infrastructuring entails the ongoing redesign of arrangements and artifacts that shape and are shaped by conventions of work practice (Pipek & Wulf, 2009). A key difference between infrastructuring and professional design is leveraging the expertise of users during design, as infrastructures are embedded in usage patterns that may or may not align with intended design. Infrastructuring efforts focused on redesigning the network's Instructional Guidance Infrastructures (IGIs) to support physics instruction aligned with the *Next Generation Science Standards* (NGSS). IGIs include learning standards, curriculum materials, assessments, pacing guides, sustained professional development (PD), instructional coaching routines, and other artifacts that codify what counts as effective instruction (Penuel, 2019). This study analyzes ethnographic data collected during infrastructuring efforts, including IGI artifacts, interviews with designers, and participant observations. In doing so, we attempt to answer the following questions:

1. How can the IGIs of a no-excuses charter network be modified to support NGSS-aligned physics instruction?
2. What do modified IGIs reveal about the possibilities and limitations of instructional improvement efforts in no-excuses charter networks?

Approach to infrastructuring

Infrastructuring took place in four distinct stages: 1) establishing a negotiated vision of effective science instruction, 2) surfacing tensions between existing IGIs and this vision, 3) participatory redesign of IGIs, and 4) iterative redesign of IGIs in use. To create a negotiated vision, stakeholders first identified a focus for instructional improvement, assessing both current instructional practices and targeted growth areas. Then, using scaffolded questions, stakeholders identified what they should see in classrooms if improvement efforts were successful, including teacher/student and student/content interactions. The resulting vision was, "*Usage of instruction that increases student engagement in scientific practices through the inductive method, while also supporting conceptual science learning, college access, and the development of mathematical knowledge and skills.*"

Stakeholders then surfaced tensions between the network's original IGIs and the improvement goals outlined by the partnership. In particular, stakeholders surfaced design conflicts and practical concerns that had to be negotiated through compromise. For example, teachers expressed concern that the amount of content contained in the network's original pacing guide would limit their ability to implement university-designed lessons in which students were responsible for producing knowledge. Administrators expressed concern that they lacked the capacity to provide instructional coaching grounded in the negotiated vision of effective instruction, or fairly evaluate reform teachers. Surfacing these and other tensions provided focus to redesign efforts.

Stakeholders then began the process of redesigning existing IGIs, including teachers, district leaders, and university-based researchers, particularly the first author. Meeting facilitators used intentional protocols to elicit

practitioner and administrator ideas about ameliorating tensions between existing IGIs and the negotiated vision of effective instruction. For example, when redesigning instructional effectiveness rubrics, teachers first collaboratively brainstormed the instructional moves that administrators would observe in their classroom if they were enacting instruction consistent with the reform vision. Administrators and researchers then reviewed these observables, added input, negotiated with teachers, and then modified the existing observation rubric.

The experiences of IGI users during implementation were used to inform downstream revisions to IGIs. To facilitate this process, this article's first author was relied upon to document the experiences of infrastructure users, including observing lessons, conducting interviews, and documenting informal conversations. He then presented the findings of these inquiries to stakeholders as a method of both documenting and influencing change.

Data collection and analysis

Data collection and analysis followed an ethnographic case study approach, as we attempted to produce thick descriptions of infrastructuring efforts and the artifacts they produced (Hammersley & Atkinson, 2003). Artifacts included College for All's IGIs before and after changes were negotiated through the partnership. Additionally, audiotapes and fieldnotes from 24 infrastructuring sessions that varied in length from an hour to an entire day were collected. We also interviewed all stakeholders involved in infrastructuring efforts. Finally, although not reported on in these findings, we observed over 90 lessons of teachers involved in infrastructuring.

For our first analytic step, we identified characteristics of College for All's IGIs before and after infrastructuring efforts. We then made inferences regarding similarities within the mutable elements and similarities within the immutable elements in efforts of roughly generalizing what types of things are subject to change in a context similar to the one under study. These inferences were drawn from inductively coded field notes and transcripts, specifically those that included rationale behind design decisions. Finally, interpretive memos concerning why certain IGI elements were more mutable to design than others were developed.

Findings

To work towards its goal of NGSS-aligned physics instruction, College for All was eager to collaborate with university partners to redesign IGI elements that help shape daily physics instruction. These redesigns included changes to the 1) instructional practices considered effective by the network, 2) expectations for student learning, and 3) focus of professional learning. These resulting IGI components were better aligned with ambitious science teaching practices, showcasing the potential of infrastructuring to disrupt the usage of instructional techniques solely focused on transmitting content. What counted as effective instruction was mutable, even in a network that had previously received national and local praise for closing achievement and access gaps. College for All's broader mission of eliminating educational inequity was a major catalyst for this change, as stakeholders theorized that NGSS-aligned physics instruction would promote more equitable outcomes in STEM courses.

On the other hand, components of IGIs that help maintain instructional consistency and predictable outcomes across the network's physics classrooms proved less susceptible to infrastructuring efforts. These included the network's expectations of 1) consistent instruction across classrooms, 2) data-driven instruction and evaluation, and 3) standards coverage. This commitment to instructional coherence and test-based decision making has both benefits and drawbacks. From a student achievement sense, instructional consistency may help College for All maintain its success preparing students for standardized exams and continue to ensure that 100% of graduates are accepted into a four-year college. However, a continued emphasis on standard coverage may influence teachers to interrupt student engagement in scientific practices in order to use more didactic techniques when coverage pressures are present. A College for All teacher described this tension, stating that the pressure to cover standards caused her to implement some student investigations as demonstrations. In her words, the impact of this decision on students was to "Jib them of learning it on their own. Because I knew they could do it. But I just didn't have time." Although enforcing standard coverage may ensure that all students are exposed to disciplinary content, it may also interrupt teachers' attempts to engage students in NGSS-aligned instruction.

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Does Coercing the Use of a Group Awareness Tool Help Groups Achieve More Equal Participation?

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Abstract: Unequal participation is a source of frustration during collaboration. Group awareness tools (GATs) facilitate monitoring of the collaboration and help groups regulate the distribution of participation. However, the effectiveness of these tools depends on students' tool-use. In this work-in-progress paper, we describe the design of a field-experiment ($n = 57$) in which we examined if coercing active processing of the information provided by a GAT promotes equal participation and increases students' satisfaction with the collaboration.

Introduction: Regulating collaboration using group awareness tools

Social loafing during collaborative learning (Aggarwal & O'Brien, 2008) reduces the opportunities for interactions which are associated with learning (e.g., giving explanations) and also causes dissatisfaction (Capdeferro & Romero, 2012). Thus, the regulation of participation is crucial for effective collaborative learning. Group awareness tools (GATs) can support regulation of the group by visualizing information relevant for coordination, such as participation. While research on GATs for participation has not identified direct effects of GATs on the distribution of participation, results suggest that students' use of the GAT is important for its effectiveness (Janssen et al., 2011). Phielix and colleagues (2011) showed that a collaborative reflection task which included discussing the information offered by a GAT (peer assessment of group members' social performance) and planning future steps for the collaboration helped groups engage more actively in regulation of their collaboration. In a field-experiment we investigated if an additional reflection activity which aimed at increasing groups' deliberate processing of the information from the GAT helped them achieve more equal participation. Data collection has just been finished at the time of submitting this paper, hence the results will be presented at the conference.

Method

We conducted a field-experiment in an online-course on computer-mediated communication at a German university to investigate if coercing students to co-reflect on participation information from a GAT fosters equal participation (RQ1) and satisfaction with the collaboration (RQ2). Further, we explored the groups' reflection processes. The course was offered on the university's LMS Moodle. In each course topic (duration: two weeks), students were provided with learning material (video lecture, literature, quiz) and collaborated in small groups to solve a joint task. These tasks required groups to select and summarize theoretical aspects relevant for the current task, derive and evaluate possible solutions for the problem, and propose a solution. Groups used private forums for coordination and private group wikis to construct the answer text. 57 undergraduate students majoring in various humanities (66.7% female; age: $M = 23.82$; $SD = 3.31$) volunteered to participate in the study for monetary reward. Participants were randomly assigned to one of two experimental conditions. Within their respective condition, students were randomly assigned to groups of four (or five, in order to avoid groups with less than 3 members). The seven groups in the GAT+CoR condition ($n = 31$) received a GAT and completed a mandatory co-reflection activity, the six groups in the GAT condition ($n = 26$) only received the GAT. The *group awareness tool* visualized the word count in the group forum and group wiki as stacked bars without dials (see Figure 1). On mouse-over, the absolute word count was displayed next to the bars. The GAT was always visible in Moodle and the graph was automatically updated every time a student made a new contribution to the forum or wiki. Students could view a short explanation of the GAT in a collapsible text box below the IDs.

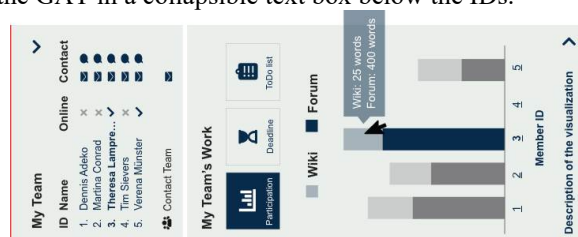


Figure 1. GAT which visualizes word count. On mouse-over, the absolute word count was revealed.

The *reflection activity* was based on Phielix and colleagues (2011) and was implemented on Moodle together with the GAT following the model proposed by Wise (2014): A familiarization email grounded the pedagogical intent of the GAT by describing the importance of active and equal participation during collaboration and how this is represented in the GAT. To retain students' agency over the interpretation of the GAT and the regulation of the collaboration, students individually set a goal for the distribution of participation in the group, reflected on the current distribution of participation, and collaboratively discussed if regulation of the collaboration was necessary and which actions should be taken. Specifically, students answered two questions individually (questions 1 and 2), and discussed two questions collaboratively (questions 3 and 4). Question 4 also required a group to compose a joint answer in a collaborative writing tool. (1) In your opinion: How should participation be distributed during collaboration in a team like yours? Explain. (2) Take a look at the visualization: How well is the participation in your team currently distributed? Give a rating from 1 (bad) to 5 (good) and explain it. (3) Examine the visualization again and post your rating into the forum. (4) Discuss your individual ratings and agree on a rating. Is it necessary to change the way you participate? Develop a plan and set specific goals for your team regarding the distribution of participation. Write down your plan in Etherpad.

At the start of the collaboration, all participants received the familiarization email. Students in the GAT+CoR condition were also informed about the schedule for the reflection activity. At the end of the first week, students in the GAT+CoR condition completed individual reflection. The co-reflection activity was performed at the start of the second week. At the end of the study, students answered a post-questionnaire online. *Participation* was measured by the total number of words each student had contributed to the group's forum and wiki. Based on this, *equality of participation* was calculated using the gini-coefficient (c.f., Janssen et al., 2011). This coefficient assesses the deviation from equal distribution, ranging from 0 (perfectly equal distribution) to 1 (perfectly unequal distribution). *Satisfaction with the collaboration* was measured with four items that captured satisfaction with the coordination, and the result of the collaboration, willingness to stay in the team, and overall satisfaction with the collaboration. *Collaborative reflection and the derived plan* in the group forum and Etherpad were analyzed using the coding schema used by Phielix and colleagues (2011).

Expected findings and contribution of the study

We investigated the effect of coercing students to process and reflect the information provided by a GAT on equal participation and satisfaction with the collaboration. We expect that the collaborative reflection leads to active processing and catalyzes regulation of participation. Consequently, groups that received a GAT and performed the co-reflection will achieve a more equal distribution of participation (H1) and satisfaction with the collaboration (H2). By analyzing the reflection activity in the groups' forums and written plans, we will be able to better understand collaboration norms and the collaboration processes which are required for leveraging the feedback provided by a GAT. Taken together, we hope to advance CSCL research by gaining insights into boundary conditions for the effectiveness of collaboration support, especially GATs, and shed light onto regulation processes which are initiated by this type support.

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How One Implementation of an Educational Innovation Died

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Abstract: The problem of sustaining and spreading educational innovations is one that has vexed many researchers. The flipside of this question, equally important, is what leads to the ‘death’ of educational innovations? Here, to shed light on this question, we provide an autopsy on the death of one local implementation of an otherwise successful STEAM exploration program called FUSE.

The problem of sustaining and spreading educational innovations is one that has vexed many researchers. While it is important to study how educational innovations succeed and spread, it is also important to understand how educational innovations fail. One way they may fail is to become ‘lethal mutations’ (Brown & Campione, 1996)—modifications that so depart from the original philosophy that the innovation becomes unrecognizable. In some cases, implementations die altogether. As Cole has argued, studying how implementations die is critically important (Cole, no date). Here, we conduct, one such autopsy.

This case study is part of a larger study of the spread of a specific educational innovation called FUSE Studios, a STEAM learning environment in which students choose tangible, digital, and hybrid tangible-digital challenges based on their interests. They complete these challenges at their own pace, individually or collaboratively, supported by a website that provides many resources and allows them to track their progress. FUSE has grown from two afterschool implementations in 2012 to 200, mostly in-school implementations across the U.S. and in Helsinki, Finland. In prior work, we have shown how FUSE has spread and been adapted successfully, while maintaining integrity to its core design principles (Stevens, et al., 2018).

In framing our current investigation, we draw on Actor Network Theory (e.g., Latour, 2005). We draw two specific, framing principles from ANT: (1) as an innovation is adopted into new contexts, it undergoes translations (Callon, 1986) through which it is adapted; and (2) the persistence of an educational innovation, like all innovations, is dependent upon the strength and durability of the associations between human and non-human actors in a network (Latour, 2005).

Method

To understand how FUSE was adapted and implemented in different contexts and what types of networks led to success or failure, we drew on data from 57 schools newly implementing FUSE during the 2017-18 school year, selecting 17 cases for close analysis. We followed these cases from their initial conversations with the FUSE team in Spring 2017 through implementation during the 2017-18 and 2018-19 school years. Using broadly ethnographic methods, we collected: (1) written materials produced by the school partners; (2) video-observations of facilitator training and students doing FUSE; (3) interviews with students, teachers, and administrators; (4) emails and recordings of phone conversations with schools; and (5) social media posts. We analyzed these data using the broad frame of ANT (Latour, 2005).

Findings

Schools get FUSE in one of two ways. Either they pay for a license and yearly renewal fee or they receive a two-year grant. If granted schools wish to continue into a third year, they pay the yearly renewal fee. Of our 17 focal research cases (11 granted, 6 not), only one school decided not to continue FUSE into a third year, Shuri Middle School. We therefore characterize Shuri as a context where FUSE ‘died’. When we interviewed the facilitator and administrators at Shuri about why they decided not to continue FUSE, they all cited lack of funds. However, despite expressing similar concerns, they other granted schools all found funds to continue the program in year three. In what follows, we show that the ‘death’ of FUSE at Shuri was influenced by at least two other factors.

First, this facilitator interpreted and adapted FUSE in ways that were misaligned with program philosophies. For example, unlike many FUSE facilitators, the Shuri facilitator assigned students to seats, making it hard for them to move freely and collaborate with peers, a key finding about what generates learning in FUSE (Stevens, et al., 2016). Second, he significantly transformed the intended free-choice environment of FUSE by adding required, graded assignments to the experience. Most teachers overseeing successful FUSE implementation mitigate, work around, or set aside assignments and grades in order to maintain integrity to a core feature of FUSE—student choice or agency. Third, the facilitator at Shuri interpreted FUSE more as a collection

of STEM tools and skills, rather than as a different way to organize learning and teaching (in which students learn from each other and make choices about what to work on based on their interests). We saw evidence of this when he talked about how he would teach STEM without FUSE the following year saying, “[O]bviously not having the program aspect would be a loss, but still just kind of, I guess, incorporating, because two years ago I didn’t know what STEM was really...whether it’s like SketchUp, and you know, 3D software there, with houses, but you could also do other things, or some coding type things...” In sum, one reason for the death of FUSE at Shuri appears to have been a ‘lethal mutation’ with respect to the core features of the approach, features that prior work has shown to make FUSE a successful alternative infrastructure for learning in classrooms (Stevens et al, 2016).

The second factor at Shuri that distinguished it from successful FUSE implementations was the small size and relative disconnectedness of its network of implementation, which included only the 8th grade STEM teacher with weak connections to the principal and a technology coach. In year two, even the STEM teacher was pulled partly away, because he was asked to teach more math classes and less STEM. At other schools, when one facilitator left, others were brought in, but at Shuri, this was not the case, for two reasons. First, unlike facilitators at other schools, the STEM teacher was reluctant to recruit new allies. He said he didn’t talk about FUSE with other teachers, because “[they’re] just not going to understand, because [they] don’t have the program.” Second, when he did try to recruit a new Assistant Principal (AP), she resisted. He described this saying, “When [the new AP] came in...I was excited about FUSE. I was trying to figure out how we were going to renew it, whatever. And long story short...I had a meeting with her to talk about FUSE, and I was prepared, like I had my laptop and I was prepared to show her a challenge...and the meeting lasted like 10 minutes. So I got a little discouraged.”

Conclusion

Our analysis suggests that it was not just a lack of funds that led to the death of FUSE at Shuri, but also: (1) the facilitator’s lack of philosophical alignment with the features that prior research has shown to be key to successful implementation, and (2) his inability to enlist other locally relevant allies. Our analysis also suggests a couple directions for practical improvements to support implementations so that they don’t die. First, consistent with insights from Coburn, Penuel, & Geil (2013), our findings suggest a need to enroll more stakeholders at different organizational levels. Second, our findings suggest giving stakeholders more support to articulate what the educational innovation offers, especially if it differs substantially from traditional educational infrastructure.

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A Theory of Action for Classifying and Implementing Online Text-Based Curriculum Materials Using Natural Language Processing

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Abstract: The purpose of this work is to propose a theory of action for how educators can use Natural Language Processing (NLP) as a way to explore, classify, and implement online text-based curricular materials. Within the context of open and free online text-based curricular materials, this work forwards and operationalizes the theory of action for using NLP in the context of higher education physics instruction. Results demonstrate the feasibility of such a model with implications for the importance of educators being “in the loop” instead of black boxing such processes.

Significance of work

Research has repeatedly shown the impact of curricular materials on students’ formal learning experiences depends on a number of factors associated with the educator (teacher, instructional designer, faculty member) and the materials themselves (Stigler & Hiebert, 2004; Forbes & Davis, 2010). The increasing number of online curricular materials, especially open and free materials, presents a unique opportunity to think about and consider how educators organize and implement such distributed curriculum resources. Building on a number of frameworks from across mathematics and science education (Cartier et al., 2013; Cohen, Raudenbush, & Ball, 2003), we present a Theory of Action (TOA) that describes a mechanism by which educators can utilize trusted resources to train natural language processing (NLP) algorithms in order to better classify other sets of online resources that can be implemented by the educator. In this manuscript we propose how previous research can guide the use of NLP and online materials to assist educators in developing learning opportunities.

A theory of action for exploring curriculum using NLP

The TOA presented in Figure 1 is predicated on a set of four assumptions. 1) The use of the term educators is intended to be very broad in the proposed TOA. Educators may be teachers, instructors, instructional designers, learning engineers, and others. 2) Educators know their context and the requirements needed of curricular materials beyond the one size fits all model of traditional curriculum. 3) Resources and processes that allow educators to create better learning opportunities can improve student learning outcomes. 4) Educators may not be able to interrogate and improve their work when the processes associated with searching and categorizing curricular materials are black boxed from them. Based on these assumptions, Figure 2 presents a visual representation of the TOA for how educators can utilize NLP tools to train a model to classify online curricular resources in order to organize and implement such resources.

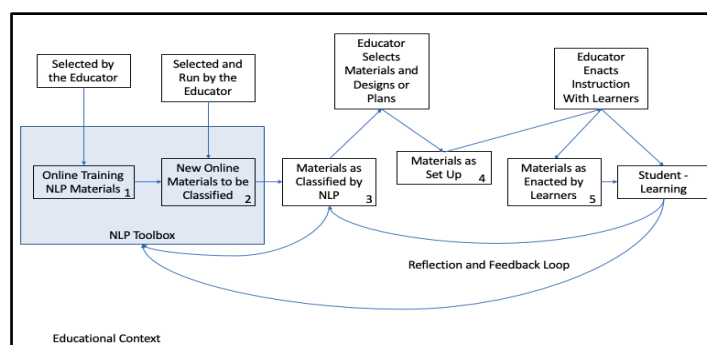


Figure 1. Theory of action for educators using NLP to classify and enact online-text based materials.

Methodological approach

We grounded this exploration of applying NLP to resource classification in the content area of Physics, as the field has a well-defined set of OER and two of the paper authors have content backgrounds in physics. We trained a topic model based on the OpenStax physics textbook “University Physics Vol. 1”, to demonstrate how such a

model could be used to identify topics from a set of OER with unknown topics. Then, as an example, we applied the OpenStax topic model to classify the following OER on circular motion: 1) The Wikipedia article on circular motion, 2) A pdf document from an MIT Open Learning Library (MIT OLL) physics course (Mechanics), and 3) A transcript file of a 80-second video from the same course. We use an implementation of Latent Dirichlet Allocation (LDA) (Blei et al., 2003) based on the popular NLP package gensim (Rehurek et al., 2010).

Results

Once we trained our model with the OpenStax physics textbook, we applied the resulting 94-topic model on the 3 unseen documents specified earlier. In Figure 2 we show the results schematically: the model associates the Wikipedia article titled “Circular Motion” with 2 topics, and the MIT OLL introductory text and the subtitle file on *circular motion* with one topic. The Wikipedia article is associated primarily with 2 topics, #9 and #88, with topic-distribution probabilities 0.54 and 0.25 respectively, while the text and the subtitle file from MIT OLL shows a very strong association with the topic #9 (a probability of 0.89 and 0.90, respectively).

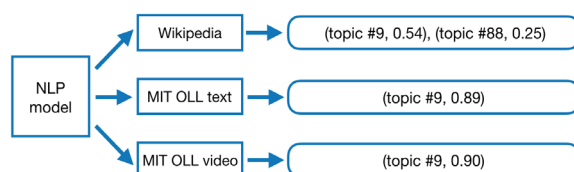


Figure 2. Application of the NLP model on 3 specific resources and the inferred topics with associated topic-distribution probability.

Conclusions and implications

By making the TOA explicit this work hopes to provide the NLP and Learning Sciences communities with a frame for thinking about the next steps in exploring, understanding, and testing how educators can and should engage with NLP as a way to find and classify online text-based curricular resources. In grounding this work in research related to curriculum material implementation, we hope to point researchers and educators to critical portions of the TOA that demand attention in support of learners and learning outcomes. Most importantly, the education community must move beyond the black box approach to curriculum in order to make explicit how we conduct the work of finding, organizing, and enacting distributed curricular materials. More research is needed in order to build effective NLP toolkits for educators and to understand how educators implement such tools.

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Towards Obtaining Affect-Based Proxies for Attentional Behaviour in TEL

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Abstract: Current multimodal studies have a common limitation of not being able to scale up the implications since the apparatus used is not scalable. In this paper, we propose a simple method to find measurements from scalable data modes such as facial data and examine the measures in richer and more granular data modes like eye-tracking that they correspond most closely to. In other words, we find pervasive proxies to the measurements that have been reported to be obtrusive. We exemplify this approach using eye-tracking and facial data from two different studies.

Keywords: Eye-tracking, Facial Expressions, Multimodal Learning Analytics.

Introduction and background

The motivation for this research is twofold. First, sensing students' cognitive and affective states in online learning environments needs to be achieved through ubiquitous devices such as webcams or Fitbits, since current off-the-shelf solutions for eye-tracking and EEG measures are not scalable in terms of cost-effectiveness. Secondly, ubiquitous sensing of student behaviors during learning has potential for classroom orchestration research, with the aim of informing the teacher about students' cognitive and/or affective states at any moment during interaction with the learning environment (Prieto et al., 2018). In classroom settings, especially with a large student population, current methods for reliably sensing students' cognitive and affective states do not support principles of ecological validity. A solution would be using multimodal learning analytics (MMLA) techniques to fuse data sources that identify cognitive-affective states - such as eye-tracking, electroencephalography (EEG), heart rate, facial data, to mention a few.

Current research in MMLA (Giannakos et al., 2019; Sharma et al., 2019) is focused on fusion of different data modalities to model attentive and cognitive processes, affective states along with arousal trends, to explain the learning outcomes and behaviors. Since all the different data sources used in current MMLA research are not ecologically valid, fusing these sources together can not only help us achieve a higher level of understanding about student behaviors but also enable improvement of our sensing methods to move towards a ubiquitous sensing of learning processes. In this contribution, we present an exemplar method to achieve this by finding interconnections between gaze and facial data streams using data from two different classroom studies.

Eye-tracking has been used to understand the learning processes (Sharma et al., 2015) and provide students with adaptive feedback on their learning processes (D'Angelo & Begel, 2017). Within affective states, eye-tracking has been used to gauge student boredom, curiosity, and attention or mind-wandering (Bixler & D'Mello, 2016); identifying these states helps design interventions to regulate student affect during learning. Bearing in mind the innate connection between emotions and facial expressions, a sizeable body of research is dedicated to assessing learning and performance through emotions inferred from facial expressions (Graesser et al., 2006; Baker et al., 2010;). D'Mello et al. (2012) collected facial expressions of students while interacting with AutoTutor; and modeled transition likelihoods among affective states of boredom, flow (engagement), and confusion during learning (D'Mello et al., 2012).

Methodology

Study 1 This study used Betty's Brain, an open-ended learning environment (OELE) that helps middle school students learn scientific processes (Leelawong & Biswas, 2008). During our study in Dec 2018 with 60 sixth-grade participants of a public middle school in USA, students worked on Betty's Brain to build causal models of climate change, using individual laptops equipped with webcams and Tobii-4c eye-tracking devices, thereby enabling the collection of facial landmarks data from webcam video frames and gaze data from eye-tracker logs. After initial processing, the facial and gaze data logs were synchronized by time for analysis purposes.

Study 2 The second study took place in controlled settings. Students' responses and system usage logs were collected with LAERS (Papamitsiou et al, 2013), a web-based implementation of a layered architecture for testing systems. Thirty-two undergraduate students at a European university enrolled in an online adaptive self-assessment procedure for a Web Technologies course (related to front-end development) in Oct 2018. Students' gaze was recorded using the Tobii X3-120 eye-tracking device at 120 Hz sampling rate using 5-point calibration. The device was mounted at the bottom of the screen, facial video recording was done with 640x480 video resolution at 10 FPS using a Logitech Webcam that was zoomed 150% onto participant faces.

Finding facial proxies to gaze data First, we scale gaze and facial measurements to be in the same range of zero to one. Next, we conduct rotated Principal Component Analysis (PCA) on the combined data (gaze + face). We then select the appropriate number of Principal Components (PC) that explain the relation between gaze and facial measurements, applying a PC threshold of 75%. For each gaze measure that has smallest angle with each PC, we rotate the vector corresponding vector to be parallel to the PC, and recompute all the angles for facial measures with the selected PC. We then identify the top five closest facial vectors in each of the rotated dimensions to be the proxies to the gaze measurements.

Measurements From facial data we extracted the intensity of 16 Action Units (AUs) such as ChinRaiser, JawDrop, LipPressor, LipStretcher, and LipPucker using iMotions Affectiva (for Betty's Brain) and OpenFace (for adaptive assessment system). From gaze data we computed the following gaze variables (for definitions and relation between these measurements and cognitive/behavioral processes, cf., Holmqvist et al, 2011): Mean Saccade Angle (MSA), Scan-path Velocity (SPV), Saccade Velocity Skewness (SVS), Local/Global Information processing (IP), Saccade Amplitude (SA), Saccade Velocity (SV) .

Results and discussion

For Betty's Brain, PCA resulted in 12 components explaining a total of 75% variance from the original data. For adaptive assessment, PCA resulted in 7 components explaining a total of 79% variance from the original data. Striking similarities are observed in terms of the relationship between gaze and facial measurements across the two studies, with an overlap of 86.16% in terms of affinity (correlation irrespective of being positive or negative) between the individual gaze measures and AUs, and an overlap of 66.67% (when considering affinity direction i.e., positive or negative correlation). Only in 16.84% cases the two studies are completely different, which could be attributed to the diversity in the two contexts, one being a complex Intelligent Tutoring system (Betty's Brain) and the other an adaptive self-assessment testing system. The similarities in gaze-face relations across the two studies could be exploited to design interventions solely based on the intensity of AUs. For example, low intensities of ChinRaiser, JawDrop, LipPressor, LipStretcher, and LipPucker might suggest global processing. Similarly, high intensities of LipPressor, LipStretcher, LipTightener, NoseWrinkler and UpperLipRaiser might suggest high saccade velocity skewness, which depicts strong anticipatory patterns. Such inferences can enable the provision of appropriate feedback to students or adaptation of the learning system.

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Scaling a System of Professional Learning for Formative Assessment Co-Design: The Aspire Project

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Abstract: We have scaled an approach to support science teacher professional learning around classroom assessment using a learning progression and associated tools and routines to support student modeling of the crosscutting concept of energy. We describe the design of the learning progression and the ways in which it allowed us to scale science classroom assessment co-design across high school physics, chemistry, and biology professional learning communities.

Introduction

The *Framework for K-12 Science Education* (National Research Council [NRC], 2012) established a new vision for science learning where students engage in scientific practices and apply crosscutting concepts as they learn disciplinary core ideas in order to develop explanations of novel phenomena in the world around them. Creating assessments consistent with this vision has been difficult to achieve, along with supporting teachers to understand, develop, and use those assessments to inform classroom practice. School districts need coordinated systems to realize the potential of *Framework*-aligned assessments that inform classroom instruction (Penuel, 2019).

We have developed a professional learning system with the intention of transforming science teaching and learning based on a crosscutting concept, defined as concepts that unify the sciences (e.g. cause and effect, patterns, matter and energy flows in systems). This system has been developed as part of a larger Design-Based Implementation Research project conducted in partnership with a large school district (Penuel et al., 2011) between district-based curriculum specialists and researchers at the University of Colorado Boulder. In this poster, we describe (1) the learning progression that is the foundation of the professional learning system, (2) the affordances of that learning progression in scaling a professional development approach for high school physics, chemistry, and biology teachers, and (3) the tools and routines for supporting formative assessment co-design.

Building learning progressions for modeling energy flows in systems

Learning progressions are representations of the empirically grounded and testable hypotheses about how students' understanding within a subject domain becomes more sophisticated over time (Corcoran, Mosher, & Rogat, 2009). Our learning progression (Buell et al., 2019) traces the ways students can create increasingly sophisticated models (Pierson et al., 2017; Schwarz et al., 2009) of phenomena related to energy flows within systems (Neumann et al., 2013; Park & Liu, 2012). This progression then served as the center point to create performance expectation (PE)-specific three-dimensional learning progressions consisting of a scientific practice (in this case, modeling); a crosscutting concept (energy) and a disciplinary core idea (Figure 1).

Scaling professional learning approach

We then used these three-dimensional progressions as the foundation for the co-design of classroom assessments in discipline-specific professional learning community meetings with high school physics, chemistry, and biology teachers (see Figure 2 for an example). University-based researchers and district science coaches then engaged teachers in routines around these PE-specific learning progressions to explore student thinking about energy, co-design assessment tasks, enact those assessments in their classrooms, and then identify next steps for instruction. These routines were

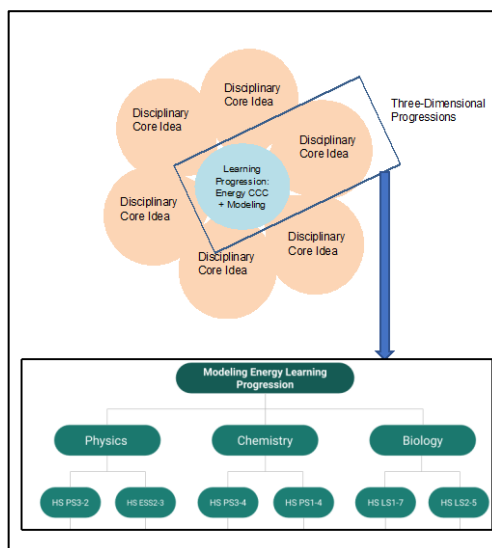


Figure 1. Scaling approach to produce three-dimensional learning progressions for HS physics, chemistry and biology.

supported with a suite of tools including common templates for modeling tasks, assessment quality checklists, and processes for using the learning progression to analyze samples of student work. In the 2018-2019 academic year, we facilitated over 100 on-site meetings with teachers and supported iterative cycles of formative assessment design in high school physics, chemistry, and biology units focused on energy, ultimately designing nine new tasks with teachers to engage students in three-dimensional science learning experiences.

Level	A Learning Progression for Modeling Energy Flows	Look fors for PS 3-4
5	<ul style="list-style-type: none"> <input type="checkbox"/> Students are able to generalize their model to unknown or multiple <u>phenomena</u>, and can explain limitations of applying the model to a new <u>phenomenon</u>. 	<ul style="list-style-type: none"> o Multiple phenomena OR o Limitations to generalization in scope or intensity
4	<ul style="list-style-type: none"> <input type="checkbox"/> Students develop a model that illustrates a <u>mechanism</u> that can explain or predict the <u>phenomenon</u>, AND use the model to make predictions about how changing one part of the model would influence energy flows elsewhere in the <u>system</u>. <input type="checkbox"/> Students can explain how the total energy of the <u>system</u> constrains the magnitude of change possible. <input type="checkbox"/> Students can describe limitations of the model in explaining or predicting the phenomenon 	<ul style="list-style-type: none"> o Multiple scales within model (zoom-in) showing molecular motion including speed and direction. o Quantitative change in temperature, formulas or graphs. o That temperature becomes more uniform but total energy does not increase. o Identify a possible change in phenomenon and what model predicts would happen
3	<ul style="list-style-type: none"> <input type="checkbox"/> Students use or develop a model that relates changes in the phenomenon directly to changes in energy through transfers/transformations by identifying specific <u>indicators</u>. <input type="checkbox"/> Students begin to show evidence that their model is accounting for conservation and dissipation. <input type="checkbox"/> Model includes energy flows into, within, and out of the <u>system</u>. 	<ul style="list-style-type: none"> o Changing relative temperature of systems and surroundings or between different objects. Every temperature increase should also have a temperature decrease somewhere else. o Explicit links between changing temperatures and energy transfers shown.
2	<ul style="list-style-type: none"> <input type="checkbox"/> Students use or develop a model to illustrate a relationship or pattern between the increase in one form of energy and the decrease in another form, or transferred from one location or object to another. <input type="checkbox"/> Students identify the most relevant components and relationships in the model and distinguish between the <u>system and surroundings</u> <input type="checkbox"/> Model focuses on energy flows within the <u>system</u> only. 	<ul style="list-style-type: none"> o Correctly labeled arrows showing conduction or convection (transfers). o Arrows indicating net flow of thermal energy from one object to another or between system and surroundings. o Circle or label to indicate system and surroundings.
1	<ul style="list-style-type: none"> <input type="checkbox"/> Students use or develop a model that shows, through drawings or labels, the components involved in a <u>phenomenon</u>, some (but not necessarily all relevant) energy forms, transfers, or transformations. 	<ul style="list-style-type: none"> o Literal components o Some energy forms labeled o Energy transfers may not start or end in an object

Figure 2. Sample learning progression with PE-specific “look-fors”.

Significance

This poster presents a key affordance of the crosscutting concepts: how following one concept into different grade bands can create the foundation for a scalable professional learning approach that is not only discipline-specific, but also supports students in related trajectories of learning across grade bands. In the poster, we share vignettes of teachers engaging in co-design routines in professional learning communities, examples of the co-designed assessments developed with the learning progression, and the tools we used to support those routines as we sought to improve the quality of high school physics, chemistry, and biology teaching, learning, and assessment.

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Instructor Feedback Practices in Undergraduate Writing at Scale

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Abstract: The current research study is the first phase in a multiphase research project aiming to improve instructor writing feedback through the creation of an artificial intelligence powered scoring and feedback system. This first study will investigate how instructors give writing feedback via a survey and interviews. Understanding the various ways feedback is delivered and perceived by students at scale will inform the design of an automated feedback system.

Introduction

Effective writing is a necessary tool for thinking, learning, and success in our society. A key outcome of an undergraduate education is the ability to be an effective writer (AAC&U, 2007; Thaiss & Porter, 2010). Despite this emphasis, writing remains an area of difficulty. Many students enter college with limited writing proficiency, a substantial number of students make minimal gains in writing during college, and many employers find that college graduates lack necessary writing skills (Arum & Roksa, 2011; Business Roundtable, 2017; National Center for Education Statistics, 2012). Understandably, instructors, employers, and policy-makers are intent on finding effective ways to support college students' ability to write in service of learning in their respective disciplines (Kiefer, Palmquist, Carbone, Cox, & Melzer, 2018). Feedback is a powerful tool for improving students' writing and learning, as it simultaneously indicates students' current strengths and weaknesses and provides guidance for improvement (Konold, Miller, & Konold, 2004; MacArthur, 2007). However, higher education instructors are often given little training or support in providing effective feedback, or in adjusting this feedback for writing to learn or writing in the discipline contexts (Lee, 2008). This lack of proper feedback can leave students at a disadvantage regarding writing improvement.

Significance

Instructors who teach at online universities can spend on average 43 to 63% of their time on grading and providing feedback on papers (Mandernach & Holbeck, 2016; Van de Vord & Pogue, 2012). This workload is a significant challenge and we aim to explore ways to reduce instructor time. The current research study is the first phase in a multiphase research project aiming to improve instructor feedback through the creation of an artificial intelligence powered scoring and feedback system around writing. Using artificial intelligence to augment and support instructor feedback could exponentially increase the accessibility, efficiency, and effectiveness of writing and content instruction. This first study will investigate how instructors give feedback around writing. Understanding the various ways feedback is delivered and perceived to be important at a wide scale will help us understand what should be prioritized for such an automated feedback system.

Methods

This work is in partnership with a large university that serves over 130,000 learners enrolled across the globe and supports learning through writing, no matter the discipline. This mixed-methods study will combine quantitative data from an instructor survey (approximately 500 instructors from a representative sample of instructors across course content areas) and qualitative data from instructor interviews. Specifically, the instructor survey will gather data on the landscape of writing feedback-giving practices. This will capture instructors' current practices, as well as their ideal practices. Coupled with national, scaffolded standards for writing feedback and best practices from the empirical literature, we will conduct a gap analysis on how we can augment and improve writing instruction. Specifically, the instructor survey will gather data on the following topics: (a) What writing skills do students struggle with, (b) What writing skills do instructors think they are good at supporting, (c) The frequency of providing feedback on writing skills (current state), (d) The importance of providing feedback on writing skills (ideal state), (e) The frequency of delivering particular feedback practices (current state), and (f) The importance of delivering particular feedback practices (ideal state). Qualitative interviews and think-alouds will then be

conducted with a subset of the instructors. Table 1 displays our model of writing skills (adopted from the AAC&U writing VALUE rubric to define writing skills; AAC&U, 2009). Feedback practices will be pulled from an exhaustive list of feedback characteristics we are gathering from the research literature. Examples include: praise, localization, directiveness, elaboration, and the like.

Table 1: Writing Skills Definition

Genre and Disciplinary Conventions	Chooses writing construction based on demonstrated attention to and successful execution of a wide range of conventions particular to a specific discipline and/or writing task(s), including organization, content, presentation, formatting, and stylistic choices.
Sources and Evidence	Skillfully arranges high-quality, credible, and relevant sources to develop ideas that are appropriate for the discipline and genre of the writing.
Context of and Purpose for Writing	Synthesizes understanding of context, audience and purpose of the assigned task in order to compose all elements of the work.
Content	Assembles appropriate, relevant, and compelling content to illustrate mastery of the subject, conveying the writer's understanding, and shaping the whole work.
Control of Syntax and Mechanics	Composes graceful language that skillfully communicates meaning to readers with clarity and fluency, and is virtually error-free.
Revision	Sufficiently makes revisions based on feedback from an instructor.

Implications

From the survey data, we will look at the gap between what feedback practices instructors value and the frequency with which they use certain feedback practices, and compare these to the national standards for effective writing instruction. We will conduct analyses among the set of feedback practices to identify personas of feedback practices within the sample. The interview results will further shed light on the motivations behind why instructors give different feedback.

This study is the first step in a multiphase research project aimed to create an artificial intelligence powered scoring and feedback system around writing. This first study will help us identify feedback practices that can be useful for improving writing skills and will inform the design of automated feedback and scoring capabilities in later phases of the project. These results will also be used to guide student interviews around feedback in an effort to further investigate how different feedback practices impact writing skills.

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Crowdsourcing Explanations for Improving Assessment Content and Identifying Knowledge Components

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Abstract: Refining assessment items to improve their clarity and identifying the intended knowledge components required to solve them is a time-consuming task. In this study, we present the results of crowdsourcing insights into the underlying concepts of problems in mathematics and English writing, as a step towards leveraging the crowd to expedite the task. This work demonstrates a method to use the crowd's knowledge that can lead to knowledge component identification and improved assessments.

Introduction

Intelligent tutoring systems and other adaptive courseware often employ knowledge component modeling, which treats student knowledge as a set of interrelated knowledge components (KCs), where each KC is “an acquired unit of cognitive function or structure that can be inferred from performance on a set of related tasks” (Koedinger et al., 2012). Operationally, a KC model is defined as a mapping between each question item and a hypothesized set of associated KCs that represent the skills or knowledge needed to solve that item. This mapping is intended to capture the student's underlying cognitive process and is vital to many core functionalities of an intelligent educational software, enabling features such as adaptive feedback and hints (Moore & Stamper, 2019). Once student data has been collected, the initial mapping can then be improved as poorly associated KCs come to light (Corbett & Anderson, 1994). As the next step, instructional designers are often leveraged to revise the KC model; however, this is often a time consuming task, making this continuous iteration challenging. While machine learning methodologies have been developed to assist in the automatic identification of new KCs, prior research has shown that human judgment remains critical in the interpretation of the improved model and acquisition of actionable insights (Liu & Koedinger, 2017; Nguyen et al., 2019).

An emerging area that has the potential to provide the human resources needed for scaling KC modeling is crowdsourcing, although the challenge with this approach is that the population of crowdworkers is highly varied in their education level and domain knowledge proficiency. Therefore, as a first step towards examining and promoting the feasibility of crowdsourced KC modeling, we studied how crowdworkers can provide insights into identifying KCs in a set of word problems. Using a crowdsourcing platform, we gathered participants with no background in pedagogical training or learning sciences and varying levels of math and English writing expertise. We then asked them to provide explanations of what makes a problem challenging, particularly for questions involving geometry and prose writing style. Based on their responses, our research questions are as follows:

RQ1: Are the explanations provided by crowdworkers indicative of any KCs that the problems require?

RQ2: Do the explanations provide insights into how the presented assessment items may be improved?

Methods

Our study consists of two experiments with the same procedure but involve different domain knowledge. The first domain is mathematics, with a focus on the area of shapes; the second is English writing, with a focus on prose style involving agents and clause topics. In both domains, we deployed an experiment using AMT. Forty crowd workers on AMT, known as “turkers,” completed the math experiment, and thirty turkers completed the writing experiment, for a total of 70 participants. In each domain, the tasks took roughly five minutes to complete. Participants were compensated \$0.75 upon completion, providing a mean hourly wage of \$9.

Participants completed a series of demographic questions about gender, education level, and occupational field. They were then asked two questions regarding their expertise in the given domain, either English writing or math. Following this, they moved onto the main task of the experiment, where they were presented with two word problems positioned next to one another. In the math experiment, both of these problems involved finding the area of two different shapes, composed of squares and triangles. In the writing experiment, both word problems involved identifying the agents and actions of different sentences. Across both experiments, participants were asked to compare the two side-by-side questions and provide three explanations as to why students might find one problem more challenging than the other.

The participant provided explanations were then coded, using a unique codebook for each experiment, by two researchers following the process of DeCuir-Gunby et al. (2011). In total 11 codes were created and applied to the 120 explanations from the math experiment and 10 different codes were created and applied to the 90 writing experiment explanations. Due to space limitations, the codebook can not be shared here, but the results extrapolate on the codes that were found to be the most meaningful.

Results

From the coded explanations in the math experiment, six of the eleven codes were applied to explanations that were indicative of a KC that was fitting to the problems. These codes involved the number of steps a problem took, the layout of the depicted shapes, and the need to calculate different areas. Additionally, two other codes from the math experiment were tagged to explanations that indicated an area of question improvement. These often involved the wording being confusing or the shapes used in the problems being hard to decipher. In total 90/120 (75%) of the participant explanations were suggestive of at least one KC and 15/120 (12.5%) of the explanations suggested an area of the problem(s) that could be improved.

The writing experiment yielded slightly lower results, as only four of the ten codes applied to participant explanations were ones indicative of a KC that was fitting the problems. These four codes covered explanations that detailed the grammatical rules of a sentence and the need for technical jargon to identify the different parts of the word problem. Three other codes of the ten were tagged to explanations that indicated an area of question improvement, akin to the math experiment ones. These often detailed the format of the question, being open ended or multiple choice, and the wording of one of the questions being not as understandable. In total, 20/90 (22.22%) of the participant explanations were suggestive of at least one KC in the writing experiment and 42/90 (46.67%) of them suggested an area of the problem(s) that could be improved.

Discussion

The results indicate that many of the provided explanations were relevant to the problems more often than not, either indicating a KC required to solve the problem or suggesting an area of improvement. Understandably the math experiment achieved a greater number of explanations indicative of a KC than the writing one, likely due to the domain being more familiar to participants. These explanations that suggested a KC required to solve the problems could be leveraged to help create a KC model or as a starting point for experts to begin developing such a knowledge mapping. Across both experiments, participants were also able to suggest more surface level features of the problems, such as confusing wording or confusing images, that could lead students to have difficulty in solving them. These explanations could be leveraged by course designers to indicate where their efforts should be spent in correcting assessments items. They also may lead to clarification as to why students are struggling with a particular set of problems, not due to the content, but due to the question semantics.

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Integrating Computer Science in Science: Considerations for Scale

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Abstract: While the push to integrate computer science (CS) within core subjects shows promise for broadening access to CS learning, research is needed to understand how such approaches can be realized at scale. Our ongoing research aims to design learning sequences that integrate CS and science learning at scale, and interrogate that design with practitioners. We report emerging design principles that can inform future efforts to integrate CS and disciplinary learning in required courses like science.

Introduction

Facility with foundational practices in computer science (CS) is increasingly recognized as critical for the 21st century workforce. Developing this capacity and broadening participation in CS disciplines will require learning experiences that can engage a larger and more diverse student population (Margolis et al., 2008). One promising approach involves including CS concepts and practices in required subjects like science. Yet, research on the scalability of educational innovations consistently demonstrates that their successful uptake in formal classrooms depends on teachers' perceived alignment of the innovations with their goals and expectations for student learning, as well as with the specific needs of their school context and culture (Blumenfeld et al., 2000; Penuel et al., 2007; Bernstein et al., 2016). Research is nascent, however, about how exactly to achieve this alignment and thereby position integrated instructional models for uptake at scale. To contribute to this understanding, we are developing and studying two units for core middle school science classrooms, known as Coding Science Internships. The units are designed to support broader participation in CS, with a particular emphasis on females, by expanding students' perception of the nature and value of coding. CS and science learning are integrated through a simulated internship model, in which students, as interns, apply science knowledge and use computer programming as a tool to address real-world problems. In one unit, students gain first-hand experience with sequences, loops, and conditionals as they program and debug an interactive scientific model of a coral reef ecosystem under threat. The second unit engages students in learning concepts related to data analysis and visualization, abstraction, and modularity as they code data visualizations using real EPA air quality data. A core goal for both units is to provide students experience with some of the increasingly prevalent ways that computer science is integrated into the work of scientists.

Methods

Data collection and analyses are grounded in principles from Design-Based Research (Barab, 2014) and Design-Based Implementation Research (Penuel et al., 2011), emphasizing iterative design and inquiry in collaboration with practitioners to understand what instructional design features position a CS-in-science integrated model for effective and scalable implementation. Reported findings focus on practitioner perceptions regarding implementation feasibility and alignment with school and district learning goals and are drawn from: a) iterative classroom piloting and observations of both instructional units in 19 classrooms, with 475 students; b) student survey and assessment data (n=391) from a research trial of the first of two 10-lesson instructional units; c) teacher surveys and reflection logs (n=10); d) teacher and district administrator interviews (n=8); and e) development team and stakeholder meeting notes from the first two years of the project.

Emerging design principles

Attending to time constraints. Teachers and administrators echoed the well-recognized feasibility constraint of *time* as an exceedingly precious commodity: the school day is limited and subject area teachers must contend with voluminous content standards and competing priorities for instructional time. Responsive to these constraints, we limited each instructional sequence to a unit of ten 45-minute lessons, which we have found to be feasible for uptake at scale in middle school classrooms (Jen et al., in review). In addition, we found that uptake of integrated instructional approaches was facilitated by attention to the implementation ecosystem, through supporting teachers and administrators in determining the timing of instructional sequences such that they interleave within and augment the school's adopted science curriculum progression.

Designing for face validity. Our experiences during recruitment and implementation suggest uptake in science classrooms will depend in part on whether teachers and administrators perceive CS integration to be legitimate science with instructional value. CS learning must *do work* for formal science classrooms, rather than simply “add coding” to the already ambitious learning goals set forth by science standards. Documentation that demonstrated alignment with science content (e.g., standards crosswalks with CS-in-science instructional sequences) proved invaluable for recruitment. Participating teachers also valued the opportunity to implement curricular sequences that demonstrated learning gains in computational thinking (CT), which represents a pivotal link between science and CS standards (Greenwald & Krakowski, 2020). This is especially salient because science teachers may recognize CT as a science and engineering practice in science standards, yet remain uncertain about how best to promote CT learning in concert with disciplinary learning.

Supporting teachers to navigate unfamiliar content and its integration. First, we found that instructional design features are critical to support the development of teacher capacity and confidence with CS. In particular, teachers in our study, most of whom identified as CS novices, consistently reported the value of extensive just-in-time teacher resources, including educative curriculum materials with background information and support documentation for using and supporting student engagement with the coding environment. Teachers also indicated that the simulated internship model itself allowed them to play more of a “guide on the side” role, shifting the onus of expertise and providing an opportunity to learn alongside their students. Second, we found that supports for differentiation are essential with integrated approaches in that students varied in both science and, especially, coding prior experiences. Accordingly, teachers regularly identified the differentiated resources within the units as critical to support the diverse learning needs in their classrooms. In addition to activity-based supports, we structured the design of coding tasks into clusters along a conceptual progression. This approach enabled all students to engage with core concepts for each cluster, while providing additional more scaffolded as well as more challenging tasks within each cluster to enable students to work at their own pace and in accordance with their prior coding experience.

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Partnering for Equity: Research Practice Partnerships and Community Contexts

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Abstract: Acknowledging the goals of many learning scientists to contribute to educational equity, we posit that not enough analyses consider activities of partnerships as they are situated within community contexts. In this poster, we examine six RPPs, their relationship-building practices, and embedded power dynamics. We conclude with a discussion around ways that RPPs and co-designed research projects can better attend to community contexts, voices, and needs.

Overview

We, a group of early career scholars, examine our experiences with research-practice partnerships (RPPs) and other participatory research efforts to understand how projects situated in community contexts can work toward equity. We draw upon critical theory to define equity, and suggest that educational research that claims equity as a goal must disrupt systems of power that have historically privileged some and marginalized others (e.g., Yosso, 2005). We then examine ways that research projects can build infrastructures for equity-oriented partnerships. We posit that more analyses should consider the activities of research as it is situated in broader communities. We then look across RPP projects to examine the ways these efforts have interacted with embedded power dynamics, sociohistorical assets, systemic conflicts, and divergent visions around equity building in community spaces. We conclude by offering recommendations for building relationships that attend to the sociopolitical contexts shaping future studies.

Major issues addressed

Research practice partnerships are long term collaborations where “researchers and system leaders share an open-ended commitment to build and sustain a working collaboration” focused on “problems of practices–key dilemmas and challenges that practitioners face” (Coburn & Penuel, 2016, p .49). An essential part of orienting RPPs towards issues of equity in education has been interrogating the power dynamics inherent in collaborations between multiple levels of stakeholders (e.g. Vakil et al., 2016). We argue that there is a need for more research that examines the interactions between RPPs and the communities in which they are situated. In order to address this gap, we examine the following questions: 1) How can RPPs build relationships within communities to address inequities embedded in education? and 2) What are the strategies researchers can use to develop new forms of RPPs that attend to issues of equity both within educational practice and within the positioning of communities?

Projects examined

Integrated infrastructures to support student agency in RPPs (Lee)

This study examines how RPP infrastructure (Penuel, 2019) distributed across multiple levels of the school ecology created opportunities for nondominant students to leverage community cultural wealth (Yosso, 2005) in designing school technology practices. We found that school structures built to support local autonomy created opportunities for researchers to engage with students in sustained partnership that privileged student goals during the design.

Conversations at the kitchen table: Perspectives on partnerships (Stamatis & Pacheco)

In order to examine the ways that relationships within research have potential to grow liberatory and justice-oriented pedagogies in both formal and informal educational spaces (e.g., Bang & Vossoughi, 2016), we examine

our experiences building partnerships across a number of community stakeholders by leveraging personal relationships to engage stakeholders in participatory research. We then consider the ways that research can cause tension within participants lives and consider how partnership research should sometimes center refusal (Tuck & Yang, 2014).

Partnership work is relational (Roque, Widman, & Stamatis)

We examine the ways that partnerships with several public libraries worked to attend to community histories and the power relations inherent in partnership work. We argue that equity in partnership work lies in the *how* of relationship building and present our strategies to develop relationships, discussing what aspects of these strategies contributed to the collaborative work between researchers and practitioners. Our findings illustrate the importance of relationship building with community partners as a starting point for working with families in informal spaces.

Surveillance and re-mediation in an environmental justice partnership (Wingert)

This study is situated within a youth organizing program that was committed to designing a high school chemistry unit that centered issues of environmental justice. I examine the community context to problematize the concept of surveillance within partnership spaces. Findings show that interpreting, understanding, and removing *surveillance* may lead to more youth-driven, transformative partnership.

Community-based participatory research practices for re-situating RPPs (Wegemer)

Designing equitable educational systems through requires consideration of power dynamics and positionality within communities (Penuel, 2019). I reflect on the potential usefulness of community-based practices for equitably re-situating an RPP within a non-dominant community.

Collaborative practices to enhance equity in computer science education (Huang)

The aim of this RPP was to apply collaborative learning approaches to the design of learning environments to promote equity through access to computer science in middle school classrooms. This designed curriculum was intended to teach students basic programming skills through collaborative design activities in Scratch. This work suggests RPPs have potential to support educators in building content area understandings that shift policy climates.

Conclusions

Each project examined brought to bear a deep commitment to use research as a vehicle to facilitate meaningful social change alongside community partners through community-based research methodologies. When relationships with partners and their communities are centered in RPPs, there is great potential for these projects to not only support equity but for designed interventions to be sustained. In examining our own relationship-building practices and how they have interacted with the embedded power dynamics, sociohistorical assets, systemic conflicts, and divergent visions around equity, we argue that there is a need for further theory and methodology to guide the work of emerging scholars as they take on projects to build sustainable infrastructures within equity-oriented RPPs.

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NetLogo Mobile: An Agent-Based Modeling Platform and Community for Learners, Teachers, and Researchers

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Abstract: A complex systems perspective provides a major opportunity for learning. NetLogo is a powerful tool to foster computational thinking with complex systems. This poster reports on our prototype of NetLogo Mobile, a new interface to NetLogo designed for wide scaling. We introduce its underlying design principles. Through scaling the community, expanding the interactive repertoire, and scaffolding, we empower a variety of stakeholders to create models and curricula for localized needs, embracing learning designs and social behaviors to emerge.

Introduction

Powerful ideas are ideas that can be used as tools to think with over a lifetime (Papert, 1980). The idea of a complex system is inherently powerful. A complex systems perspective enables overcoming the deterministic-centralized mindset (Wilensky & Resnick, 1999), and provides a major opportunity to bridge the widening gap between our current best understanding in academia and the working knowledge of professionals, policy makers, and citizens (Jacobson & Wilensky, 2006). NetLogo, the most widely used agent-based modeling language (with hundreds of thousands of users worldwide), is a powerful tool to foster computational thinking with complex systems (Wilensky, 2001; Wilensky & Rand, 2015). However, its interactive design and visual representation is now two decades old, and it does not well support mobile platforms, which offer many new opportunities for learning (Sharples, et al., 2009). While a number of efforts such as NetLogo Web (Wilensky, 2015) or NetTango (Horn & Wilensky 2011; Horn, et al., 2014) have been designed to further scale NetLogo, there still exists much room for an innovative design to draw on the full power of the mobile age and empower all stakeholders.

While NetLogo is in widespread use, our belief is that there is great potential to significantly further scale the NetLogo community. In this poster, we report on a prototype implementation of NetLogo Mobile, a new modern interface to the NetLogo agent-based modeling platform, for which we are designing supports for a community for learners, teachers, and researchers. Our goal is to enable the community to 1) design, develop, and use agent-based models with a more intuitive and scaffolded interactive design; 2) share and discuss their models in an online community; 3) deploy their agent-based modeling experiences more felicitously including educational research-oriented features, 4) collaborate remotely through future design. To sum up, NetLogo Mobile is designed to serve both informal and formal learning, students, citizens, and researchers, aiming at a wide social impact.

Design principles

Focus on the constructionism goal with a mobile-friendly interactive design

Following Logo's example, NetLogo is intentionally built upon constructionist principles (Papert, 1980; Wilensky, 2001). Hence it is our main goal to not only maintain the existing constructionist features and the ability to build an endless variety of simulations, but expand the degree of freedom with a mobile-friendly interactive design. Stakeholders may construct both agent-based models and *interactive curricula* around it; distribute, fetch, and remix them through the built-in online community; draw upon not only the current NetLogo models library and modeling commons, but also a rich library of templates, visual/audio representations, and code snippets. We aim to empower the community to create a mobile-friendly experience with a standardized set of design primitives scaffolded by intuitive interface design and abundant resources from the community.

Leave important design decisions to stakeholders as much as possible

While we are significantly expanding the interactive repertoire of NetLogo, e.g., by introducing a 3D rendering layer and Augmented Reality (AR) support, the nature of learning requires us to maximize stakeholders' design repertoire. By allowing variations in a massive online learning community, we expect a large number of emergent learning designs targeting at different localized contexts and needs. Highlighted features include:

- To create, design, and modify agent-based models in either block-based or text-based editors, or both;
- To switch between realistic 3D, simplistic 3D, or vanilla NetLogo 2D graphics, with or without AR;

- Customizable interface widgets for users to draw upon with a standardized design.

Empower researchers to study a massive audience with research-oriented features

While NetLogo Mobile aims at a massive audience, it is also designed for researchers to study its use. We intend to build several research features into it, including a) contextual surveys, b) session recording and analysis, 3) automatic A/B testing, 4) full privacy control and electronic IRB consent, in order to empower researchers with features available in both localized or general environment.

Current progress

At the time of this abstract, we have created a full-scale working prototype of NetLogo Mobile, received feedback from fellow researchers and another online constructionist learning community (Physics Lab AR) informally. It is compatible with the models library of NetLogo Web and smoothly runs all models without modification. It supports Windows, Mac, iOS, and Android platforms. The poster will be accompanied by an interactive demo.

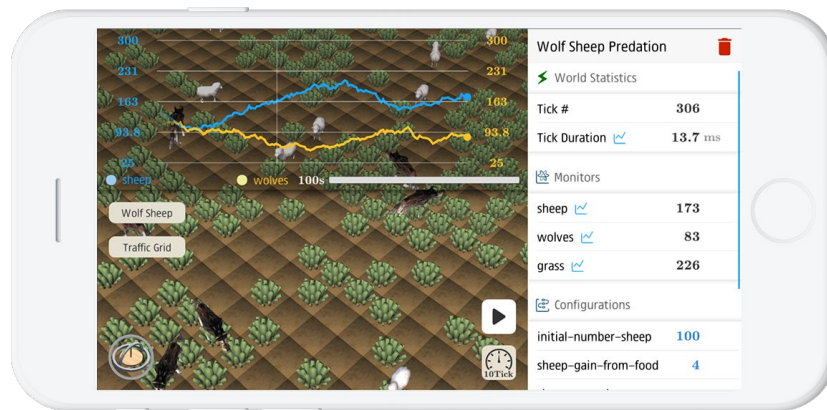


Figure 1. Screenshot. Note the real-time 3D rendering in phones & tablets and mobile-friendly UI.

Future work and implications

NetLogo Mobile is planned to launch an initial release in 2020, with the expectation that it will continue to develop for years to come. We expect that its instrumentation for research studies will lead to realizing its full potential. At this time, we are particularly interested in: a) the emergent learning designs for localized needs and their effects on learners; b) how to convey the powerful ideas in an informal, online, and massive setting; c) the emergent social behaviors in its learning community and how we can design to better support them.

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Toward a Nodal Design: Relational Design Across Scale

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Abstract: This poster presents emergent theorizing about designing for human relationships across scales with sustained attention to historic power relations expressed through and within learning environments. Early development of the premises for a nodal design prioritize honoring difference, working with cultural ways of knowing, remaining clear-eyed about power relations, recognizing representation is necessary but not sufficient, and insisting upon reciprocal and mutual learning across positions available within participatory design methods.

Some methodological premises

To open, I begin with a set of methodological aims expressed as questions I have been pursuing through twenty years of work with youth and families seeking to shape their lived circumstances. What methods can organize us to be fully responsible for the following seven stances?: (1) honor difference, and at times disruption, (2) work with cultural ways of knowing, (3) remain clear-eyed about power relations, (4) recognize our roles in living the Belmont Principles guiding human subjects research—respect for persons, beneficence, and justice, (5) organize for collective *and* individual ethical development, (6) recognize representation as necessary but *not* sufficient, and (7) insist upon reciprocal and mutual learning and change. Let us think broadly about marginalization and its historic reach. Think of people grappling with marginalization and the historic consistency of these conditions, despite shifts in representational evidence over time. Think also of people who live as bystanders, not actively aiming to marginalize others yet not particularly aware or concerned with marginalization as a thread in the collective fabric. Meanwhile, less contentious meritocratic and more contentious supremacist logics operate to normalize, accept, justify, or produce marginalization. And yet, conditions arise—even where, we are often told, they are not supposed to—that draw people out in our fullness and insist the arc of our development, regardless of our relative sociohistorical positions, draws toward mutual contribution and evidence of magnificent possibility. This bit is often denied, rendered exceptional, or remains unremarked, invisible. How can design methods generate sufficient momentum to pull against this current?

Relational design discourses and potentials for mutual development

These questions have led me to review the range of relational design discourses that have constructed much of our field's engagement, and in turn, my engagement with the methodological family of design as conceptually and practically central to inquiry into learning environments in which people's lives and practices are frequently held, guided, neglected, abandoned, and even changed. Emphasis on relational discourse intends to grapple with dynamics of discerning, navigating, and re-organizing mutual power relations while engaging in informed design processes that prioritize exchange among participants as designers. Iterative and user-centered design were among my earliest course-related encounters with design as a student, and they easily allowed me to incorporate my prior experiences of design into my practice. Yet their engagement with power relations can be rendered optional, providing necessary methodological practice but not sufficient to address the persistence of marginalization. Because my lines of inquiry have asked how and when families, youth, and community organizations negotiate participation rights and contradictions (Rosaldo, 1997; Engeström, 2011), engage in advocacy, civic practice, and political development, my design practice has consistently been rooted in ethnographic methods and participant observation as critical means for learning how varied communities construct meaning and negotiate relationships (Hawkins & Pea, 1987; Barab, et al., 2004; Bang & Vossoughi, 2016; Hoadley, 2017). Community organizing projects with youth and families have frequently involved critical pedagogy, participatory action research, and youth participatory action research (Boal, 1974; Freire 1982; Cammarota & Fine, 2008). Yet in varied communities, interest in participating in design as a research process has varied. In these cases, social design experiments that “expand learning” through reorganized community practice (Gutiérrez & Jurow, 2016) and partnerships that allow for mutual appropriation (Downing-Wilson, Lecusay, & Cole, 2011) have effectively aligned theory and practice while honoring community commitments. More recently, Escobar's (2017) ontological design has been instructive in working with complex, multi-vocal and intersecting communities, addressing the possibility of “many worlds existing within a world.” Each of these addresses a core component of relational design discourse that can insist upon reciprocal and mutual learning.

Problems of social pattern maintenance: some sticking points

It is heartening to follow trajectories that have led to the development of participatory design research methods, and yet social pattern maintenance remains a formidable challenge where marginalization is the pattern. Losing sight of core structures of power relations raises some sticking points and conundrums, and three of these are particularly salient for our field. First, a unidirectional focus on people as participants, subjects, or students representing particular groups or social conditions results in a form of persistent “gaze pressure” that undermines the potential for reciprocity and mutual development. This is often fueled by developmental logics that frame who is understood to be “advanced” and who is not in linear and often age-graded fashion. A second is what I refer to here as sticky dualisms. Consider, for instance, the subject positions of designers and makers versus users, consumers, participants, or learners. Particularly with mediators of production, selection, and circulation, these persistent binaries frequently render mechanisms that re-instantiate power relations invisible. A third is the appeal of for-all strategies. While the aims of such framings are admirable and important to develop, the challenge is revealed when this type of framing becomes an easy place to lose sight of historic power relations and to allow for a sort of neutrality to emerge that delays moves necessary to deal with injustice and to deal with equity.

Theorizing nodal design

A key opportunity of the learning sciences is the field’s access to influencing the design of learning environments “at scale.” Yet, when relationships are given full attention alongside a commitment to attendant power relations and ethical opportunities for learning and development, relational scaling and its socio-historical production (Bronfenbrenner, 1977; Neumann, 2009) demand a distinct and carefully theorized framing that can speak in the register of design. I draw on cases from two distinct approaches to university-community partnerships—one addressing democratic practice in daily life and the other addressing participatory access to land, water, and activity—to illustrate a design process I characterize as “nodal design.” Here, I use nodal as a metaphor, referring to the location (node and anti-node) on a material, such as a xylophone, metal pipe, or wooden dowel, where wave vibration has minimal amplitude, allowing a resonant tone (note that I am not a physicist and request a bit of grace for the limits of my description). Nodal design offers form and creates place for practice, yet strives for the lightest touch, the least limit possible on the flow of our lives, hearts, and minds, while reckoning with historic power relations and hegemonic habits and finally, that sustains and adapts relational work as ethical work. Here I have laid out a history of our field’s approach to design-based research while holding close attention to scale as a relational problem that operates beyond infrastructures for broad dissemination. Nodal design prioritizes the free movement and expression of people while addressing historic and persistent needs for repair in our learning environments. It offers tools for theorizing relationships first at the smallest person-to-person interactions and up through community, organizational, and institutional relations.

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Workshops

Pre-Conference Workshops

Improving Science Education Through Interdisciplinary Collaborations Between Learning Sciences and Discipline-Based Education Research: A Workshop for New and Established Interdisciplinary Researchers

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Theme and goals of the event

Although interdisciplinary collaborations between learning sciences (LS) and discipline-based education researchers and can be particularly fruitful for improving our understanding of how students learn and understand science, these types of collaborations tend to not form naturally. We propose holding a workshop designed to connect LS and DBER researchers interested in science, particularly biology, education together and equip workshop attendees with the language and skills necessary for successful interdisciplinary collaboration. Our goals for the event are to help participants explore disciplinary differences, build strategies for interdisciplinary collaborations, learn about current interdisciplinary research efforts, and network with other participants.

This event will be facilitated by three experienced researchers (Dr. Melanie Peffer, University of Colorado Boulder; Dr. Kristy Daniel, Texas State University; and Dr. Anita Schuchardt, University of Minnesota) who have expertise in both LS and DBER in biology. Our team has received an invitation from the National Science Foundation to submit a conference proposal to support travel of up to 24 participants to this workshop, in addition to supporting the travel of up to four panellists to speak at the workshop.

Theoretical background

Interdisciplinary research is distinguished from other forms of collaborative research in that it relies on a synergistic combination of viewpoints to solve a problem. Rather than individuals from different backgrounds approaching the same problem using the practices of their home discipline, different perspectives are combined to create an altogether different view. Our prior work (Peffer & Renken, 2016) used a prism analogy to present a model of interdisciplinary science education research where individuals interested in science education from a variety of disciplines, namely LS, DBER, and teacher educators are represented as a rectangular face of the prism. When synergistically combined with the others, the triangular ends form, representing, for example, novel theories and innovative pedagogical practices. Similar to how a prism is used to bend light to create a rainbow, without each constituent or face of the prism, the novel product would not result.

Recent studies and advances in the field of biology education research suggest that collaborations between LS and DBER researchers may be particularly fruitful for improving our understanding of how students learn and understand biology. Results from the literature (e.g. Coley & Tanner, 2015; Dowd, Thompson, Schiff, & Reynolds, 2018) have demonstrated that the synergistic combination of these perspectives can lead to the generation of new theories and development of new pedagogical strategies, resulting in increased understanding of learning in biology. This interdisciplinary perspective draws from content and cultural knowledge of DBER in biology and understanding of human learning by LS and fits in with calls by the National Research Council and others for the “second generation” of DBER (Dolan, 2015; Singer, Nielsen, Schweingruber, 2012).

Although there are a few examples of interdisciplinary work in biology education as defined here, it is relatively uncommon. If interdisciplinary research is a valuable method for generating novel research questions and new knowledge about biology learning, why is it not more common? As discussed in Peffer and Renken (2016) although the two communities share the goal of understanding learning, collaborations tend not to occur naturally between LS and DBER researchers for several reasons including differences in training, methodologies, and practices. For example, the use of the word *theory* varies widely between psychology and biology. The field of biology is united by several unifying theories such as evolutionary or cell theory. Therefore, in the practice of biology research it is not necessary to give a theoretical framing as part of a research manuscript. This is in stark contrast to educational psychology, where multiple theories such as behaviorism or constructivism can be used to describe learning, and research manuscripts often include extensive theoretical framing sections. Consequently, when those from a biology or DBER background are asked to give a theoretical framing for research, there is often confusion.

Another example identified by Peffer and Renken (2016) that is particularly important to consider with interdisciplinary collaborations between LS and DBER is the animosity between the so called “hard” and “soft”

sciences. Peffer and Renken (2016) contend that part of this animosity stems from a fundamental misunderstanding of the diversity of scientific practices. For example, although biologists pursue measures such as using inbred mice reared under precise conditions to minimize variability in research, this is not ethically possible with human subjects in noisy classrooms. The lack of stringent control can lead to more variability in results and the perception by DBER that social science research is not rigorous. Furthermore, LS and DBER are often housed in different units within universities, contributing to siloed perspectives.

Relevance to the field and conference theme

As stated above in the theoretical framing section, interdisciplinary collaborations between LS and DBER tend to not occur naturally due to a wide range of barriers. However, these collaborations are particularly beneficial to improving our understanding of how people learn science. Therefore, this workshop would facilitate these types of collaborations, equipping members of the LS and DBER communities with the skills to collaborate successfully and increasing contact between the two disciplines. Our workshop will enable cross talk between two disciplines that can struggle to connect naturally, enhancing research in both fields, both by intentionally connect researchers from different fields with one another and equipping participants with the skills to engage in successful interdisciplinary research. Furthermore, given that the academic interests of members of the International Society of the Learning Sciences represent a large number of disciplines (Yoon & Hmelo-Silver, 2017), the skills fostered during the workshop are relevant to the entire community, and not just those interested in science education research. The timing of our workshop prior to the main conference, and associated shifting disciplinary perspectives of attendees, may also improve their overall conference experience. For example, increased attention to disciplinary differences may make various sessions more accessible and/or facilitate the genesis of new collaborations.

As stated in the description of the conference theme, the learning sciences as a field is historically interdisciplinary. Our proposed workshop “draws on and highlights the ways our understandings of learning can be deepened” through activities designed to allow researchers from different backgrounds to explore the same data set and share different methodologies, theories, and perspectives for interpretation of that data. Since there are some who already engage in interdisciplinary collaborations between DBER and LS, and we intend to invite both established and early career researchers to participate, the activities in the workshop will also have “an eye toward opening new conversations and enriching existing ones.”

Expected outcomes and contributions of the event

A survey that attendees would complete at the end of the workshop will be created to assess outcomes of the workshop. The survey will assess how participants’ views have changed about LS, DBER, and interdisciplinary collaboration. For example, prompts could include: Describe in what way you see value in conducting interdisciplinary research; What is something that you learned about doing interdisciplinary research that you have not previously considered? Information collected on the survey would provide insights into aspects of interdisciplinary research that are not intuitive and are therefore important to target during future professional development efforts. We also intend to share the perspectives and outcomes of the workshop through a meeting report allowing the insights and strategies on interdisciplinary collaboration generated in the workshop to reach a broad audience. Furthermore, since the challenges to interdisciplinary research between LS and DBER are not unique to biology, but to all interdisciplinary collaborations in STEM education, the findings may generalize to other STEM disciplines therefore leading to improve educational outcomes across the STEM spectrum.

We anticipate that by the end of the workshop, attendees will be convinced of the value of interdisciplinary research and be intent on pursuing interdisciplinary research in their future endeavours. Since many of the workshop participants will likely be mentoring graduate students, it is expected that learning about the perspectives of another field and productive interdisciplinary collaboration strategies will benefit the next generation of researchers. LS researchers who teach biology preservice teachers and/or mentor graduate students in biology education will be able to couch LS theories and methods within a disciplinary perspective and share strategies learned for productive collaboration with their students. This interdisciplinary approach will facilitate applications of theories and methods to classroom practices, leading to broader application and possibly new pedagogical strategies. Many biology education researchers teach undergraduate students and by applying the LS perspectives to their classes, they will be better able to explain to students why pedagogical strategies are successful, allowing students to understand their purpose and facilitating generalization of these strategies to the students’ other classes. We also expect that working in small groups and the networking activities will facilitate communication between the two disciplines and foster the genesis of new ideas and potential future collaborations.

Since we are pursuing funding from the National Science Foundation to support travel of up to 24 attendees from both the DBER biology and LS communities to attend the workshop, this may facilitate attendees

at ICLS from outside of the LS who either would not typically attend, or who lack the institutional resources to do so.

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Expanding the Field: How the Learning Sciences Might Further Computing Education Research

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Theme and goals

Learning Scientists have been leaders in the field of Computing Education Research (CER) since before the organized field of the Learning Sciences even existed. Roy Pea, Marcia Linn, Andy DiSessa, and Elliot Soloway all made early and foundational contributions to CER (Pea, 1986; Linn, 1985; DiSessa & Abelson, 1989; Soloway, 1985). Despite this early leadership, the theoretical and methodological bases of CER and LS have drifted apart, and many rich ideas from LS are absent from the zeitgeist in CER (Margulieux, Dorn, & Searle, 2019). *The goal for this workshop is to invite the LS community to work with members of the CER community to identify key ideas, theoretical frameworks, design principles, and empirical work relevant to critical questions and challenges of CER. We see this activity as developing an LS-driven roadmap for expanding CER. That is, if Learning Scientists were to shape a research agenda of the CER community, what are the new questions that could be answered and what foundational theories, frameworks, and methods would be key in deriving those answers?* We hope that this research agenda contributes to CER while providing new opportunities for Learning Scientists to build upon their research.

Theoretical background

The history of LS is one of simultaneous rejection and integration. Foundational to LS is the rejection of the idea that learning, or interventions to support learning, can be studied outside of “blooming, buzzing confusion” of authentic contexts of practice (Brown, 1992). Early learning scientists instead sought to develop theories, methods, and exemplars of research that integrated ideas and approaches from anthropology, psychology, cognitive science, computer science, and design (Hoadley, 2004). LS research typically involves attention to how learning unfolds in context, including careful scrutiny of how individual characteristics interact with the social, cultural, and material organization of the learning environment. Within this framework, LS researchers attend to how individual psychological factors shape and are shaped by participation. They do so while also analyzing the ways in which that participation is shaped and shapes social processes that construct the environments and communities that mediate activity (Cole, 1998).

Learning Scientists have been particularly attentive to design of learning experiences, tools, and environments -- what it means to design, what we can learn by doing it, and even how we can effectively describe it (Edelson, 2002; Sandoval, 2014). Design is part of a research methodology that has become a central and defining aspect of the field--Design-Based Research. Fundamental to Design-Based Research is the notion that designs instantiate theories of learning, and that the process of developing and analyzing the results of instantiating designs is theory development work. Designed enactments are, in this view, reifications of theories, and analysis of those enactments enables theory refinement through (among other means) comparisons between what was expected and what was observed. Inasmuch as all design work is motivated by designers' intents for what ought to happen or be supported by a designed tool (be it a physical or virtual artifact, process, or environment), all design work in education can be conceived of as both drawing upon theory and potentially contributing to it. From this view, it also follows that rich, contextual descriptions how designed enactments unfold are at least as valuable as quantitative evaluations of those outcomes.

In many ways, CER is poised for the same simultaneous rejection and integration that LS experienced when it split from cognition-focused conceptions of education. Historically, much of CER work is split between 1) action-based research in both K-12 and higher education focused on design and evaluation without aiming to contribute to theory and 2) experimental research primarily conducted in higher education courses focused on building theory but without much leeway to radically change course design. Whether as a result or as a cause of this split, CER publications tend to favor either experience reports focusing on improving practice or theory-based empirical papers discussing the average effects of an intervention on performance. As more types of stakeholders engage in CER and as the opportunities to study computing education become more plentiful and varied, CER is looking for theories, frameworks, and methods to bridge this split and engage in research that

both builds theory and considers a more holistic representation of the learning environment and learners. We believe that Learning Scientists are particularly suited to building this bridge and that CER offers unique opportunities further Learning Scientists' research agendas, such as those about identity and equity.

Critique of computing education research today

Computing Education Research today is primarily published outside of venues populated by Learning Scientists. The most popular peer-reviewed venues for publication of computing education research include Association for Computing Machinery's (ACM) conferences, like SIGCSE Technical Symposium and International Computing Education Research (ICER), and journals, like *Transactions of Computing Education*. Other popular non-ACM venues include *Computer Science Education* and *Computers & Education*.

While Learning Sciences perspectives on educational research do sometimes manifest in research appearing in these venues, it is more typical for research in these spaces to represent more traditional cognitive and educational psychology perspectives. These perspectives explore the individual learner's role in learning, particularly focusing on cognition and what is happening in the brain, and primarily view other aspects of the learning environment as potential sources of error. As such, methodologies emphasize AB testing with as much error as possible removed from the experimental environment to better isolate variables related to the theory being examined. This approach to education research is the same approach that LS rebelled against when it split from cognitive science. Learning Scientists viewed authentic learning environments and sociocultural and historical perspectives of learners and their communities as critical components of education, in addition to cognition. As such, they sought to include these components of learning in their theories and formed a community that valued this approach.

Within the CER community, researchers are pushing against this narrow view of learning theory as well. This sentiment is highlighted in Nelson and Ko's 2018 ICER paper that critiqued CER for focusing too much on theory. The authors had three main critiques of the work on theory in CER, first that work on theory distracts from designing and testing quality interventions, second that there is a lack of domain specific learning theory applied to CS education research, and third that bias toward theory among peer reviewers prevents publication of literature reporting on design intervention.

Kafai, Proctor, and Lui (2018) took issue with Nelson and Ko's representation of learning theory. Rather than focusing on potential negative bias toward theory they highlighted how a broader idea of learning theory is often used in CER and gave attention to how we might address this better in future research. Much of this emphasis was on the diversity of theory, that was overlooked by Nelson and Ko, and how this diversity could inform CER. In this workshop, we seek to lay out the 3 divergent bodies of theory work cited by Kafai et al, "(1) skill and competence building, (2) creative expression and participation, or (3) social justice and ethics" and how they might better inform CER.

In addition we seek to identify other ways that theory can be better integrated and communicated within the CER community.

Our position here is not to suggest that CER should be left only to the Learning Scientists, nor to exclude CS experts in research on computing education. We need ongoing conversation between Learning Scientists and Computer Scientists who are not educational researchers in order to ensure that computing education does not drift away from the intellectual vitality of CS. Computer Scientists must be part of the conversation of what computing education is about. However, we also acknowledge that decades of Learning Sciences research has made it clear that determining *what* is to be learned is intimately tied up in *how* and *why* it is to be learned. Consequently, while CS voices are absolutely vital to productive and meaningful CER, LS scholarship is necessary to situate potential content and practices in meaningful contexts and sociopolitical systems.

Relevance to the field and conference theme

The workshop directly addresses the conference theme, The Interdisciplinarity of the Learning Sciences. Computing education currently happens through two primary framings: computer science for computer scientists and computing in other disciplines. The latter is fundamentally interdisciplinary, but the former tends to adopt only cognitivist theories and methodologies to study how people learn, commonly in an introduction to programming course. As a result, many theories in CER that describe how people learn computer science and programming are disproportionately based on undergraduate computer science students in large introductory courses. The approach makes sense as many CERers are computer scientists teaching in departments of computer science and their introductory courses have large sample sizes to test interventions. Our goal for this workshop is to identify viable alternative approaches to conducting research, finding collaborators, and measuring outcomes that enables CERers and Learning Scientists to expand and integrate their research

agendas. We can help CER to adopt more interdisciplinary perspectives and practices, and by working with CER, we can gain knowledge about the nature of knowledge and how to design and study learning environments.

Expected outcomes and contributions

The primary objective of this workshop is creating a LS-inspired research agenda for central questions in CER created collaboratively by Learning Scientists and Computing Education Researchers. To achieve this objective, the workshop will require peer education between the two groups. We want to educate CERers about LS theories, frameworks, and methods and educate LSists about CER problems, existing work, and contexts. By bringing both perspectives together, we can expand the impact of both groups. To maximize time spent at the workshop collaborating, each attendee will be asked to solidify their goals for the workshop beforehand by submitting a position paper. During the workshop, we will use these position papers as starting points for discussions to build upon. We intend for the outcome of the workshop to be a short series of position papers for a special issue to appear in a CER venue like ACM TOCE or Computer Science Education. Recently, review papers and position papers have been of increasing interest and publishability in the CER community as it reflects on its progress and considers the most impactful strategies for progress (e.g., Denny et al., 2019).

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Communicating Design-based Research: A Workshop for Creating and Interpreting Design Arguments

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The proposed NAPLeS-sponsored workshop involves individual and community skill-building in the communication of design-based research. Over the past several decades, design-based research (DBR) has become a central methodological tool for the Learning Sciences (Anderson & Shattuck, 2012; Barab & Squire, 2004; Barab, 2014; Bell, Hoadley, & Linn, 2013; Brown, 1992; Design-Based Research Collaborative, 2003; Sandoval & Bell, 2004). During this time, and continuing today, researchers have made strides in defining DBR in both its practice and philosophical underpinnings (e.g. Easterday, Rees Lewis & Gerber, 2016; McKenney & Reeves, 2018; Sandoval, 2014). However, while the increase in popularity and discussions about rigor have begun the process of standardizing DBR as a methodology, there is still a lack of specification when it comes to *communicating* DBR. In other words, the field of learning sciences has moved from defining what DBR is to detailed descriptions of how to do it, but we still struggle with how to talk about it. This is despite an increased call within the learning sciences for well-articulated examinations of DBR, including its processes and outcomes, both positive and negative (Kali, 2016; Svihla & Reeve, 2016). In order to increase the impact of DBR studies we need more specification in how researchers compose, encode, and transmit descriptions of their DBR projects and how the community receives, decodes, and interprets those descriptions. Yet, the nature of DBR—its focus on iteration, its recursive nesting of multiple data collection techniques (Easterday, Rees Lewis & Gerber, 2018), and its atypical products—make it difficult to communicate within the constraints of traditional academic articles. To make decisions about “what works” (for whom and under what conditions) from a highly contextualized methodology, we need the ability to unpack the logic of the study, pull out key pieces of information: not just quantitative details (like effect size, p-value, etc.) nor just qualitative details (like coding scheme, theoretical framework, etc.) but the specific learning theories, context, design principles, and research methods. We then need to understand how these details align with one another to form a *design argument*, a logically reasoned message describing how people should learn.

The main goal of this workshop is to improve how we compose and interpret design arguments. To that end, we welcome both novice and experienced design researchers to participate in this interactive workshop. Participants will work together to deconstruct design arguments in prior literature to understand the strengths and weaknesses of current DBR communication. They will have the opportunity to share their own in-progress work and to collaborate with other participants and the organizers to improve how they talk about their design. In this way, individual participants will develop skills as both producers and consumers of design research. At the community level, our discussions will contribute to ongoing work about the development of a framework for communicating DBR that aims to increase the standardization of DBR reports. Furthermore, we stress that although DBR is a core method taught in a majority of Learning Sciences academic programs, DBR training is not available to students in all programs (Sommerhoff et al., 2018). Therefore, in this workshop we would like to offer our expertise on conducting and teaching DBR to both students and teaching staff of Learning Sciences programs.

In her recent ICLS keynote, Kali (2016) urged researchers to clearly articulate the *entire research process* rather than focusing solely on the “successes” and to include “the non-linear, often surprising and sometimes frustrating process of design research.” While there have been increased attempts to discuss these processes (Svihla & Reeve, 2016; Tissenbaum & Slotka, 2019); as a whole, there has been very little focus on how effectively and consistently communicate DBR.

This is a serious need as there are major challenges to effectively communicating DBR. First, the varying scales and stages of DBR mean individual descriptions of research do not necessarily capture the breadth of the research. In DBR projects there is “too much story to tell” (McKenney & Reeves, 2018, p. 201). The iterative nature of DBR results in write-ups that (necessarily) focus on a small portion of the research—sometimes one or two iterations, but rarely more than that. In addition, the emphasis in publications can often only be on one aspect:

the theoretical developments; the impact of the intervention on learning outcomes; or the nature of the design (and possibly its iterations) itself. Unless researchers turn to alternative modes outside of academic journal articles (McKenney & Reeves, 2018), this results in a fragmented literature, requiring putting together multiple papers, each framed to make a unique contribution, in order to “grasp” (and then evaluate) the full impact and use of the methodology.

Second, the products of the research are (or should be) arguments for how people should learn (so both theory-driven and theory-producing). However, there is no agreed-upon way for presenting such arguments. There are some that have been proposed in the literature (e.g. van den Aaker, 1999; Sandoval, 2014). However, these approaches only cover a small subsection of the logic needed to make design arguments. For example, Sandoval’s (2014) *conjecture mapping* is a useful tool for explicating the alignment between theoretical perspectives and design commitments, but this alignment is only part of a design argument, and leaves out how to derive conjectures from broader theory or specify contextualize needs. It is particularly difficult for novice design researchers to use such tools to inform their own projects or judge arguments they find in the research literature. This is the very reason we need an agreed-upon communicative DBR framework: a lot of arguments are flawed simply by leaving some aspects of the argument implicit. These arguments are often piecemeal or fractured and are therefore difficult to interpret or judge. Furthermore, the lack of clear communication of design arguments leads to undertheorized DBR and ultimately to bad research.

Finally, the lack of standard accounts for DBR results in major barriers of entry for new or less experienced writers and readers. Engaging in academic discourse requires an understanding of the specific genres employed by the community (Marshall, 1991; Swales, 1990), which in turn requires specific rhetorical skills. From a pedagogical perspective, new learning scientists require a heuristic to analyze DBR texts both as a means to judge them and to assist them in creating their own texts (Bruce, 2008). However, there has been very little work in understanding DBR as a genre of academic writing, so less experienced readers and writers often struggle to understand and use the products of DBR. This also leads to issues in convincing key stakeholders of the value of DBR. For example, Edelson (2006) complains that a lack of methodological clarity in DBR makes it less fundable and harder to know what a “good” proposal looks like. Recently, McKenney and Reeves proposed a checklist for writing DBR proposals (2018, p. 198), which provides a useful way to plan DBR studies at the outset. In this workshop we seek to build upon this work to provide a framework which helps analyze and communicate design arguments, the theoretical products of DBR.

We argue for the need for a standard way of *evaluating* DBR proposals, methods, and findings (i.e. design arguments), and *presenting* them such that they can be evaluated. In the words of Swale (1990), we need to know “what is sayable and how and when it is sayable” (p. 88). Therefore, this workshop is a necessary first step in coming together as a community to understand and improve how we communicate one of the key methodologies of our discipline.

In this workshop, we will present and refine a framework for communicating and analyzing design arguments in a more standardized way that both producers and consumers of design research can use to make sense of the products of design research. This framework is meant to be flexible rather than dogmatic or prescriptive. It does not tell you how to do DBR or provide a template that a design argument must strictly follow. Instead it will provide a skeleton to make and judge arguments about designs for learning.

Accordingly, we view outcomes of this workshop to be three main applications of this framework: Research, design, and evaluation.

Research. The first outcome is the development of a flexible and shareable structure for linking theory and design to produce usable knowledge. This begins the process of standardizing the presentation of design arguments in academic write-ups. It also fleshes out the “big picture” of DBR, so that even if a particular article or presentation focuses on a single aspect or iteration, the larger context of the DBR is still clear and explicitly communicated.

Design. The second outcome is a refinement in the way we make design decisions. It illuminates how existing design frameworks/processes “fit” into DBR. It also provides explicit delineation between various aspects of the research/design cycle, so that the alignment between design and theory is distinct and connected.

Evaluation. The final outcome is providing a way to analyze design arguments (proposing and then answering meaningful questions about designing for learning); and a way to unpack assumptions in the design (and study design) process. This can actually help multiple audiences: training novice learning scientists on how to analyze and unpack DBR; helping learning scientists more quickly communicate/avoid reinventing the wheel; helping teachers understand the messages they receive about using certain educational innovations, tools, or technologies in their classrooms; providing support for parents/teachers/administrators etc attempting to appraise commercially available learning technologies; and offering tools for other stakeholders (e.g. funders) to evaluate proposed DBR studies and assess their products.

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Researching the Ecologies of Interdisciplinary Learning

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The recent decade has brought a significant shift in curriculum focus from disciplinary learning to various interdisciplinary learning options. STEAM projects, innovation-focused courses, and similar project-based programs have become widespread in schools and universities. However, research and design for interdisciplinary learning are challenging, fragmented and lags behind institutional decisions that change practice.

This workshop aims to create opportunities for the learning scientists interested in interdisciplinary learning to share their research questions and challenges and expand their theoretical and methodological approaches. It seeks to make connections and extend theories and methods that are established in the learning sciences with theories and methods from other fields that have been studying different aspects of interdisciplinary practices in the workplace and research settings.

The workshop will cover and integrate conceptual, methodological and design aspects of interdisciplinary learning. It will be structured to explore the ecology of the field at four broad levels: institutional, curriculum, group and individual. Plenary activities will explore cross-cutting questions across these levels.

We expect that ideas discussed in this workshop will provide a foundation for developing a special journal issue that synthesizes current approaches and charts a future research agenda for studying interdisciplinary learning.

Analyzing Learning with Speech Analytics and Computer Vision Methods: Technologies, Principles, and Ethics

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Theme, goals, and expected outcomes or contributions

We propose a half-day workshop about video and audio data collection methods that allow researchers to effectively use emerging analytical methods that leverage speech analytics and computer vision techniques, in combination with human-focused analysis (e.g. qualitative analysis). The main goals for participants attending the workshop are to:

1. Become familiar with innovative computational methods (e.g., computer vision and speech analytics) that can be used directly with audio and video data, and consider how computational methods can be used with human-focused analysis to develop new theory in the learning sciences.
2. Understand which features of audio and video data have a large influence on whether computational methods can be applied successfully.
3. Develop principles and strategies for collecting audio and video data in learning environments that increases the successful application of computational methods, including equipment positioning, recording formats and codecs, and equipment features or specifications.
4. Consider ethical implications of using innovative computational methods, both in terms of ethics of conducting research with these methods and potential uses of these methods for education practice and policy.
5. Contribute to a collective methodological research agenda and goals for future development of existing computer vision and speech analytics methods for learning sciences research.

The primary outcome of the workshop is for participants to be able to make informed decisions about collecting audio and video data of learning that will make it possible to use computational methods in analysis. The session will also produce a methodological research agenda for improving the computational methods in their applications to research questions and data used in the learning sciences.

Relevance to the field and conference theme

The learning sciences has a long history of using video and audio to examine processes of human interaction that unfold over time (Goldman, Zahn, & Derry, 2014). Video enables researchers to capture longitudinal data on processes that unfold over time and at multiple time scales, leading to analyses that consider connections between micro- and macro-level phenomena. Video and audio data, in conjunction with multi-modal records of activity, continue to be a central data source in learning sciences, particularly for examining social processes of learning and development.

As capturing and storing video data becomes increasingly accessible and cost-effective, video is emerging as a dominant source of “big data” in the social sciences. Large video databases allow researchers to see social phenomena first hand and provide both breadth in timespan (footage that spans weeks or months of activity) and detail (a rich moment-to-moment interactional and spatial record; Goldman et al., 2014).

Despite the promise and opportunity to use video data in new ways, analytic methods and tools for video have lagged behind innovations in data collection methods, data analytics, and visualization. Video research often relies on processes developed for text-based data (e.g., creating and analyzing transcripts), essentially hiding the temporal and visuospatial dimensions of the data. These traditional analysis methods limit the ability to apply humans’ sophisticated visual processing, such as tracking movement over time or seeing relationships in spatially-aligned data points.

Recent advances in computational methods (e.g., computer vision, speech analytics) provide exciting new opportunities to improve the analysis of learning in video and audio data, particularly in large datasets. Some examples of these methods include automated detection of body positioning, emotion, gaze, collaboration, tone, speakers, and prosody. However, because these methods rely on computational power, which differs from human interpretive power, they have different requirements of the data quality and quantity. In the case of speech

analytics, computers are able to do many things, but if the wrong type of audio data is collected (e.g., using a lapel mic to try to capture whole class audio), the computational methods are limited in how well they can interpret the data (Richey, D'Angelo, Alozie, Bratt, & Shriberg, 2016). Additionally, speech analytics methods benefit from high resolution audio that may be almost indistinguishable for a human. With computer vision methods, it can be difficult for computers to identify a person over time if they leave the frame at some point in the video (Wu et al., 2019). Each of these examples represents concerns relating to the quality of the audio and video data that are unique to their use with computational methods. As a result, there are new considerations and principles for collecting video and audio data that can be successfully used with new computational methods.

We, along with other scholars, argue that computational methods are most powerful when integrated with human-conducted analysis and decision-making (Baker, 2016; Berland, Baker, & Blikstein, 2014; Nelson, 2017). These arguments come from a concern over losing the richness and complexity inherent in learning for the sake of convenience and scalability. Additionally, they recognize that humans and computers often have different analytical strengths. For example, Baker (2016) argues for relying on the computational system simply for reporting relevant, low-inference information and patterns, which humans can use for higher-inference analysis to guide future action. We believe that these computational methods provide an opportunity for greater methodological interdisciplinarity when they are used in a methodological framework that combines computer- and human-focused analysis, such as computational grounded theory (Nelson, 2017).

Theoretical background

Learning environments are complex social systems in which learning—shifts in knowledge, its collective use, and the related patterns of interaction that demonstrate knowledge development in use—is an emergent outcome. Developing theory about learning requires understanding how interactive (i.e., social and spatial) aspects of classrooms are integral parts of student learning. For example, aspects such as the nature of collaboration, use of gesture and embodiment, the nuances of discursive tone and prosody, and student positional identities are important for understanding learning (Esmonde, 2009; Roth, 2001). This work has demonstrated the need for research methodologies to capture and represent the complexity and nuance in social and spatial aspects of learning. As such, researchers have consistently argued that video and audio data are especially well-suited to capture the visuospatial and acoustic features of interactive processes.

Current research methodologies require Herculean efforts to conduct analyses that simultaneously attend to complexity *and* nuance at a large scale, especially with video and audio data. There are strong qualitative traditions that actively attend to—and even prioritize—visuospatial and/or acoustic features (e.g., Jordan & Henderson, 1995), but these methods are incredibly arduous and time-consuming, making it all-but-impossible to carry out more than a few rich case studies. For example, qualitative studies that look across multiple contexts (e.g., comparing across 100 classrooms) and long time scales (e.g., tracking changes across multiple school years) are incredibly rare. In practice, video data are often reduced to text: transcripts of words spoken, which sometimes include meta-discursive markers or descriptions of gesture. This is a problem, as text is a poor representational form for capturing and communicating visual, spatial, and acoustic dynamics. However, the small repertoire of alternative representational practices for analysis reflected in the literature (e.g., multimodal transcription; Bezemer & Mavers, 2011) are incredibly time-consuming. These challenges to analyzing visuospatial and acoustic aspects of video are partly due to human limitations: people cannot simultaneously attend to all the multimodal dimensions of video and audio data systematically or recognize patterns in these dimensions, even with small data corpuses or a focused microanalysis. As a consequence of these challenges, we need new methodologies for analyzing the social and visuospatial dimensions of learning in video and audio data, especially with the potential to do so at scale.

Computational methods have shown promise for modeling and investigating complex phenomena with large corpora of data, including educational phenomena (Berland et al., 2014). For example, analytic techniques such as vector-space models, topic models, and deep learning/neural networks have all been applied meaningfully to educational research. Importantly, advances in applying these models to educational data sources show their potential for increasing coding efficiency (e.g., Liu et al., 2016), making analysis of large datasets more feasible; and they can be used to detect change over time (e.g., Sherin, 2013), making longitudinal analyses more feasible.

Recent advances in computer vision, coupled with existing speech analytics methods, make it feasible to identify theoretically and practically important features from video in ways that preserve the complexity and nuance that draws educational researchers to audiovisual data—particularly with respect to visuospatial and acoustic features of learning. As an example, computer vision techniques have advanced to the extent that it is possible to use 2D cameras to identify body positioning for multiple people in real time (*OpenPose*; Cao et al., 2017). *OpenPose* estimates the position of up to 135 key skeletal points (e.g., location of each ankle, finger, top of head, etc.) for individuals in still images and videos. It is robust to partial occlusion, which is key for

applications to many learning environments—for example, students might sit behind desks or be partially hidden from view by other students in front of them. OpenPose also produces visual representation of the skeletal points overlaid on video, as shown below.



Figure 1. Automatic detection of body positioning and visual overlay produced using *OpenPose*.

Similarly, previous research in speech analytics has developed successful feature extraction techniques for a wide variety of acoustic features, including detecting speech activity and a variety of spectral, temporal, and prosodic features (e.g., Boersma, 2002; Ghosh, Tsiartas, & Narayanan, 2011). These acoustic features have also been shown to predict the quality of small-group collaborations in mathematics problem-solving using exploratory computational methods (D'Angelo et al., 2019).

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Learning to Facilitate and Support the Exploration of Complex Socioecological Systems: A Teaching and Teaching Learning Workshop

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Join us for a full-day workshop that explores the following question: *How do teachers learn to support students' socio-ecological sense-making and ethical deliberation and decision-making through the intersections of phenological field-based science practices and family and community knowledges and practices?* This workshop stems from a National Science Foundation-funded project called *Learning in Places*. Using community-based design research, project partners seek to increase Kindergarten through third grade learners' opportunities to engage in complex socio-ecological reasoning and decision-making through the use of field-based science learning in outdoor places (e.g., learning gardens, parks, neighborhoods), and in ways that are intentionally connected to classrooms and students' families and communities. During this workshop, we will explore methodological innovations in professional development for supporting and studying teachers' learning as they work to better support student learning. The goals of the workshop include:

- Using project frameworks to analyze data of student and family thinking gathered from the use of instructional tools in elementary classrooms.
- Engaging with select project frameworks that embody elements of the overall project, as well as classroom instructional tools that those frameworks support, and then co-designing those frameworks and tools.
- Engaging with a research design for studying teacher learning at scale, as well as engaging with example associated data collection instruments and tools.

We are hopeful that this workshop will spark discussions about the possibilities and challenges (theoretically, conceptually, methodologically, and practically) related to supporting teacher learning at scale, learning specifically about complex socio-ecological systems, field-based science education, and nature-culture relations, and in ways that foreground power and historicity. What types of resources and other supports are needed to not only engage teachers in this learning, but to also see them begin to embody this learning in their pedagogical practices and decision-making to support student learning? We hope you will join us for explorations of data and tools, engaging theoretical, conceptual, and methodological terrain, and interesting and productive discussions.

Interdisciplinary Design and New Educational Technology for Engaging Learners in Role-based Simulations

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Theme and goals of the event

This proposed workshop's theme is exploring and innovating on the process of designing and implementing role-playing simulations in diverse educational settings through interdisciplinary design and use of new educational technology. As learning sciences researchers and learning experience designers, we (the workshop organizers) are often tasked with supporting instructional teams who desire to implement role-based simulations within their own contexts of teaching and learning. These contexts include K-12 classrooms, residential higher education learning settings, and asynchronous online learning environments. Frequently we are asked to provide guidance and support to new simulation designers as they engage in complex design processes. As we have observed these challenges, we are inspired to bring together a group of designers and researchers who are interested in delving into simulation pedagogies and exploring new tools for enacting complex designs. Through examples, hands-on participation, and discussion, we hope to surface insights regarding the design process, towards developing appropriate methods and processes for supporting designers of simulations.

We have outlined multiple goals, each tailored to the needs and likely interests of different groups of participants: novice simulation designers, experienced simulation designers, and workshop organizers (who are also experienced simulation designers).

For novice simulation designers, the goals of the workshop are to learn about simulation pedagogy, and to gain hands-on experience designing and participating in a role-playing simulation. Additionally, novice simulation designers will receive an introduction to the ViewPoint software platform, a web-based tool designed to support instructors in the delivery and facilitation of role-based simulations.

For experienced simulation designers, the workshop goals are to exchange perspectives and experiences with other simulation designers on defining learning goals, outlining design strategies, explaining debriefing and facilitation processes, and recommending approaches to student assessment. They will also receive an introduction to the ViewPoint software platform.

For the workshop organizers, the goals are to observe and document organic design processes related to simulation design, to collect ideas and suggestions about debriefing and assessment of student performance within a simulation, and to obtain comments and feedback on the ViewPoint software platform towards improving the experience for designers and simulation participants. Through this workshop, we hope to be able to improve the resources and guidelines that we can provide to both novice and experienced simulation designers.

Theoretical background

Many instructors—in K-12 settings and also in higher education—are embracing the move towards experiential learning (Cassidy, Charles, & Slotta, 2019). Simulation-based teaching approaches can immerse learners in complex contexts, such as those that imitate a system, phenomenon, or process (Lean, Moizer, Towler, & Abbey, 2006). Such approaches allow students to actively explore complex scenarios in settings where they may gather information, discuss and debate ideas, pose hypotheses, and arrive at conclusions with support from instructors and peers. Many disciplines such as health sciences, business, and law have a tradition of using educational simulations (Cook, Dow, & Hammer, 2017). But the idea of simulations as a teaching tool is gaining momentum and simulations are increasingly being seen outside of disciplines that have traditionally embraced them (Carnes, 2018).

Different types of simulations for learning are emerging within the learning sciences, including participatory simulations (c.f., Colella, 2000) and simulations for collective inquiry (c.f., Moher, 2006). Another approach that is rising in prominence within classroom learning environments is that of role-based simulations, where participants *act out* the role of a character who is embedded in a specific context or situation (Cook et al., 2017; Lean et al., 2016). Role-based simulations are similar to participatory and collective inquiry simulations in that students take on a role within a larger simulation context to explore some issue. The difference is that in role-based simulations, participants take on well-defined, identity-based roles and follow a set of rules specific to the context of the simulation that allow them to advance towards a specific goal or desired outcome (Cook et al.,

2017). Through interactions with roles and elements of the simulation, participants are able to represent aspects of the issue under study and influence the direction of the narrative.

Role-based simulations also have roots in serious games, in which designers lay out “an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement” (Abt, 1970, p. 9). Within serious games, participants can anticipate and experience the effects or consequences of action in an ill-defined problem space (Raybourn, Deagle, Mendini, & Heneghan, 2005). Serious *educational* games have similar qualities, but they also allow instructors to target specific learning goals and attempt to connect educational content with real-world scenarios (Annetta, 2010). Simulations are a form of serious games that allow participants to be active agents within a scenario and take actions consequential to the activity (Wright-Maley, 2015). Simulations allow students to engage in life-like scenarios that might otherwise be too costly or dangerous to reproduce and implement. In simulations that are enacted within learning contexts, learners can assume active roles through which phenomena are revealed (Wright-Maley, 2015). Simulations for learning also connect to Shaffer’s (2004) notion of epistemic games, in which participation within a simulation environment prepares students for engagement with real-world environments, by allowing them to consider real-world problems through the epistemic frame that they experienced within the simulation.

ViewPoint: Technology support for role-based simulations

Role-based simulations offer a powerful pedagogy for instructors in diverse educational settings to teach learners a wide range of hard and soft skills. However, simulations are also multifaceted and ripe for technology support as their effective use requires managing a range of participants, roles, resources, information streams, and communication. Role-based simulations may require 50% more time to prepare than a lecture (Lean et al., 2016). There are also significant demands on instructors during enactment, such as informing students of their roles and responsibilities, organizing and sharing relevant materials, and keeping time. Instructors may need to coordinate roles and resources using various tools such as spreadsheets, timers, and notes to ensure that the simulation runs smoothly. Demands are also placed on participating students, such as being required to step into a role or identity that may be different from their own, and communicating with other participants to make progress towards common goals. These authoring, implementation, and participation challenges have the potential to be mediated by technology (Grisoni, 2012), although few solutions currently exist.

Through this workshop, we seek to introduce the participants to ViewPoint, a web-based tool designed by the workshop organizers to support instructors in the delivery and facilitation of role-based simulations. ViewPoint is content agnostic and supports large-scale simulations that occur synchronously, asynchronously, or in a hybrid mode. Within ViewPoint, instructors can assign participants to roles and groups, create a timeline of events, queue content and messages, and include supplemental resources and materials. Instructors can also create branching timelines that are dependent on the outcome of simulation events (e.g., results of a poll or vote). In ViewPoint, participants can edit their role’s public-facing profile description, browse other participants’ role profiles, send and receive private messages, view external links, check and post updates in a public newsfeed, and view a timeline of past, current, and planned events in the simulation (see Figure 1). For instructors and researchers, ViewPoint also acts as an index to relevant information, such as role descriptions, group descriptions, timeline progression, and simulation outcomes.

Prior to the workshop, participants in the workshop will receive access to a ViewPoint account, including facilitator and participant views.

Figure 1. Left: ViewPoint interface showing where learners can view role description, groups and roles, and newsfeed. Right: Private messaging functionality of ViewPoint.

Relevance to the field and conference theme

The proposed workshop relates in a number of ways to the field of learning sciences and to the conference theme of *Interdisciplinarity in the Learning Sciences*. First, simulation design of the type that we will explore in our proposed workshop requires and integrates various aspects of learning sciences work, including instantiating social constructivist perspectives on teaching and learning (Palincsar, 1998), investigating matters of learning related to identity (Annetta, 2010), and providing an arena to discuss issues of diversity, equity, and inclusion (Lee & Hoadley, 2006). Throughout our presentation of our sample cases, within the pre-designed simulation that participants will explore, and as part of our whole group discussions, we will seek to foreground these aspects of learning sciences work and highlight the connections that participants are making from their own work and research to these topics. Finally, as a primary concern of the learning sciences is to investigate the potential role for technology to support learning, we will explore how simulation designers can support and scaffold these types of complex activities using various pedagogical approaches and technological tools.

Second, the goals of the workshop clearly relate to interdisciplinary design processes as well as interdisciplinary design products. The workshop is designed to expose participants to example simulations, and design principles and processes common to both their own fields and to other fields that may face similar challenges and opportunities. Workshop participants will work directly with diverse educators and scholars from other fields as they collaboratively design an interdisciplinary simulation, consider best practices, and share their experiences and perspectives.

Expected outcomes and contributions of the event

A desired outcome of this workshop is to improve our own existing resources and design guidelines so that we can provide these as a starting point for future simulation designers. Following the workshop, the organizers will send participants updated materials and resources that are informed by outcomes of the workshop, including access to a website that focuses on simulation design using ViewPoint. We anticipate this engaged learning opportunity will help to catalyse a network (or networks) of interdisciplinary scholars who may continue their interactions beyond the workshop setting.

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What's Power Got to Do With It?: Exploring Participatory Research in the Learning Sciences

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Introduction/Goals/Themes

We propose this workshop to create a time and space for members of the Learning Sciences community to explore the role of participatory research methods in our field. The purpose of this workshop is to engage a scholarly community in exploring the ways that participatory methods challenge traditional notions of research (data, validity, analysis etc.) rooted in colonial approaches to knowledge creation. We aim to collaboratively question: what is the role of participatory methods in the Learning Sciences; how do we practice participatory methods that value the knowledges of participants in critical and decolonial ways; and how do the boundaries between research, practice, researcher, and participant emerge?

This workshop is structured as a co-constructive knowledge building activity that engages participants in the key methodological questions and work that participatory research methods require. The workshop consists of activities, case presentations, and discussions that lead to a collaborative outline of 1) the different forms of participatory methods that scholars bring to the Learning Sciences and the tensions they help produce in research activity, 2) the methodological commitments that participatory research methods have in common, 3) the role of researchers in the communities they research with and 4) a vision of the future contribution of this kind of research practice to the academic community and the communities with whom we do research.

Theoretical roots and methodological branches

Participatory research methods are rooted in critical theories and challenge traditional power hierarchies between researchers and participants, towards less oppressive approaches to understanding learning spaces. Grounded in dialogic practices (Freire, 1970), this approach challenges unbalanced researcher-participant power dynamics that often lead to an extraction of participant practices from the researcher point of view, devaluing and erasing participant knowledges. We build on the foundations of critical theories in education (Freire, 1970; hooks, 1994), critical race theory (Ladson-Billings, 1996), black feminist (Collins, 2000) and Indigenous (Smith, 1999) theories, and sociocultural perspectives of learning (Lave & Wenger, 1991) to consider knowledge construction through co-theorizing (Switzer, 2019) within a community of participants, interacting through and across power differences and hierarchies. Important in this approach is our commitment to the tenets of participatory research both theoretically and methodologically, positioning ourselves on decolonial grounds that reject traditional notions of research (Tuck and Guishard, 2013). Yet, not all research that uses participatory methods is decolonial or has decolonial outcomes. It can be inauthentic to the communities that the research works with in performative ways that merely act as validation to the researcher perspective.

Participatory research has been taken up in many ways, including youth participatory action research (YPAR), video voice projects (VVP), and participatory design research (PDR) more, broadly aimed at “a collective process enriched by the multiple perspectives of several researchers working together” (Camarota & Fine, 2008, p.5). YPAR praxis creates a “politically and intellectually charged space where very differently positioned youth and adults are able to experience and analyze power inequities, together” (Torre, Fine, Alexander, Billups, Blanding, Genao, Marboe, Salah, & Urdang, 2008, p.24). By giving youth camera equipment and the director’s role, VVPs are structured to develop an understanding of participants’ perspectives on their own terms (Erickson, 1996). Particular to the learning sciences, PDR is deliberate about disrupting traditional hierarchies of power between researcher and researched, committed to promoting just social change from the perspectives and through the agency of participants. The focus here is on “re-mediating” the conventional roles of “researcher” and “participant” throughout the research process, from research design to data collection to analysis to writing (Bang and Vossoughi, 2016).

Participatory methods, therefore, require rethinking our stance as researchers both (with)in the communities we research and in the research practice itself. This beseeches a shift away from a research goal of rigor and validity to valorizing authenticity (Guba & Lincoln, 1989) judged in terms of how much the research practice engages authentically with the experiences of community members. In this workshop, we propose

engaging with the tensions and affordances for making participatory research decolonial, to truly value the experience, expertise, and knowledges that participants bring to the research process.

Tensions and concerns of participatory work

The theoretical roots and commitments of participatory research, along with the research design examples described above, point to some emergent tensions and concerns to be addressed: representation, co-theorizing, research questions, analysis, temporality and ownership, and co-writing/co-presenting. In the interest of space, we present a general question related to each of these, to be explored, revised, and nuanced by workshop participants.

- Representation: In what ways do participants have opportunities and decision-making agency to (re)present/disrupt/enhance the telling of their own stories, in data, and in knowledge dissemination products?
- Co-theorizing: How do power dynamics (e.g. the contours of gender, race, class, university access etc.) influence how knowledge is produced in a space and how do we negotiate researcher and community expertise?
- Research questions: How are research questions formulated; whose concerns, values, theories, and resources shape them?
- Analysis: Who decides what kinds of analysis are appropriate, recognizable, rigorous, and generative of new knowledge, and for whom? Before that, how does what counts as data, and what should not be included, get negotiated?
- Temporality & Ownership: If “professional” researchers work on different, often longer and more resourced timescales than participant collaborators, how do all voices and values (understood to be under continual development) persist throughout research activity? How do participant collaborators retain ownership of representations of their lives, and knowledge produced?
- Co-writing & Co-presenting: What does writing together and authorship look like? How do we present together and how does that subvert the norms of academic presentations and conferences?

Relevance to the field and conference theme

In the learning sciences, we are increasingly recognizing the need to include participants in representation and analyses of learning communities (both teachers, and students), if we are truly committed to challenging the oppressive ways that teaching and learning occur in “traditional” formal and less formal spaces. While PDR is somewhat more recognizable in the field due to its roots in design research, we hope to learn by considering a variety of participatory methods, presented by workshop organizers and participants in order to expand and shift the role participants in the communities we study can have in research practice. This workshop can help both to build collective vision for how this work can be done authentically and rigorously, and to surface emerging tensions as we develop new strategies for revising our own practices and epistemologies to learn anew from research partners. We aim to develop more tools for researchers to ensure participatory work does not become co-optive and transactional, and rather engaged with and empowering for communities involved. How do we genuinely encounter and accept research data “as a gift” (Marin, 2019), and research participation as truly collaborative? We value participants’ perspectives beyond just data to be collected and interpreted, to having a consequential role to play in the embrace of sociopolitical perspectives on learning communities in education research. We aim to develop strategies toward theory and methodology in alignment with the conference theme of interdisciplinarity; treating seriously members’ perspectives as a form of disciplinary expertise, and producing new knowledge for the field that reflects hybrid ontologies and epistemologies of learning sciences and the young people with whom we have the honor to work.

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Multimodal Learning Analytics and Interaction Analysis: Connections, Tensions and New Directions

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Multimodal learning analytics (MMLA) and Interaction analysis (IA) are robust, generative methodologies used in the Learning Sciences (Blikstein & Worsley, 2016; Ezen-Can, Grafsgaard, Lester, & Boyer, 2016; Jordan & Henderson, 1995; Hall & Stevens, 2015; Marin & Bang, 2018; Vossoughi & Escudé, 2016), and yet research teams rarely deploy them in tandem to address a common research question or analyze data. Despite their obvious differences — MMLA often focuses on large data sets, automated pattern analysis, and sensor-based data collection technology, whereas IA often focuses on generating new types of questions through work with small data sets, manual data analysis, and predominantly video/audio recording equipment — both methodologies share a focus on how multiple modalities, temporal regularities and irregularities, social interaction, and changing contexts shape learning.

Building on the momentum of a recent NSF-funded workshop addressing their possible integration, the proposed ICLS workshop investigates points of connection (e.g., how MMLA data overlaid on video during IA sessions can guide/enhance what the researcher notices) and points of tension (e.g., how the IA commitment to limiting inferences to the observable video/audio record might be reconciled with the longitudinal context afforded by MMLA data) in educational research that draws at once on both methodological traditions.

Bringing these methodological traditions together to tackle common research questions is possible and central now perhaps more than ever before. This is in part because the amount of data collected on research projects often makes it possible to apply both methodologies at once, serving the purpose of seeing both the forest and the trees in the ways participants navigate learning over time and across contexts. With respect to the core conference theme of “sociopolitical dimensions of learning and social justice,” and echoing broader trends in our research community (Esmonde & Booker, 2016; Gutiérrez & Vossoughi, 2009), we explore how learning scientists can consider power and equity when applying both methodologies, and in particular, how stitching these methodologies together would throw new light on sociopolitical dynamics.

Workshop participants will engage in shared data analysis sessions (hosted by the conference organizers) to investigate central opportunities and tensions in MMLA + IA research, including how MMLA can augment video during IA sessions, what kinds of information interfaces bridge both methodologies, how MMLA can help shape the selection of data and focal research questions for IA, and how computational methods can intersect with grounded, theory-based interactional research. Participants will also have opportunities to share their own project contexts, existing data analyses, research questions, and exploratory considerations about MMLA + IA.

We hope that this workshop continues the process of cultivating a community of researchers interested in developing skills in both methodologies and applying them simultaneously in research that addresses persistent inequities in learning environments. By the end of this workshop, participants will have engaged with cutting edge methods of data collection and analysis in ways that also foreground the importance of context. Likewise, we expect participants to have the time and space to explore future projects that integrate MMLA and IA in new ways.

Early Career Workshop

The Constitutive Features of Relational Equity: A Cross-Cultural Investigation of Adult-Youth Relationships in Diverse Teaching and Learning Contexts

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Abstract: This study aims to add value to the Learning Sciences and Teacher Education research and practice communities by investigating, mapping, testing and refining the types of learning relationalities amongst educators and youth that are capable of producing relational equity amongst adults and young people with differing social identities.

Research goals

As human beings in a social world, we learn by and through our relationships with others. The way we make sense of ourselves, the world around us, and our place within it, is largely shaped by social relations—relations themselves shaped by shifting material, economic, and political realities. In the third decade of the 21st century, we find ourselves in a moment where our capacity as social beings to thrive depends simultaneously on our ability to *compete* and to *co-exist* within a highly diverse yet interconnected network of human relations. Within such a context, what is the role of educators, in both informal and formal educational contexts, in preparing young people to be successful in the 21st century? And how can we, as learning scientists, design relational interventions that support young people to lead the lives they have reason to value (Sen, 1999), in our rapidly changing and increasingly polarized world?

Propelled by these broad questions, I propose to carry out a cross-cultural comparative case study of teaching and learning relations in formal and informal educational environments within diverse settings in the United States. My research seeks to understand better the texture of human relationships within teaching and learning settings, especially those where the educator and youth populations occupy distinct social identities—that is, settings where the adults in the space do not understand themselves to be from similar socioeconomic, racial, or linguistic communities as the young people with whom they are working. In particular, I aim to leverage a conjecture mapping approach (Sandoval, 2014) to the testing and refinement of conjectures related to the behavioral and discursive embodiments of “relational equity”—that is, relationalities between teachers and learners in which neither’s way of being in the world, or making sense of it, dominates the other (DiGiacomo & Gutiérrez, 2015; 2017; DiGiacomo & Penuel, 2018).

Background

This research agenda contributes to contemporary conversations within the Learning Sciences and Teacher Education on how to design more equitable learning environments that support consequential learning for all young people (Juwon & Hall, 2015). While there is substantive research within both fields on innovative curricula, rigorous instruction, and inclusive pedagogies, there is less inquiry that brings together what is known about **how people learn** with **how to effectively, equitably, and critically organize educational spaces** in ways that *all* youth’s cultural repertoires of practice (Gutiérrez & Rogoff, 2003) and funds of knowledge (Gonzalez et al., 2006)—not just those from high income communities—are taken up and valued equitably. This project is driven by a desire not only to bridge theoretical perspectives, but to make the consequences of that bridge usable for educators working with a diversity of youth. While there is indeed research from formal classrooms that attends to the connection between teacher-student relations and educational outcomes for youth (e.g. Gehlbach et al., 2012), there is not a broad base of evidence within Learning Sciences scholarship from which to suggest strategies for how to design teaching and learning relations in ways that take seriously the political nature of learning and issues around relational trust. This is in part because of the dearth of empirical research into the constitutive elements of adult-youth relationships in such settings, including the ways in which these relations take shape in varying contexts, as well as how they are mediated by various and intersecting social identities.

Methodology

Through a cross-cultural case study design, my research investigates teaching and learning relationships amongst adults and youth in diverse formal and informal educational environments (d’Andrade & Strauss, 1992). The guiding research questions that animate my study are: (1) What are the dimensions of teaching and learning relationships in formal and informal educational contexts? (2) What are the material and discursive embodiments of adult-youth relationships in formal and informal educational contexts? And how can they be organized more equitably? To answer these questions, I plan to carry out a multi-phased study that will bring together school- and

community-based researchers of youth learning based in Schools of Information Science at the University of Kentucky and the University of Wisconsin Madison and focus on the following contexts: **Context 1:** Afterschool Making program in Madison, WI; **Context 2:** In-school classroom in rural Wisconsin; **Context 3:** Afterschool program in a library space in rural Kentucky; **Context 4:** In-school STEAM classroom in Lexington, KY.

The first phase of my study will include data collection, analysis, and representation related to the constitutive features of adult-youth teaching and learning relationships. The approach to design-based research I will carry out is informed by Sandoval (2014)'s notion of "conjecture mapping" to interventionist education research. The 'embodiments' of my design principles will be parsed into (1) task structure (2) participant structure (3) tools/materials and (4) discursive practices. I will make clear the links between the embodiments, design conjectures, and theoretical conjectures being investigated through this process. Central to this plan is the development of a type of heuristic that clearly maps the dimensions of learning relationalities in both formal and informal learning environments, as well as conjectured outcomes and documented iterations of these relationalities in practice. While I conjecture that the dimensions of learning relationalities are multiple, I anticipate the following types of elements: **Tools and Materials:** Formal versus informal learning environment characteristics; types of disciplinary resources available to adults and youth; space availabilities/constraints; **Task Structures:** Assessment and/or testing requirements of environments; warrants/ accountability structure of involved participants; espoused goals/aims of environment; **Participant Structures:** Available learning and/or pedagogical arrangements; rules/norms of engagement; prevalence and type of learning supports/scaffolds, including heterogeneity of ability, expertise, interests; **Discursive Practices:** Behavioral and linguistic interactional cues amongst adults and youth; dominant linguistic preferences of participants; race, class, gender, and/or other intersectional identities of participants.

Expected findings and contributions

After the exploratory and analysis phases of the study, I aim to test and refine my conjectures within practicum-oriented experiences within both university settings. With the aforementioned heuristic as a mediating pedagogical artifact, I will carry out additional design-based interventions that encourage educator reflection on the normativization of context and culturally specific teaching and learning relationalities, as well as spearhead the co-planning of productive supports for the enactment of new pedagogical relations and imaginations. I am well positioned to carry out this next phase of the study, as this project directly builds upon my dissertation work from case studies in Scotland and the United States. I will add value to the Learning Sciences and Teacher Education research and practice communities by investigating, mapping, testing and refining the types of learning relationalities amongst educators and youth in both informal and formal settings characterized by high degrees of socioeconomic, racial, and linguistic diversity.

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Eye on Collaborative Creativity: Insights From Multiple-Person Mobile Gaze Tracking in the Context of Collaborative Design

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Abstract. This research aims to further understanding of creative collaboration: the roles of intertwined speech, visualisations and gaze. This continuation to my PhD research on collaborative sketching utilizes multiple-person mobile gaze tracking and builds on two established approaches: Exploratory Talk, which features high-level collaborative productive talk, and Linkography, a design cognition research method. This cross-disciplinary research has value for Learning Sciences, design, creativity, interaction and eye movement research.

Cross-disciplinary research is required to understand creative collaboration

The complex and multifaceted problems of contemporary society require creative collaboration (Fischer 2016; Dede, 2010), especially situational creativity, which provides novel and specific solutions to that particular situation and purpose (Gero, 2000). Both collaboration and creativity are practices that can be learned – if taught properly. So far, creativity research has focused extensively on individuals and delivered few models of collaborative face-to-face creative, open-ended problem solving (Reiter-Palmond & Leone 2018; Shalley 2008) in which multimodal interaction is central. Design research, the field with creativity at its core, promotes combining visual and verbal thinking as beneficial for creativity (Bar-Eli, 2013). In my PhD project combining Learning Sciences and design research, I identified four micro-level patterns of collaborative sketching that diverge both in group regulation and building on verbal and visual ideas (Härkki 2018). I also noticed that students' attention to each other's contributions varied, which yielded differing levels of collaboration.

Current methodologies have been unable to resolve the fundamental question of how speech and sketching interact. However, mobile gaze tracking has delivered answers to similar questions in other fields of Learning Sciences (e.g. Hannula, 2016). I argue that extremely fine-grained methodologies (i.e. gaze tracking) are needed if creative action patterns among interacting individuals are to be understood fully. As mobile gaze tracking analysis is extremely time-consuming, productive research needs a highly selective lens. A robust base for this selection is provided by acknowledged approaches capable of identifying potentially collaborative or creative time periods. Such approaches entail Linkography (Goldschmidt, 2014), an established design research methodology to study design cognition, and Exploratory Talk (Littleton and Mercer, 2013), a Learning Sciences approach that separates collaborative and productive talk from less collaborative forms. From these premises, my research applies multiple-person mobile gaze tracking with the aims of revealing previously unattainable relationships between speech, sketching and the development of novel solutions, and identifying micro-level multimodal productive patterns of collaborative creativity.

Methods: Triangulation of collaboration, creativity and gaze measures

Mobile gaze tracking measures – such as individuals scan paths and gaze synchrony (i.e. participants simultaneously directing their gaze to the same location) – are objectively observable and can provide otherwise unattainable information about collaboration and emergence of ideas. For instance, a qualitative gaze synchrony displays participants' gaze locations for selected areas as a function of time (Haataja et al., 2017), and a quantitative gaze synchrony identifies precisely and robustly when gaze synchrony reaches statistically significant levels (Garcia Moreno-Esteva et al., submitted).

However, these measures provide no information about which actions are central to creative outcomes; thus, I use Linkography (Goldschmidt, 2014) to identify interesting ideation sections. Linkography represents cognition as networks of interlinked 'design moves' (i.e. statements introducing a change). A so-called 'critical move' has multiple links to other moves and is considered especially productive. Network structures linked to critical moves are understood as 'significant moments' – the main targets to gaze tracking analyses in this research. Comparing these 'significant moments' to gaze synchrony reveals how collaborative the contributions have been. This constitutes research phase I (scheduled 1-12/2020, funded by the Emil Aaltonen Foundation).

To better understand the role of interacting characters of different modalities, features of Exploratory Talk (Littleton & Mercer, 2013) are used to identify sections using language as a tool for reasoning. These sections are triangulated with 'significant moments' and gaze synchrony, i.e. collaborative gaze and creativity measures. This constitutes research phase II (pending to applied funding).

The research setting entails two groups of three design students designing (and sketching) a sustainable Christmas basket (a 90-to-120-minute task). The primary data comprise gaze videos and overall video scenes.

Secondary data comprise pre-questionnaires, produced sketches and audios of video-stimulated interviews. The cutting-edge mobile gaze tracker, developed at the Finnish Institute of Occupational Health, is more accurate and robust than commercial alternatives (Toivanen, Lukander & Puolamäki 2017). Mobile gaze tracking (i.e. tracking how an individual directs his/her gaze while moving unrestricted) is particularly laborious. However, several weeks of labour will be saved by automated gaze data processing based on graphic markers placed in the environment – algorithms developed by the MathTrack project.

The support network for my research involves Prof. Pirita Seitamaa-Hakkarainen's design research team, Prof. Kai Hakkarainen's international knowledge creation community, and methodological support from Prof. Markku Hannula's MathTrack team. Prof. Emerita Gabriela Goldschmidt, the developer of Linkography and a design research heavyweight, has accepted a senior reviewer role.

Expected results and their implications

To the best of my knowledge, multiple person mobile gaze tracking has not yet been used in either design process or in creative face-to-face collaborative problem-solving research, as studies using multiple trackers commonly involve static trackers and subjects interacting with or through computers. Thus, I expect the results to produce novel insights into patterns of multimodal participation within creative activity. The patterns build theoretical and pedagogical understanding. Moreover, building on the MathTrack findings, I anticipate that this research will identify candidates for novel mobile gaze-tracking measures. Ultimately, I hope these measures will develop an understanding of "Exploratory Gaze" – a way to use gaze for creative purposes.

Publications will include open access, peer-reviewed original journal articles. The one targeting eye movement research field highlights the possibilities of marker-based gaze tracking in studying the focused interactions of three participants – an extremely rare setting with the potential to methodological implications. Another article will target the design research field. To conclude, the results have cross-disciplinary theoretical, methodological and pedagogical implications, relevant at least to Learning Sciences, design, creativity, collaboration and eye movement research, as well as to design and collaboration education.

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Promoting Children's Positive Attitudes Towards Pro-Environmental Behaviours: Encouraging Understanding, Agency and Motivation Through Gamebooks

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Abstract: While many individuals understand what actions can be taken to combat climate change, actual behavioural change is limited. Drawing on the Reasoned Action Approach, this project aims to increase children's (9- to 11-years-old) intentions to engage in pro-environmental behaviours. Using a DBR approach, educational materials will be co-created and evaluated. Materials include a gamebook (a non-linear narrative) and accompanying dialogic lessons that allow children to explore the impact their decisions can have on their future.

Background of the project

Research suggests that education is effective at developing an understanding of what climate change is and what preventative measures can be taken. However, many individuals do not engage in behaviours that could tackle climate change and will even perform actions that they know to be detrimental (Pruneau, Khattabi & Demers, 2010). Essentially, individuals may hold negative perceptions about pro-environmental behaviour and, therefore, behavioural change is limited. What is needed to combat climate change is a more educated, action-oriented public and this should begin young.

This project explores two approaches to overcome negative perceptions about pro-environmental behaviour. The first concerns cognitive barriers; patterns of reasoning that effect perception and inhibit action. Primarily, these barriers relate to the perceived limited impact of an individual's actions (Lorenzoni, Nicholson-Cole & Whitmarsh, 2007). For example, the belief that individual action is a drop in the ocean.

The second is the Reasoned Action Approach (RAA) (Fishbein & Ajzen, 2010). This outlines three constructs that interact to determine the likelihood of behavioural intention. For example, the action of recycling requires 1) a positive attitude towards the behaviour (e.g., reducing landfill), 2) a favourable subjective norm (e.g., it is established cultural behaviour) and 3) a sense of perceived behavioural control (e.g., it is practicable). Negative views of these constructs will decrease the likelihood of the behaviour. Educational materials drawing on this approach support increased in commitment to pro-environmental behaviour (Steg & Vlek, 2009).

Goals of the research

The primary aim of this project is to improve children's (9-11-years-old) perception of pro-environmental behaviours. To affect this, a comic-style gamebook (a branching, interactive comic that is shaped by reader decisions) will be designed with an accompanying dialogic-intervention. This format enables the personalisation of materials to develop children's understanding of the effects that their behaviour has on their lives, thus fostering a sense of agency about and motivation for pro-environmental behaviour. Early education is critical to promoting pro-environmental behaviour at a societal level (Bangay & Blum, 2009) and interventions with similar age-ranges show positive results (Pruneau, et al. 2010). The goal of this project is prevention rather than cure. Educating today's children will affect the general public of tomorrow (Bagay & Blum, 2009).

Many educational materials focus on the impact that actions have for society and the environment. However, considering research on cognitive barriers and RAA suggests that educating individuals to act against climate change should focus on the tangible impact individuals' behaviour has on their lives and their sense of perceived behavioural control (or agency). This proposed conceptual framework also draws upon two pedagogical theories. Firstly, dialogic education, that children's perception of pro-environmental behaviours can be co-constructed through social interaction. Secondly, future education, that contextualising the consequences of climate change allows children to envision their futures. Both are suggested to be effective in developing positive views of pro-environmental behaviour (Pruneau, et al. 2010). Nevertheless, evaluation of how such theories can be used to support commitments to pro-environmental behaviours is currently lacking (Steg & Vlek, 2009); therefore, a secondary research aim is to contribute to this theoretical discussion.

Methodology

Gamebooks are a form of interactive fiction that provide opportunities to develop children's knowledge and attitudes, especially when supported by further discussion (Cavallari, Hedber & Harper, 1992). A gamebook will be created to promote children's sense of agency towards and motivation for pro-environmental behaviours. The

interactive aspect will enable children to see the impact that their decisions have on their life. The actions children take earlier in the book (e.g., turning off electrical devices) will influence how climate change affects the character later in the book. The gamebook will address pertinent cognitive barriers and construals of reasoned action that may inhibit pro-environmental behaviour. It will take the form of a multimodal comic-style book. Authoring tools (e.g., <http://twinery.org>) will be used to develop the gamebook as an interactive app.

An intervention will complement the gamebook. It will draw upon the theory of dialogic teaching (Alexander, 2006), consisting of groups of children discussing their decisions in the gamebook. The intervention will challenge cognitive barriers and target children's beliefs (e.g., control beliefs) in line with RAA.

This is a design-based research (DBR) project (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003) with three main phases. Phase 1 will involve five activities, the outcome of which is the co-designed gamebook-app. Firstly, focus groups of children ($n = 60$), teachers ($n = 6$) and academics ($n = 3$) will be consulted in the development of the gamebook (i.e., direction of the narrative and possible decisions), to ensure it is relevant to children's lives and scientifically correct. This co-design team will be integral to the project and will be involved throughout the iterations to support the development of the educational materials. Using RAA methodology (Fishbein & Ajzen, 2010), preliminary work with the child co-participants will develop a set of measurement items to assess children's beliefs about, and proximal predictors for, engaging in pro-environmental behaviours. Secondly, these assessment items form a standardised questionnaire that when administered to a different sample of 90 children (9- to 11-years-old) can be used to produce a statistical model, mapping beliefs to behavioural intentions. Based on the model, beliefs most pertinent to behavioural intentions can be determined and, therefore, targeted. Thirdly, the gamebook will be developed based upon the findings from activities 1 and 2, and existing theories about pro-environmental education. Fourthly, the co-design team will use and evaluate the gamebook, which will be refined based on findings. Finally, the gamebook-app, intervention and assessment-items will be piloted. Participants will include a new sample of 30 children (9- to 11-years-old). Pre-/post-test questionnaires, based on RAA, will be used to assess changes in children's attitudes towards pro-environmental behaviour.

Phase 2 involves several iterative efficacy tests using experimental designs. Treatment groups will read the gamebook (via tablets) and partake in dialogic-based lessons that explore the choices children made in the book. Initially, control groups will be waitlist-control, however, later evaluations will use more complex active control groups. After each study the results and feedback from co-designers will be used to improve the gamebook. The outcome of Phase 2 is the evaluation of the educational materials. Phase 3 is a large-scale evaluation, using multiple teachers at multiple sites, to explore how materials are used and adapted by classroom teachers.

Expected findings and contribution

Currently, the project is in the early stages; however, preliminary findings from Phase 1 will be available by ICLS 2020. Expected contributions are twofold. Firstly, the co-designed educational materials (gamebook/gamebook-app and intervention) will contribute towards the body of resources and pedagogical approaches for promoting a sense of agency towards and motivation for pro-environmental behavior. Secondly, the findings will provide a theoretical contribution to the literature. Specifically, how psychological theories about cognitive barriers and the Reasoned Action Approach, and pedagogical methods of dialogic teaching and future education, can underpin education about pro-environmental behaviors.

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Fostering Elementary School Students' Visuospatial Skills and Mathematical Competencies through an Origami-based Program

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Abstract: This National Science Foundation (NSF)-funded three-year project builds on a previous project in which elementary-school students rated purposeful origami as one of the most engaging hands-on STEM activities they have experienced. The project will refine and evaluate the effectiveness, durability, and transfer of an innovative origami-based program on visuospatial skills, with a focus on elementary school English Language Learners.

Goals of the research

Project VisMO is an NSF-funded research project that seeks to advance knowledge in Research on STEM Learning and Learning Environments and Research on Broadening Participation in STEM fields. The project will refine and evaluate the effectiveness, durability, and transfer of an innovative origami-based program on visuospatial skills, with a focus on elementary school low-achieving English Language Learners (ELLs). This program builds on a previously NSF-funded project, in which elementary-school students rated purposeful origami as one of the most engaging hands-on STEM activities they have experienced. Importantly, this project extends previous longitudinal correlational studies to investigate the causal links between the gains in visuospatial skills and students' mathematical competencies using an experimental design and a 12-month follow-up study with more than 200 fourth grader students.

Background of the project

The United States has a severe shortage of STEM professionals, and this gap is even more pronounced for underrepresented learners. In 2017, the average mathematics score on the National Assessment of Educational Progress for 4th-grade English Language Learner (ELL) students was 26 points lower than the average score for their non-ELL peers. The closing of this gap will require interventions that focus on mathematics and on the visuospatial competencies that support mathematics learning. Although there are increasing efforts to develop evidence-based mathematics curriculum and to present mathematical concepts or problems in a visual way, most visuospatial interventions were implemented in a lab setting (e.g., video games; training on mental rotation) and in ways that would be difficult to translate into existing educational settings. The project is a collaborative effort between educators, cognitive psychologists, learning scientists, mathematicians, and origamists that is focused on creating developmentally appropriate and engaging educational interventions and on better understanding the relationship between children's visuospatial reasoning and their mathematical learning.

Methodology

The VisMO program is composed of a set of eight lessons with carefully designed progressive origami-based activities focusing heavily on promoting visuospatial reasoning. Each lesson lasts for 90 mins. The first six lessons had an individual folding session for students to explore and fold with guiding questions, an explication sessions that the educator explicitly introduce new spatial concepts and vocabulary embedded in the individual folding session, a embodied learning session where students engage in spatial games through full body movement, a problem solving session that students engage in challenging folding, sketching, and constructing tasks in teams, and an intentional reflection session that students share how they used or can use the spatial concepts and their successful and unsuccessful approaches to solve the problem. The lessons aim to build students' confidence and create a culture that embraces fun, patience, precision, and practice, and the concept of productive struggle will be promoted throughout the program.

In these next six lessons, students will explore three different types of modular origami models: the Sonobe unit, the Tubis unit, and preliminary base unit, and the Super Nobu unit. These models were chosen based on the learning objectives of the lesson. We chose these models because of their rich cognitive, physical, and functional affordances associated with the large variation in 1) possible designs and folding steps for creating one unit, 2) how two units lock, and 3) the design of the final 3D configurations obtained with multiple interlocking units.

The last two lessons will focus on reviewing the concepts through completing a "VisMO magic box" in which students will showcase their 2D and 3D paper models and label the spatial concepts that they used when folding the models. They will also have the opportunities to fold and construct additional difficult but amazing new paper models to push their boundaries.

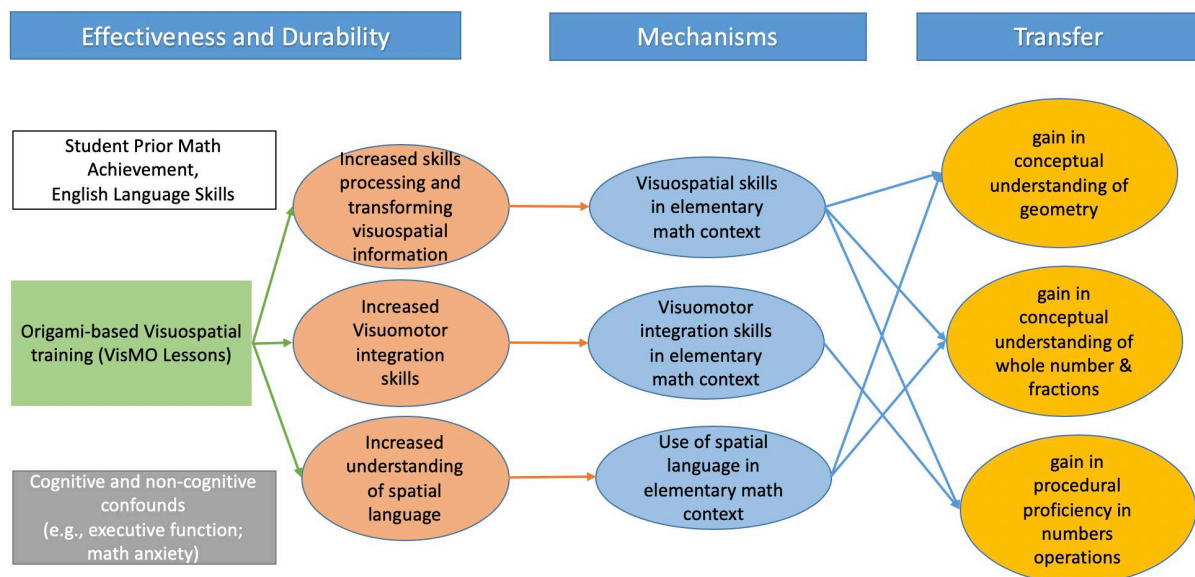


Figure 1. Conceptual Framework of the Project VisMO.

Based on the conceptual framework (Fig.1), the proposed research project consists of three stages:

Stage 1: Intervention development and formative studies: Stage 1 research focuses on the intervention development and refinement, as well as the student engagement with modular origami activities.

Stage 2: Impact study of VisMO Lessons: a full-power blocked-randomized control trial study will be conducted with 240 4th grade students from a partner school district, most of whom are ELLs who are currently low-achieving in mathematics.

Stage 3 Study of Durability and Transfer: The sustained impacts of VisMO Lessons will be examined through a 12-month follow-up assessment of students' visuospatial skills and mathematical competencies.

Preliminary or expected findings

We are currently in the process of designing the lesson plans, new assessments, facilitator training sessions, and conducting pilots with 4th grade students to understand students' spatial reasoning, effective instructional strategies, and to refine the curriculum. Focus groups were conducted after each piloting lesson. We also conducted a multimodal study with undergraduate students to understand the collaborative problem-solving process with visuospatial tasks (design, sketch, and construct a cube using Sonobe units). The video, audio, sketches, and survey data have been collected. We are in the process of analyzing this rich dataset. We are interested in understanding the effective gestures, language, and sketching strategies that influence the collaboration quality and the quality of the final solution.

Expected contributions

This project will provide a unique and comprehensive experimental assessment of the contributions of an origami-based program on the development of different types of visuospatial skills and how the latter contributes to children's mathematical competency development. This program has the potential to provide an authentic learning experience and showcase effective instructional strategies that support children's spatial reasoning and the acquirement of new spatial vocabulary. Research results will be disseminated and shared via scholarly research conferences and publications in peer-reviewed research journals. Furthermore, the professional development protocols developed in the project will provide a straightforward way to scale-up this intervention and help educators integrate this new approach into their practices.

Acknowledgments

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Conceptualizing a Mobile-Assisted Funds-of-Knowledge-Featured Learning Environment for Latinx English Learners

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Abstract: This paper reports my dissertation research work that focuses on the integrated learning effects of middle-school aged Latinx English learners' writing skills using mobile-based writing tools to better understand their success and to propose a mobile-assisted funds-of-knowledge-featured learning environment and curriculum design. This research addresses the significance of using emerging technology in reshaping the learning structure in view of underrepresented digital learners' specific cultural, ethnic, and social-class experiences.

Background and research goals

From the standpoint of constructionism, I believe that learning is best achieved by engaging students in constructing their own knowledge and fostering their connectivity to authentic learning environments (Papert, 1996; Papert & Harel, 1991). Through a sociocultural lens, I have developed my research agenda to attend to the culturally sustaining integration of emerging technology as a means to support learning, particularly regarding digital learners who come from culturally and linguistically diverse backgrounds and who may have had limited access to educational opportunities. In particular, my dissertation research employed a multiphase mixed-methods design to address the learning effects of middle school-aged Latinx English learners' (ELs) writing skills using mobile-based writing tools (MBWTs) to better understand their success and to propose an innovative mobile-assisted funds-of-knowledge-featured learning environment and curriculum design (Chen, 2018; Chen, Carger, & Smith, 2017; Chen, Mayall, York, & Smith, 2019; Chen, Smith, York, & Mayall, 2019).

The original idea of my dissertation research was inspired by *The Circuit: Stories from the Life of a Migrant Child* (Jiménez, 1997), which tells the story of a Mexican immigrant child named Panchito, who grows up in the 1960s and struggles to pursue his childhood dream in a new world with a different culture and language. Like many of the migrant children in the last century, Panchito worked hard but had to miss school to help support his family. To keep up, he carried a notepad for learning new words, definitions, grammar rules, and math, even when he was working, but his notepad was lost in a fire. I was deeply touched by Panchito's experiences, and wondered what students like Panchito experience today with emerging mobile technology. I investigated many topics such as the following: what are the experiences of digital ELs? How might the ELs' home-based technology experiences be connected with their formal classroom learning? To answer such questions, I gradually formed my dissertation idea to examine how MBWTs might support Latinx ELs' narrative writing skills, through the perspective of funds of knowledge, which recognizes the significance of the students' household culture, community involvement, and lived experience (Moll, Amanti, Neff, & González, 1992).

Methodology

To implement this study, I employed a multiphase mixed-methods research design through four years of intensive fieldwork with Latinx communities and two school districts in the rural Midwest (Creswell & Plano Clark, 2017). This effort enabled me to iteratively refine my research design and to complete each research phase step-by-step. For instance, I first sought to understand ELs' funds of knowledge and to develop writing interventions by conducting participant observation in the Latinx community and home-visiting ELs' families from the community. To mix the qualitative findings into the quantitative phase, I then developed a mobile-assisted funds-of-knowledge-featured instructional framework that engaged ELs in writing through five sequential steps of discovering, connecting, writing, sharing, and preserving culture (see Figure 1). Subsequently, I implemented this learning environment via a switching replications quasi-experimental design to engage the students in completing funds-of-knowledge-featured narrative essays, such as *my family story*, *my travel story*, *my game story*, *my technology story*, and *my culture story*, both using pen and paper as well as MBWTs as learning interventions.

Preliminary findings

Findings from the ethnographic research phase revealed four funds of knowledge categories: family-based, center-based, community-based, and technology-based funds of knowledge. Findings from the quantitative research phase indicated that ELs' parents were motivated to support their children's language learning using mobile technology and that students invested more effort in the writing process, resulting in stronger narrative writing. Findings also uncovered persistent inequities in technology access for underrepresented diverse learners as well as significant gender differences for Latinx youth in learning effects within technology-enriched learning

environments. For instance, the ELs had positive perceptions toward the adoption of using MBWTs as useful writing tools, particularly through a distinctive gender perspective. The effects of MBWTs on writing performance were stronger for Latinos than Latinas.

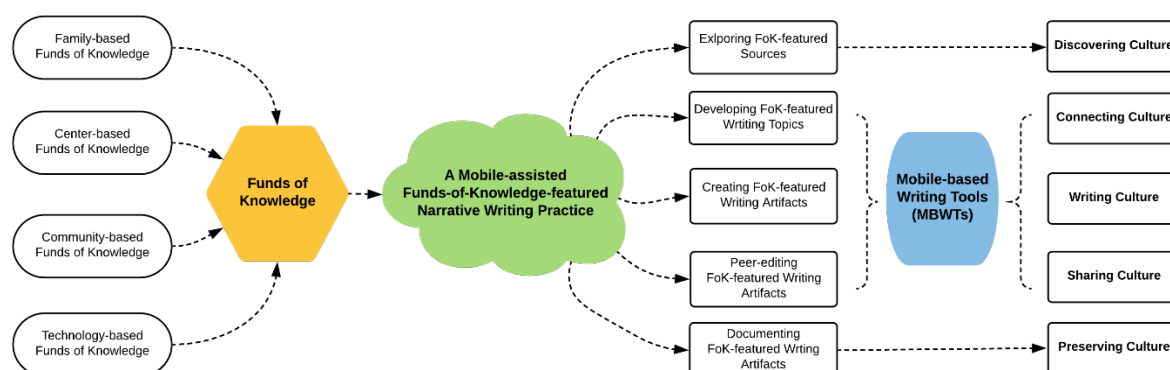


Figure 1. Mobile-assisted funds-of-knowledge-featured learning framework (adapted from Chen, 2018).

Expected contributions and future directions

This research work demonstrates an important step in addressing the need to focus on the intersection of language and literacy education for emerging mobile technology and culturally and linguistically diverse learners in our contemporary digital culture. This research addresses the significance of using emerging technology by reshaping the learning structure in view of underrepresented digital learners' cultural, ethnic, and social class experiences. This research also indicates that educators and stakeholders should consider students' different views of the hybridity of technology-enriched learning spaces so that classroom activities are perceived as relevant and valuable to diverse learners. Moving forward, I am eager to continue collaborative work on interdisciplinary research initiatives, particularly in contexts such as science education and deep learning, in order to advance theory and knowledge on aspects of students' engagement by connecting formal and informal settings through the technology-assisted funds-of-knowledge-featured learning environment that I am continuously developing.

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Acknowledgments

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Using Multimodal Learning Analytics to Capture 21st Century Skills in Digital Fabrication Laboratories

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Abstract: In this short paper I present a methodological innovation for studying changes that happen in open-ended learning environments such as makerspaces. More specifically, it has been shown that students develop many 21st century skills in makerspaces (Clapp, 2016). I propose to study this kind of phenomena using a mixed method approach: I plan to combine surveys, interviews, with highly granular data from multimodal sensors. This research sets the stage for new kinds of formative assessment, where the results of this methodology can inform new ways to support the development of students' 21st century skills.

Introduction

Maker spaces have the potential to be transformative learning environments. For some students, spending time in a maker environment allows them to become curious, persistent, confident, more willing to take on risks and explore topics they are passionate about, while learning from a community of practice, growing their agency and transforming their identities (Clapp, 2016). In other words, students go beyond developing 21st century skills, and engage in a process of self-growth that can radically shift their identities and relationships with the world and other people. I propose to study this kind of learning experience by designing a new research methodology that combines traditional data measurement tools with high frequency sensors, to objectively and rigorously record students' behavioral traces. Multimodal sensors (e.g., motion sensors, eye-trackers, physiological data, log data and post-processed video / audio feeds) can address this issue by providing "thick" data about students' learning processes. This development opens new doors for providing just-in time formative feedback, opportunities for reflection, and data-driven decision making. In this short paper, I focus on how social interactions contribute to learning and self-development in makerspaces.

Methodology

Research questions

How can we identify various types of students' social interactions with their peers and the teaching team? More specifically, by combing sensor data and surveys / interviews, can we identify interactions that provide modeling behaviors, or interactions that are useful to learners? How can we detect which students are feeling empowered by being in a makerspace, and which students are not (e.g., are empowered students displaying different behaviors in the space – for example, going through more iterations in their projects and interacting more often with other users of the space)? Which of these indicators are predictive of students' maker mindset? Finally, can these results inform future work where we manipulate parameters of the social experience and learning environment, to optimize students' growth?

Procedure

I am planning to use my course at the Harvard Graduate School of Education (HGSE) as a test bed for answering the research questions above, and eventually organize weekly workshops with students from neighboring schools that work with HGSE and serve underrepresented populations in STEM (these students would complete an after school program at HGSE for several months). I will use the current curriculum we have developed to teach digital fabrication and promote students' self-growth.

Research methods

I propose to use several data sources to conduct this work: 1) interviews with students and the teaching team at the end of the semester, to get a sense of which students went through the kind of transformative learning experience described in the introduction, and how interactions with the teaching staff impacted that transformation; 2) weekly surveys, where we will use the "Sense of Community Index" (Long & Perkins, 2003) to capture students' sense of belonging to the community; 3) a "Mood meter": we have a tablet at the exit door of the space asking students to choose their current emotional state by tapping on emoticons that have the following labels: confident, proud, empowered, delighted, indifferent, frustrated, lost, tired) 4) I have equipped the makerspace where I teach with six motion sensors (Kinect), which allow me to track students in the space, as well as their body postures and proximity to others. We are using the OpenPTrack framework, which

synchronizes and merges data from multiple depth sensors (Munaro, Basso, & Menegatti, 2016). Figure 1 describes the data stream coming from one sensor (left side) and the resulting view after data streams from multiple sensors have been merged (right side). The system can provide students' x,y,z coordinates of each body joints as well as the name of each student after training a face recognition algorithm. This represents up to millions of data points collected every week.



Figure 1: Example of data collected from our makerspace using the OpenPTrack framework (Munaro et al., 2016). Groups of two students are collaborating on each side of the table.

Data analysis

The challenge of this proposal is to reconcile rich data sources collected at different frequencies. In other words, I aim to “span several order of magnitude” (Anderson, 2002) between traditional measures and sensor data. For each week, the data will be processed to identify different types of social interactions (e.g. between makerspaces users, or with the teaching team; identify moments of joint visual attention by inferring participants' line of sight (Schneider, 2015); cycles of individual work and interaction with a peer). Additionally, the Mood Meter data will be used to identify interactions producing various emotions from the sensor data. I will also use bottom-up methods (e.g., unsupervised machine learning algorithms) to categorize types of interactions in the space. Finally, several measures of social interactions will be generated during these phases, by consulting with students, the teaching team and by watching videos recordings of interactions taking place in the makerspace.

Conclusion

There is an adage that “we teach what we can measure.” If we don't spend significant effort in developing new kinds of measurement tools for skills that we care about in education, they were unlikely to be taught. The project described in this paper is just the first step in a multi-year vision of how “thick” process data can support learning and teaching. My goal is to develop best practices in collecting rich sensor data in educational settings, using cutting edge data mining techniques to provide a complimentary understanding of students' learning trajectories, and most importantly use this data to make a difference in people's lives. Data shouldn't just be used for research purposes, but it should be shared with students to increase their agency. On the long run, my hope is that students will be routinely analyzing their own data as a way to better understand themselves. While the use of sensor data for summative assessment is a real concern and should be avoided, I believe that sensor data (in combination with teaching best practices and rich learning environments) can open new doors for formative assessment and empower students to develop the kind of mindset our society will need in the 21st century.

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Facilitating Family Learning in Making and Tinkering Experiences with Computing

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Abstract: Despite growing efforts to broaden participation in creative learning opportunities with computing, troubling gaps remain. Moving beyond access to technology, this paper presents ongoing and future work to explore opportunities that emerge when we engage the broader ecology of family, educators, and community members to support children as they pursue their interests in computing. A key finding through design iterations and early studies highlight the role of relationship building family and facilitator learning and development.

Keywords: Family learning, computational tinkering, computing, making and tinkering

Introduction and background

For more than a decade, educators, researchers, and policy makers have recognized the importance for children to create, express, and build with technology. They can develop as computational thinkers as they engage with concepts, practices, and perspectives supported by computing (Brennan & Resnick, 2013; Wing, 2006). However, there remain troubling gaps in participation (Livingstone & Helsper, 2010; Margolis & Fisher, 2003). To understand how we can support broader participation in creative activities with computing, many argue that we need to move beyond thinking about access to technology and consider the broader ecology of social support and opportunities that surround a young person (Ito et al., 2013; Barron 2004).

Broadly, my research has focused on designing family learning environments and exploring the roles that parents, educators, and other caring adults have played to support children to pursue their interests and explore their identities in the context of computing (Roque, Lin, & Liuzzi, 2016; Roque & Jain, 2018). This research has manifested in the Family Creative Learning (FCL) project, which engages families, particularly from underrepresented groups, in design-based experiences with computing (Roque, 2016). The design of this project builds on constructionist and socio-cultural frameworks around learning (Papert, 1980; Brown, Duguid, & Collins, 1989; Lave & Wenger, 1991) to engage families in personally and socially meaningful experiences with computing. FCL has been a valuable context to study family learning in the context of computing and, more recently, the broader network of relationships and resources to support family engagement such as the role of facilitators and community-based organizations such as makerspaces and libraries.

For the early career workshop, I aim to share recent work to engage children, families, and facilitators in computational thinking opportunities through *computational tinkering*. Our approach to computational tinkering aims to broaden the styles of engaging with computing, providing a more social, physical, and cross-disciplinary alternative to more dominant ways of teaching computing that focus on planning and optimization of a single solution (Turkle & Papert, 1991; Resnick & Rusk, 2019). The project involves an interdisciplinary team of researchers, designers, and educators across informal and formal learning spaces and involves three areas of investigation: (1) the iterative design and development of learning environments for children and their families to engage in computational tinkering opportunities; (2) the study of facilitators' development and their facilitation practices to support family learning; (3) the study of families' and facilitators' joint engagement and development in these opportunities.

Methods

My team and I have used ethnographic and case study approaches to study the emergent interactions and practices and individual learning experiences of families and facilitators. Data sources will include participant observation of facilitators and families, documentation in the form of photos, videos, and audio recordings, project artifacts, and interviews with facilitators and families. In addition, to assess facilitators' and families' development of computational thinking, we will collect their project artifacts and screen recordings of any digital devices. Project artifacts will also us to more closely examine their computer code and any physical materials. Screen recordings will allow us to capture moment-to-moment action on the screen as participants and facilitators interact with tools.

To analyze families' and facilitators' engagement, we plan to build on prior research from the FCL team and the Tinkering Studio at the Exploratorium (one of the collaborating institutions in this project). This includes FCL Facilitation Fundamentals, which were developed together with facilitators from implementations of FCL (Roque & Leggett, 2014), and the Learning Dimensions of Making and Tinkering, which were developed by researchers and practitioners at the Exploratorium to support facilitators in noticing and documenting learning in

their spaces as well as reflect on their how their activities, environment, and facilitation may or may not be supporting learning (Bevan, Ryoo, Vanderwerff, Wilkinson, & Petrich, 2017).

Preliminary findings and contributions

Computing outreach programs often serve children, without integrating other people in the larger learning ecology (Barron, 2004). Children are left to explain and advocate for their interests to their peers, parents, and teachers (DiSalvo et al., 2013). A key finding across design iterations and studies of family and facilitator learning is the importance of relationship building to support participation, learning, and development (Roque & Stamatis, 2019). Iterations of the FCL project involved design decisions that enabled family members and facilitators to interact and build relationships. These design decisions included having dinner together, collaborating on projects, and connecting with peers during separate sessions. Through a shared experience of designing and creating their own projects, families could apply practices that they used in other activities, such as homework help, and adapt it to the context of computing. Families can build connections to this important context in their lives while building relationships within their families and connecting to other families in their community. Facilitators recognized relationship building to be a core facilitation practice that enabled them to connect and support families in their learning experiences as well as disrupt dynamics and beliefs of facilitators as authority figures and experts.

We are continuing to investigate the role of relationship building in this project and are especially interested in exploring the network of relationships within FCL. We aim to illustrate the kinds of opportunities that can emerge when we design learning experiences to build relationships as much as to build projects and practices. These findings have implications for how we design learning environments for children and their families, especially from underrepresented groups in computing. Additionally, when we engage facilitators, we often focus on how we can “train facilitators.” Instead, we advocate for “facilitating facilitators.” When we center learning experiences on relationships, we set up opportunities to build a community of learning, where facilitators also take on the role of learners — people who are learning to welcome, support, and guide diverse learners in designing, tinkering, and making with computing.

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Supporting Youth in Exploring Disciplinary Identities with Learning Technologies

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Abstract: My research focuses on designing and developing innovative learning technologies to support youth in exploring disciplinary identities with the goal of exposing them to career options and preparing them for future career engagement. This summary presents two projects that set the foundation of my research agenda.

Overview

As an educational technologist and learning scientist, I am driven by a passion for addressing educational challenges with the design and development of innovative learning technologies. My work focuses on examining how technology can be used to broaden youth's participation in integrated STEM+L (Science, Technology, Engineering, Math, and Literacy) practices and engage youth in career exploration. In the following, I will briefly explain two projects that set the foundation for my career goal.

PhD research

My doctoral research (Jiang et al., 2018, 2019a, 2019b; Smith et al., 2018) seeks to uncover youth's collaborative learning processes and identity development, and in particular the connection between the two in collaborative multimodal composing environments. This work addresses the knowledge gap of integrating multimodal composing practices (Kress, 2010) in STEM education. As an example, my dissertation, *STEM+ L: Investigating Adolescents' Participation Trajectories in a Collaborative Multimodal Composing Environment*, is situated in an NSF-funded project (STEM+L, PIs: Drs. Ji Shen and Blaine E. Smith). In this project, sixth to eighth graders formed groups of three to five to create multimodal science fiction books (see Figure 1) in iKOS (a CSCL platform; ikos.miami.edu). In this study, we explored youth's participation in STEM+L practices through two theoretical perspectives: disciplinary identity development (Van Horne & Bell, 2017) and community of practice (Lave & Wenger, 1991). This study demonstrated that integrated STEM+L practices mediated by multiple modes can not only offer students flexibility in moving across forms of participation, but also open space for them to demonstrate their expertise as knowledge producers and explore future careers. Important implications were suggested regarding learning technology and environment design to facilitate the cultivation of positive disciplinary identities and the extension of participation in integrated STEM practices.

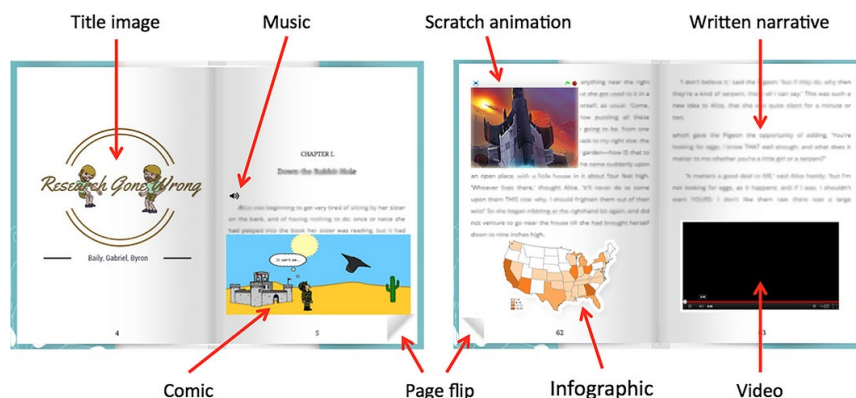


Figure 1. Multimodal science fiction book.

Postdoctoral research

My postdoctoral work at Carnegie Mellon University addresses the need of providing students with automated structural writing feedback, leveraging cutting-edge deep learning technologies (e.g., a subfield of Artificial Intelligence, AI). Funded by the Schmidt Foundation and supervised by Dr. Carolyn P. Rosé, I applied the Rhetorical Structure Theory and deep learning technologies to predict the structure of student essays (Jiang et al., 2019). We are planning a large classroom study with our collaborators at TurnItIn.com. The goal of the technology-enhanced collaborative writing deployment study will be to provide automated feedback towards enhancement of rhetorical structure in student writing.

Current work and future directions

Currently, integrating my doctoral and postdoctoral work, my research focuses on supporting K-12 AI education. In particular, I investigate how digital literacies practices and the ways youth engage with them may provide meaningful opportunities for them to understand and create AI technologies, and learn different pathways to AI-related careers.

Moving forward, I plan to explore how to use deep learning technologies in addressing the need of supporting youth in developing positive disciplinary identities. In the STEM+L project, youth explored and expressed disciplinary identities in collaborative multimodal composition. Some students presented the conflict between how they and others saw their future professions in multimodal artifacts while some students explored what they wanted to be in the future in the multimodal composing process. Deep learning technologies have the potential of identifying identity expression and exploration and support the cultivation of positive disciplinary identities. I am looking forward to examining how deep learning technologies can be used to engage youth in profound STEM learning and STEM career exploration in different contexts.

Furthermore, I utilize my expertise in data visualization to examine how data visualization technologies can be used to 1) engage youth in data science practices (Jiang, 2016; Jiang & Kahn, 2019), 2) facilitate online adult learners to understand and improve learning processes (Jiang et al., 2015), and 3) support communication and decision making in professional domains. For instance, I worked with Dr. Jennifer B. Kahn in studying how youth used big data visualization technologies to build models of family migration. Our work demonstrated that data visualization technologies were valuable instructional tools for supporting learning and communication with others about important and scientific issues and the family migration context positioned minorities as having agency and authority over big data, which addressed the tension of confirming data in the literature. Looking forward, I will continue to leverage the power of data visualization in different learning and professional contexts.

Interdisciplinary collaboration has been essential to my research. In addition to research interests explained above, my areas of study will include a wide range of technologies, approaches, and application areas. I anticipate collaborating with researchers and practitioners from different fields to use technology to address pressing challenges in education and other contexts.

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More Confidently Uncertain? Teaching Learners to Apply Bayesian Methods to Make Sense of Scientific Phenomena

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Abstract: While analyzing data is an important learning in science domains, existing methods and tools for those learning to work with data have key limitations, particularly concerning scientific modeling. This early-stage research is intended to begin a line of work on students' data analysis that is not yet widely used in K-12 learning environments, Bayesian statistical methods, with implications for how learners use evidence in science education.

Goals of the research

The goals of the research are to support science students to make sense of their world through Bayesian methods. This involves middle and secondary classroom-based design research, teacher professional development, and curriculum and statistical software development. If successful, this work has the potential to resolve difficulties with respect to how learners at the K-12 level can work with data in ways that are meaningful and empowering to them and to better prepare learners for subsequent coursework or areas of study that involve quantitative or computational dimensions. This work also has the potential to broaden conceptions of the courses in which complex work with data takes place, from mathematics and statistics to science classes.

Background

Working with data and data literacy are important capabilities individuals' everyday lives and in many domains, particularly scientific and engineering (Lovett & Shah, 2007). There have been a number of efforts to make data literacy more accessible to more individuals, including pedagogical approaches (Lee & Wilkerson, 2018; Lehrer & English, 2018). One set of strategies focuses on curricula (Lehrer & Schauble, 2004), while others focus on developing *tools* to make it easier for students to work with data (Konold et al., 2017).

While these tools that have been developed have strengths, none allows students to fully engage in the kind of data analysis activities that professionals do. A commonly-used tool, the Common Online Data Analysis Platform (CODAP) is well-suited to exploring data, but does not allow for more sophisticated data processing pipelines, like analyzing data from two sources. The SAGE Modeler tool allows for pipelines but is designed to be used primarily for computational models of complex systems, and therefore is not designed for the most widely-used statistical analyses. In the context of these tools available for learners to work with data and *technical* opportunities for enhancements, there are also *cognitive* challenges that learners face. Modeling data, and doing so to explain variation, is a core capability, but is also challenging for learners (Lehrer & English, 2018), who may tend to represent *all* of the data they collect, instead of summarizing the data with a statistic or model (Lehrer & Schauble, 2004), or may find hypothesis-testing to be counter-intuitive.

One solution to the technical and learning-related challenges is an approach that has not been widely used outside of the professional practice of statisticians, data scientists, and engineers, Bayesian methods. Bayesian methods have become popular because they allow scientists and engineers to understand and make statements about how likely phenomena in the world are--even highly complex phenomena, like voting in elections, when births occur within the year and over time, and where radon in the soil beneath homes may be a hazard to individuals' health (Gelman et al. 2013). While developmental psychologists have explored Bayesian thinking on the part of young children (see Gopnik, 2012, for a review), this work has often taken place outside of K-12 learning environments. Yet, Bayesian methods provide a helpful way to approach work with data and data literacy in terms of modeling, one which emphasizes making inferences about phenomena, in addition to (or instead of) carrying out hypothesis tests as a part of more commonly-used statistical approaches.

Methodology and preliminary findings

During the 2018-2019 academic year, I engaged in preliminary research: developing curricula and related to involving students in analyzing data sources from scientific studies. I focused on using CODAP and helping students to work toward developing data-based scientific explanations for phenomena. This work was encapsulated in a practitioner-focused article that described (for teachers) how students can use CODAP to analyze complex (and even messy) data in secondary science classrooms (Rosenberg et al., 2020a).

In the 2019-2020 year, we continued this work, with an emphasis on not only analyzing already-existing data from scientific studies but also supporting students to analyze data that they collect (and to record and

structure this data). I also have used R and R Markdown with students in the classroom of a collaborating teacher. This work has presented new opportunities (such as for students to report that the work was akin to their prior experiences in programming) as well as challenges (such as how to remain focused on being able to answer scientific questions, rather than emphasizing how to write code in R and how to use R).

At the same time, during the 2019-2020 year, I have been involved in projects that are complementary to this work and which suggest new directions for it. In particular, I began a National Science Foundation-funded project focused on providing greater opportunities for students to be involved in computer science (in light of new K-8 computer science and computational thinking standards in the state of Tennessee). Building on earlier work about how students model data from a computational science simulation (Rosenberg & Lawson, 2019), I have also begun to explore the role of data science in education through in scholarship (Rosenberg et al., 2020b). This work has collectively emphasized the potential utility to students of more accessible and useful statistical methods in science education contexts.

This work over the past two years informs the method for the proposed line of work in support of supporting science students to make sense of their world through Bayesian methods. The proposed work will involve working with more than the one collaborating teacher with whom I have worked; I am planning to work together with four area teachers. Design-based research is essential for developing curricula and pedagogical strategies, but a more systematic research strategy is also needed. The research plan will involve designing curricula for an approximately eight-week unit. The work will also involve modifying CODAP to address the main limitation I found from its use in prior research projects: making it easier to use as a part of a data processing and analysis workflow, through adding functionality to write code which can be run and reproduced.

Expected contributions

Particularly in science education, an approach to modeling that emphasizes understanding how likely different outcomes or values has the potential to resolve challenges. A key expected contribution has to do with Bayesian methods being more accessible to learners. Another contribution concerns how existing tools may need to be changed to support a Bayesian approach to modeling and inference may be designed in line with what is known about the development of statistical software that is useable by learners (McNamara, 2019). As a technique that depends on computation, this work has some implications for research on computational thinking, especially in science education (Sengupta et al., 2013). Last, this work may contribute to data science education, especially within science education contexts, but also as a set of capabilities that may useful to learners across the curriculum.

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Pedagogical and Conceptual Supports for Agency-Driven Science Practices in Knowledge Building Communities

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Abstract: Recent reforms in science education and other areas call for efforts to engage students in authentic knowledge practices in which they need to take on new roles as epistemic agents. My research focuses on how to support student agency-driven knowledge practices in technology-rich environments. This summary presents the reflective structuration approach as a conceptual framework to guide my current and future work to transform classrooms into knowledge building communities and support agency-driven science practices.

Research overview

Recent reforms in science education and other areas call for efforts to engage students in authentic science practices in line with how knowledge is constructed and practiced in the real world (e.g., MOE of People's Republic of China, 2017; NRC, 2012). To engage students in authentic science practices, students need to take on a new role as epistemic agents, who (individual or groups of learners) take on high-level responsibility to shape and adapt knowledge practices to address emergent problems and knowledge goals (Scardamalia, 2002; Stroupe, 2014). My research explores pedagogical designs to engage young students as epistemic agents drawing upon the knowledge building theory developed by Scardamalia and Bereiter (2014). This approach requires the teacher and students to co-construct and reconstruct the flow of inquiry processes as their work proceeds guided by a set of knowledge building principles (Scardamalia, 2002; Zhang et al., 2011). The principle-based approach holds promise for enhancing students' high-level agency over creative, ever-deepening knowledge processes. However, implementing knowledge building in broad classrooms confronts the challenge of how the student-driven, interactive actions of inquiry may be socially organized and pedagogically supported in a way that engages student epistemic agency.

Reflective structuration of science practices in knowledge building communities

To transform science classrooms into knowledge building communities, a reflective structuration approach was developed, which highlights a new socio-epistemic mechanism to guide and sustain student-driven, knowledge building practices (Tao & Zhang, 2018; Tao, Zhang, & Gao, 2018; Zhang et al., 2018). Different from the dominant designs to guide student inquiry using pre-scripted tasks and procedures, reflective structuration represents a reflective, emergent process by which members of a community rise above their diverse, often seemingly messy idea input to formulate emergent directions, clusters, and norms of inquiry. These directions, clusters, rules, and norms of inquiry become shared inquiry structures to channel their individual and collaborative actions for knowledge building. These structures emerge from the community's ongoing interactions provide shared interpretative frames of the unfolding knowledge practices. They are further reified and represented using various structure-bearing artifacts and resources, such as using a chart of inquiry problems, which were called "juicy questions" by teachers and students, to highlight the inquiry foci and directions (Tao & Zhang, 2018; Tao, Zhang, & Huang, 2015; Tao, Zhang, & Gao, 2018; Zhang et al., 2018); or using a chart of possible actions of inquiry, which were called "research cycle" by the community to guide their daily monitoring and planning of inquiry in the classroom and online (Tao & Zhang, 2018). As these previous studies suggest, co-constructing shared inquiry structures over time provides a means to guide student knowledge building in which they are positioned as epistemic agents. In a knowledge building community, members appropriate existing structures historically formed in their school contexts, use the structures to plan and guide their ongoing actions, reflexively monitor what is going on in individual and collective actions, and in this process contribute to adapting and transforming the structures of inquiry in response to unfolding opportunities and goals.

Current and future projects

In light of the emergent process of reflective structuration, my current research makes a further step to elaborate a systematic design framework to guide the implementation of long-term knowledge building practices in science classrooms. This design framework embraces a shift of design thinking from prescriptive to emergent design. The emergent design approach represents a productive strategy to design complex social systems and spaces (Johnson, 2001; Sawyer, 2005). Figure 1 presents an initial model of the design framework, which includes working with

initial structures to engage students in open exploration of problems and ideas, reflective capturing of emergent directions, connections, and patterns of inquiry and creating/adapting shared structures accordingly, and reflective use of the structures to inform deeper knowledge building work and discourse, leading to further adaptation and reorganization of inquiry structures over time. My current funded project adopts a design-based research methodology with three iterations in several grade 5-6 science classrooms to test and refine the conceptual and design framework.

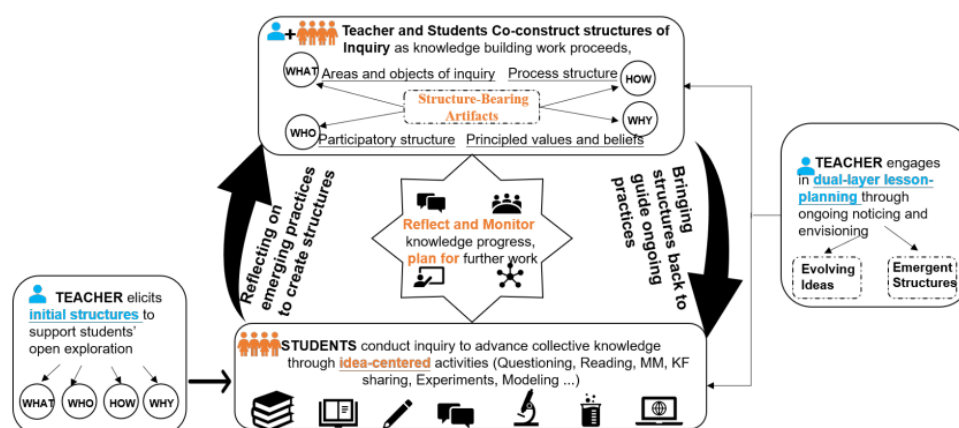


Figure 1. Emergent design of knowledge building practice through ongoing reflective structuration.

Research indicates that teachers who seek to facilitate productive learning need to attend and respond to students' evolving thinking over time (Furtak, 2012). Working the emergent design framework, the teacher needs to engage in reflective noticing at both the idea level and the meta-level of inquiry structures and to understand students' evolving ideas while making sense of emerging structures and patterns to scaffold responsive moves. My future work focus on designs and support based on the idea of learning progression as ongoing formative assessment tools to support teachers' reflective noticing and envisioning (Alonzo & Elby, 2019).

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Doctoral Consortium

'Watching My Freedom:' Consequential Forms of Critical Literacy in Trans and Queer Digital Worldmaking

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Abstract: This dissertation project follows the digital activities of transgender and gender-expansive teens to expand what we know about equitable forms of learning with an intersectional justice lens. I employ a multi-method, nested study design to trace the *consequential forms of critical literacy* in trans and queer digital worldmaking. I characterize consequential forms of critical literacy as the ways of being and doing that matter to marginalized communities interrogating relations of power toward transformative justice.

While digital media technologies weave through the daily lives of youth (Lam, 2009), most research on the forms of literacy these technologies support takes place in formal learning environments (Shrodes, in press). The focus on schools and out-of-school programs constrains our ability to mobilize how youth learn *consequential forms of critical literacy* in everyday social media use. I characterize consequential forms of critical literacy as the ways of being and doing that matter to marginalized communities as they interrogate relations of power toward transformative justice (Vasquez, Janks, Comber, 2019; Zavala, 2016; Jurow & Shea, 2015). This constraint has particular consequence for research with LGBTQ+ youth broadly and transgender and gender-expansive youth specifically, who are more likely to use social media (e.g. Twitter, YouTube, Reddit) and use it with more frequency as they navigate school environments that reproduce normative logics perpetuating discrimination, victimization, and erasure (GLSEN, 2017). Though classrooms can also be sites of emancipatory activity (e.g. Gutiérrez, 2008), classrooms often push out forms of learning that thrive on social media.

I draw on sociocultural perspectives and theories of *worldmaking* at the nexus of educational studies, queer of color critique, and queer theory to trace consequential forms of critical literacy on social media. I follow a tradition of sociocultural theory that holds that youth learn by participating in purpose-driven activities mediated by social relationships and cultural artifacts (e.g. Cole, 1998). Building on theories of worldmaking (e.g. Holland, Lachicotte, Skinner, & Cain; Lugones, 1987; Muñoz, 2009), I theorize *trans and queer digital worldmaking* as the digital activities in which transgender and gender-expansive teens construct, traverse, and transform social and symbolic spaces, as well as social frames and practices, through engagement in digital media technologies.

I will explore how activities of queer and trans digital worldmaking with transgender and gender-expansive teens emerge, take hold, and change across contexts, as well as what these activities make possible for teens. I take up three questions: 1) How and why do transgender and gender-expansive teens construct, traverse, and transform trans and queer digital worlds? 2) How do activities of queer and trans digital worldmaking unfold across contexts and scales? 3) In what ways do teens narrate these activities and the possibilities digital worldmaking opens up?

This dissertation project innovates in its multi-method approach, invoking the tradition of qualitative *bricolage* to integrate a range of theoretical and methodological perspectives in the social sciences and humanities to account for the complexity of the phenomenon and the act of research (Kincheloe, 2001). I employ case study methodology (Yin, 2003; Lam, 2009), ethnographic perspectives (Leander & McKim; Vossoughi & Gutiérrez, 2014; Erickson, 2004), and humanistic approaches to design a nested, sequential study and to construct my findings.

To conduct this project, I have partnered with an interdisciplinary gender program in a pediatric medical center in a large Midwestern city that provides wraparound services to transgender and gender-expansive children, adolescents, and young adults. We share the goals to better understand the role of social media in the lives of transgender and gender-expansive teens and improve care and educational experiences. We recruited participants ages 13-19 who identify as transgender and gender-expansive and regularly use at least three forms of social media.

The 21 participants in stage one speak from a wide range of social positions based on age, race and ethnicity, class, gender identity and expression, sexuality, 'outness' about their gender identity and sexuality, and urbanity to rurality. Fifty-two percent of participants identify as white, followed by 23% biracial or multiracial, 20% Latinx, and 5% Black. Sixty-two percent of participants identify as transgender men, followed by 24% within the non-binary umbrella, and 14% transgender women. Ninety-five percent of participants identify as lesbian, gay, bisexual, pansexual, queer, or asexual. Selection for subsequent stages are driven by attention to intersections of identity and by case-study logic to pursue both literal replication of emergent findings and theoretical replication by pursuing divergent patterns that substantiate theoretical claims (Yin, 2013, p. 47). For the final stage of data collection, the site extends to participants' homes and community contexts (Lam, 2009).

In July 2019-September 2020, I am collecting data over three research stages: Stage 1) In-depth interviews, artifact observations, and surveys with validated scale of online social connectedness and gender minority stress and resilience with 21 participants in the gender clinic from July-September 2019; 2) follow-up semi-structured interviews and structured, standardized YouTube video think alouds with 16 focal participants in the gender clinic from October-December 2019; 3) ethnographic case studies of everyday social media activities grounded by participant observation with five to eight teens in homes and community contexts from June-September 2020.

I will complete analyses during data collection to construct patterns, as well as after data collection to construct findings across a range of data sources using NVivo. I conduct initial and focused coding of interview transcripts, field notes, and artifacts (Miles, Huberman, & Saldana, 2019). I also write weekly analytic memos. After logging videos, I analyze video data using Knowledge Analysis to assess social frames (Scribner & Cole, 1981) and Interaction Analysis to assess how the video mediates shifts with attention to multiple modalities (Erickson, 2004). I will analyze stories indexed from interviews through close reading. I regularly conduct member checks to validate findings and workshop the codebook with partners at the program to discuss patterns and implications for care.

Through preliminary analysis of in-depth interviews with 22 teens, I found teens construct ‘worlds’ through which they resist and disrupt experiences of transphobia and homophobia in school. They do this by watching LGBTQ+ YouTube videos that comically ‘react’ to discriminatory media. The stories teens share with me also help us see what it looks like for education to affirm and celebrate transgender and gender-expansive students.

This study positions the digital activities of transgender and gender-expansive teens as consequential to expand what we know about equitable forms of learning and literacy with attention to intersections of race, class, gender, sexuality, and ability. This study will expand theory on critical literacy and learning on social media. This research also has purchase to inform design and pedagogy that affirm and celebrate transgender and gender-expansive students in today’s media-rich learning environments in and beyond school.

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Higher-Education Language Teachers Learning How to Design Learning Tasks in which Augmented Reality is used

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Abstract: Teachers have the opportunity to use Augmented Reality (AR) to enrich language learning. However, little is known about how they can use AR to improve teaching and learning. Hence, more involvement of teachers and other non-technical stakeholders (e.g. students and learning designers) in the design of learning tasks in which AR technology is used is needed. The engagement of end-users, in a participatory design approach, aims at bridging the gap between design and use phase.

Background

In Education, interest in AR has grown from STEM (Akçayır, Akçayır, Pektaş, & Ocak, 2016; Coimbra, Cardoso, & Mateus, 2015) to the humanities (Billinghurst & Duenser, 2012; Scrivner, Madewell, Buckley, & Perez, 2019). However, we still do not know how (language) teachers can use AR to improve teaching and learning in light of the fact, in AR educational research studies, they tend to play a passive role (Silva, Roberto, & Teichrieb, 2013). Indeed, teachers are often considered as “technology end-users” without being co-participants in the design of educational technologies. This means there exists the increasing need of involving teachers in the design of learning tasks in which AR technology is used to understand not only about the pedagogical affordances of AR, but also to give them control over AR like other educational resources.

This raises the question of how to meaningfully engage teachers into the whole learning design process of learning tasks integrating technology (from a generative stage of ideas to a low-fidelity paper prototyping through a norming and prioritizing stage) rather than involving teachers at a later phase to receive feedback when fundamental (pedagogical) decisions have already been made.

Within the learning sciences, co-design (Penuel, 2014; Penuel, Roschelle, & Shechtman, 2007; Severance, Penuel, Sumner, & Leary, 2016; Voogt et al., 2015) and participatory design (Cober, Tan, Slotta, So, & Könings, 2015) have engaged teachers and/or students with designers and researchers with the aim of gaining a better understanding about stakeholders’ needs. Additionally, above approaches have led to the empowerment of the participants and the creation of (technological) innovations with an increasing usability and usefulness (Holstein, McLaren, & Alevan, 2019). However, more work is needed to investigate how non-technical stakeholders can participate in the design of learning tasks in which AR technology is used and how challenges related to AR can be addressed in a way that pedagogical principles, learning goals and teaching practice are preserved.

Goals of the research

This study will seek to answer the following research questions: (1) What kind of resources do teachers draw on when learning how to design learning tasks in which Augmented Reality is used in a participatory design? (2) In what way can the belief system of teachers about Augmented Reality be a mediating tool in a participatory design approach?

Methodology

Participants will be attending a participatory design workshop. A pilot study was undertaken in November 2019.

Example actions, as grounded specific instances of activities extracted from a participatory design approach (video-recorded), will enable to investigate participants’ socio-material practice when learning how to design learning tasks in which AR is used. According to socio-materiality, there exists an “entanglement of the social and the material in everyday life” (Orlikowski, 2007, p. 1435). This theory analyses the relation between humans, resources, tools and technologies with language, interaction and practice within a certain environment of practice. Given the interest in investigating the resources that teachers may be using during the workshop when learning how to design learning tasks in which AR is used, I will be adopting a bottom up approach and designing my own coding scheme. In this context, resources refer both to teachers’ competences, intellectual resources, skills, knowledge and social interactions that they may establish during the workshop. In the first instance, the focus will be on the kind of resources that teachers may use or refer to while learning how to design learning task involving AR. Instead, from a social perspective, a particular focus will be on questions that teachers may be posing to other participants. Such questions may be shading a light on how they are used by teachers as a ‘tool’ to articulate their own difficulties or how the feedback received is used to address a specific issue.

Activity Theory (Engeström, 2000) will be the analytical lens to understand the fluidity of the workshop, conceptualized as an activity involving the “horizontal widening of collective expertise by means of debating, negotiating and hybridizing different perspectives and conceptualizations” (p. 960). Teachers will be entering the workshop with a set system of beliefs and orientation towards AR. Through their discourse and participation in the workshop, the aim is to understand how their activities are connected to the technology and how their belief system mediates the achievement of certain objects. Mwanza-Simwami (2013)’s Activity-Oriented Design Method (AODM) will help firstly disentangle the complexity of the activity system and then make explicit the “interrelatedness” between and among each component of the activity. I will be adopting a bottom up approach and designing my own coding scheme upon analyzing the workshop and semi-structured interviews, conducted before and after the workshop to capture teachers’ belief system. I will be looking at the spectrum of language (from acceptance to resistance, from certainty to uncertainty), direction of emotions (from positive to hesitant, from useful to useless, from firm to vague), quality of argument for using or not AR, and (future) actions for AR integration in teachers’ teaching practice.

Expected findings

By June 2020 data collection (April 2020) will have taken place and data analysis will have started.

Expected contributions

Findings will draw attention on the importance of understanding how higher education language teachers can learn how to design AR with implications on future approaches to Professional Development. The study will be also contributing to the field of the Learning Sciences by further expanding the discussion on participatory design knowledge and efforts.

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Native Computer Science Connections Ecosystem: An Exploratory Study Examining the Connections Between Culture and Technology in Indigenous Communities Across Utah

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Abstract: The purpose of this study is to examine processes through which tribal communities and academic institutions co-design and co-implement computer science education programs for Indigenous young learners. My dissertation explores how to engage Indigenous young people as they learn about design and computational practices while also fostering their own cultural awareness. The findings from this line of research has implications for access and equity in how we think about computer science interventions for Native youth.

Research summary

While American Indians/Alaskan Natives (AI/ANs) account for two percent of the U.S. population, they make up only 0.2 percent of those employed in science and engineering occupations, meaning AI/ANs are significantly underrepresented in scientific and technological fields (National Science Board, 2015). Challenges regarding inequitable access to learning opportunities (Margolis, Estrella, Goode, Holme, & Nao, 2008) as well as other unique historical, economical, and cultural factors (Varma & Galindo-Sanchez, 2006; Varma, 2009) contribute to low recruitment and retention of AI/ANs among scientific and technological fields, especially computer science (CS). Over the past few years, the number of Latinos and African-American students to take CS-related Advanced Placement (AP) exams has almost doubled (College Board, 2018b). However, these trends are not reflected across all racial groups. For example, only 88 AI/AN students took a CS-related AP exam among the thousands of students to take one in 2018 (College Board, 2018a). Some intervention programs have been implemented in order to increase scientific and technological expertise among AI/AN youth (e.g. Lameman, Lewis, & Fragnito, 2010; Kafai, Searle, Martinez, & Brayboy, 2014). While Indigenous youth may benefit from such programs, many also feel disconnected from their cultural backgrounds and struggle to see themselves belonging in scientific and technological environments where they are a small minority (Varma & Galindo-Sanchez, 2006; Varma, 2009).

The Northern Utah Native Connections program is a Title VI, federally-funded program dedicated to meeting the “unique educational and culturally-related academic needs of Native American and Alaska Native students with culture, community, and education” (“Northern Utah Native Connections,” n.d.). The goals for their program include to: (1) provide mentoring while monitoring the academic success of AI/AN students, (2) promote college and career readiness of AI/AN students, and (3) increase communication between the school and parents/guardians of AI/AN students. The Indigenous parent council for the Northern Utah Native Connections program emphasizes the importance of “self-esteem, healthy-living, and culture” alongside fundamental mathematics and language arts skills. With these principles in mind, we propose an CS-ecosystem model (Traphagen & Traill, 2014), or network of partners working together, to teach Indigenous youth key communication and computational design skills that are also culturally-relevant in nature. To better meet the needs of Indigenous youth in the Northern Utah Native Connections program, I will leverage existing partnerships with tribal and non-tribal partners that we have developed over the past year. I will continue to work with key stakeholders to facilitate this process. Stakeholders include educators, mentors, family members, and Indigenous youth. I will actively engage community stakeholders in the co-design and co-implementation of our proposed workshops.

Modeled after Lewis-Warner, Allen, and Noam (2019), I will employ a case-study methodology (Yin, 2002) that will include the collection of multiple qualitative data sources including participant work, ethnographic observations, audio/video recordings, and participant post-interviews. I will use data collected during workshops and community meetings to construct my cases. During the workshops, participants will be building digital media and participating in community conversations and storytelling sessions centered on AI/AN cultures. A typical workshop will last up to four hours a day for one to two weeks.

Endnotes

- (1) Throughout this discussion, I use American Indians/Alaskan Natives, AI/ANs, Indigenous, Aboriginal, and Native interchangeably.

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Promoting Young Children's Ecological Literacy Through Multiliteracies Pedagogy and Design Thinking

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Abstract: By integrating design thinking, the multiliteracies pedagogy and sociocultural theorizing, this PhD study aims to develop a novel pedagogy for school contexts to support children developing their ecological literacy, which is argued to be essential to understand sustainability issues. Exploring the perspectives of teachers and children in two qualitative case studies, this study intends to provide a holistic understanding of the pedagogical intervention that is needed to guide practice and policy-making regarding environmental education.

Rationale of the research

It has been argued that ecological literacy is essential for children to develop knowledge and understanding of complex sustainability issues (Stone & Barlow, 2005; Wong & Kumpulainen, 2019). However, teachers find that they lack knowledge on how to enhance children's ecological literacy skills in primary school contexts (Cutter-Mackenzie & Smith, 2003). Responding to this demand, the aim of this PhD study is to bridge this research gap by developing a novel pedagogy, preliminarily named ecological multiliteracies pedagogy, as an approach to support children developing their ecological literacy. This novel pedagogy, extended from my master's thesis (Wong, 2018) as a learning intervention, aims to engage children in exploring the interconnectedness of themselves and natural systems through holistic learning across imaginative stories, art, science and empirical experience in the natural environment. The leading research question is: *How can ecological multiliteracies pedagogy enhance children's development of ecological literacy?*

This PhD study integrates design thinking (Cross, 1982) and the multiliteracies pedagogy (New London Group, 1996) with sociocultural theorizing (Vygotsky, 1978; Fleer, 2015) as theoretical tools for the analysis. The sociocultural perspective taken in this study views social-, material- and multimodal interactions between children and their teachers in sociocultural contexts as critical for children's ecological literacy skills development and sense-making of the natural environment. This study connects sociocultural theorizing with multiliteracies pedagogy by extending it to function as a basis for developing the ecological multiliteracies pedagogy. Multiliteracies pedagogy and ecological literacy share similarities in emphasizing multimodality and holistic learning. Multiliteracies pedagogy underlines the importance of multiple modalities in representation and meaning-making. Whereas, ecological literacy (Orr, 1990) refers to the ability to realize the interconnectedness of human and natural systems. It stresses going beyond basic literacy skills towards capability to observe nature and relate knowledge with quality of thoughts. The ecological multiliteracies pedagogy urges to combine these two pedagogical insights to create an educational framework to foreground children's empathy, systematic, critical and creative thinking over their natural environment. To implement the pedagogy, design thinking is utilized as an approach supporting teachers framing the pedagogical interactions for ecological literacy enhancement. Design thinking generally refers to the engagement in an analytic and creative process of: experiment, create and prototype, gather feedback and redesign (Cross, 1982).

Methodology and preliminary findings

This PhD study will comprise four empirical articles and a summary and each of the following sub-questions will be investigated respectively in the articles: 1) the possibilities of ecological multiliteracies pedagogy: how do novel designs informed by multiliteracies pedagogy engage children in the learning of ecological literacy? 2) design thinking as an implementation approach: how does a design thinking approach support teachers to create pedagogical ideas to promote ecological literacy? 3) the role of teachers and materials: how do teachers and materials support children's engagement in ecological literacy learning activities? 4) children's ecological literacy development: how does children's ecological literacy reasoning, in particular, their understanding of interconnectedness between human and natural systems develop through multiliteracy pedagogy? This project applies an exploratory case study method (Yin, 2009). Two case studies will be conducted in two contexts: education-practitioners' (n=12) professional development for ecological literacy education in a university and children's learning (7-9 years old, n=60) of ecological literacy in a Finnish primary school. The primary data which consists of video recordings of participant's interactions will be analyzed by using multimodal interaction analysis (Norris, 2004). Sociocultural theorizing (Vygotsky, 1978) provides theoretical tools for the analysis of socio-materially mediated interaction. The multimodal interaction analysis focuses on studying the multiple modes of communication in participants' interaction, including conversations, non-verbal body movements and

the role of space and objects in the interactions. Secondary data consists of interviews will be analyzed by using qualitative content analysis (Kvale & Brinkmann, 2009). To integrate design thinking approaches into the pedagogical application, this study will utilize a transdisciplinary approach across design and educational sciences disciplines. Co-design and participatory methods (Sanders & Stappers, 2008) will be used to engage stakeholders in the investigation of functional educational practices in ecological literacy education.

The preliminary findings of the first case study show that an appropriate design structure, thinking styles and facilitation can enhance the quality of education-practitioners' creative outputs of pedagogical ideas through co-design activities. In the second case study, the preliminary findings show that utilizing imaginative stories and characters can effectively engage children to discuss climate issues from the perspective of 'nature', with a strong sense of empathy and positive emotion. However, the findings also indicate tensions in implementing a new pedagogy and learning practices in the classroom.

Expected contributions

This doctoral study aims at widening the understanding of teaching and learning practices of ecological literacy. It will develop a novel pedagogy as an accessible approach for education-practitioners and children to make sense of ecological, environmental and sustainability topics. Design thinking will be introduced to teachers for implementing this pedagogical approach in teaching practices. The study also aims at generating further strategic interventions, such as pedagogical materials, pedagogical planning frameworks and professional development program schemes, contributing to practices and policy-making regarding ecological literacy education and environmental education within schools.

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Investigating Learners' Feedback Seeking Behavior and Its Role in the Development of Representational Competence

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Abstract: Feedback seeking behavior (FSB) is a learner initiated dialogue to attain the instructional goals. This is in contrast to the predominant notion of feedback as one way transmission of information from teacher to learners. Currently FSB has been primarily investigated in the workplace context. Drawing from these studies, I adapt a well-established cost-value framework aligning it with the cultural-historical activity theory to investigate learners' FSB and its role in the development of their representational competence.

Background and research goals

There is an increasing expectation from stakeholders in education that teachers continuously monitor learners' performance and provide frequent formative feedback (Boud & Molloy, 2013). But major reviews have found the effects of such feedback on learning to be highly variable, inconsistent and even negative because of multiple interfering factors (Lipnevich & Smith, 2018). Classroom realities such as learner diversity, class size and teacher workload make the teacher driven feedback even more unsustainable (Boud & Molloy, 2013). So studying the conditions under which learners' proactively seek feedback and when and how such feedback seeking contributes to better learning is crucial for informing the design of sustainable learning environments.

I have adapted cost-value framework of feedback seeking behavior (FSB) from organizational behavior research as an analytical lens for studying educational context (Anseel, Beatty, Shen, Lievens, & Sackett, 2015). My adaptation as represented in figure 1 aligns with the cultural-historical activity theoretical approach to learning (Engeström, 2009). It suggests that interaction between characteristics of instructional artefacts and rules, the learner (subject), feedback sources (community) and the nature of cooperation (division of labour) influence learners' perceptions of cost and value in seeking feedback. This in turn determines the variables of FSB (object). Outcomes of FSB in my study align with that of representational competence (RC) such as gaining understanding of when and how to use models or diagram translation (Padalkar & Hegarty, 2015).

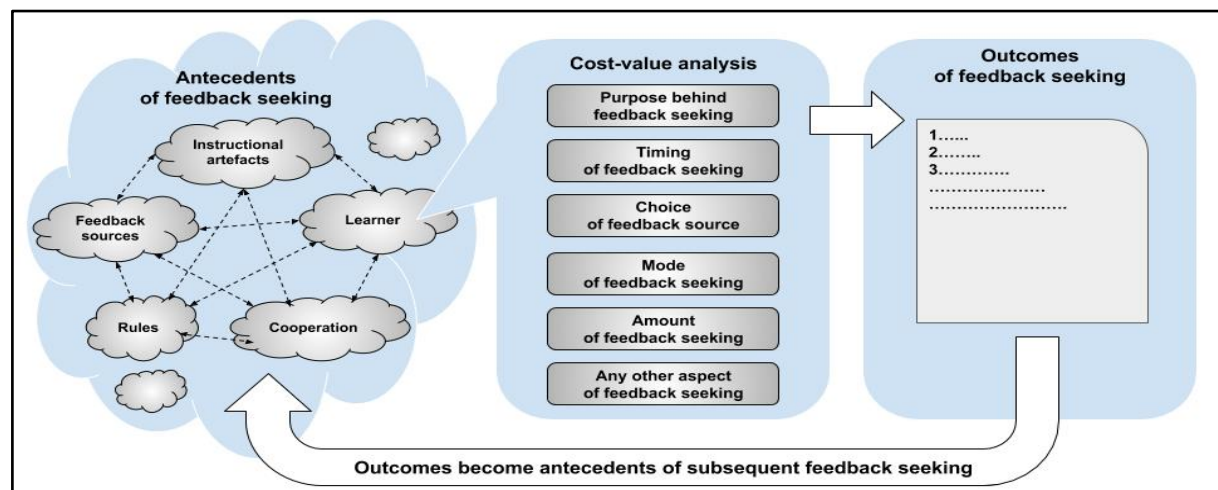


Figure 1. Cost-value framework of learner's feedback seeking behavior.

The above framework enables me to account for cognitive, emotional, motivational and identity dimensions; a much needed comprehensive view of the learner during the feedback process (Lipnevich & Smith, 2018). It also views feedback as the need for dialogue rather than as a one way transmission of information from teachers or peers to the learner (Boud & Molloy, 2013). Here dialogic interactions amongst peers, teacher and the mediating tools or conditions in the instructional environment are considered as central to the learners' feedback seeking process leading to their meaning making.

Research questions

1. How does the interaction between different characteristics such as instructional artefacts, rules, the learner, feedback sources and the cooperation influence various aspects of feedback seeking such as the timing or amount of feedback seeking, the purpose for which feedback is sought, the choice of feedback source and also the mode of seeking and using the feedback received?
2. When and how does learners' feedback seeking behavior contribute to the development of their representational competence?

Method

In my study, students were given a problem on synthesis of a medicinal drug called 'Warfarin' which is commonly used for treating complications arising due to blood clots. It requires them to interpret symbolic representations of chemical reaction steps, determine spatial arrangements of the intermediate chemical formed and predict the expected drug using chemical concepts. Here spatial arrangement of the drug formed is critical since its therapeutic effectiveness is tied to it. To solve the problem, learners had to go beyond just verbal exchange of feedback and build complex molecular models or sketch multi perspective diagrams while seeking or providing feedback. This helped generate more observable and analyzable artifacts.

I adopted a single case-study approach where undergraduate students of stereochemistry course participated in an hour long activity. Data was collected through video recording of participants' interaction with each other and researcher. Data analysis was done using a microgenetic method in which high density observations are made spanning the event's timescale which is suitable for uncovering highly variable processes leading to the emergence and stabilisation of new representational behavior. To arrive at inferences, I employed competitive argumentation with fellow researchers. The unit of analysis is an episode of proactive feedback seeking where decisions such as the timing of feedback seeking and others referred to in the research question were all made by the participants themselves. One episode is distinguished from another by considering the change in the purpose for which feedback is sought. For examining characteristics related to instructional artefacts, learner and feedback sources, I went back and forth a few seconds before and after the episode.

My analysis suggests that the amount of FSB measured in terms of conversational turns varies significantly with different forms of model based reasoning required by the task. Timing of feedback seeking was observed to be based on learners' estimate of cost and value associated with sourcing feedback information from peers or researcher as opposed to generating it by drawing from one's own internal resources and/or working with the available tools. Factors contributing to such an estimate of cost and value included not just cognitive aspects but also emotional, motivational and identity aspects. Both the timing and choice of external feedback source were also observed to occur as a result of learners' cost-value analysis of feedback availability and non-availability cues emerging dynamically amongst peers. With regard to the characteristics of feedback source, learners' perceived proficiency of source and the actual proficiency were found to affect the nature of FSB. Conditions generating optimal feedback seeking was positively correlated with instances where peers demonstrated their representational competence to each other. Findings hold promise in potentially informing design of instructional contexts with sustainable feedback practices for supporting development of learners' RC.

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Debugging Together: Learning Communities in Computing Classrooms

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Abstract: Even though debugging is an essential computing practice, it is rarely taught, perhaps because the process of learning to debug is not well understood. And while debugging is often conceptualized of and taught as a solitary act of perseverance, this conception ignores the many problem-solving benefits of social learning activities. This research investigates how young people, alongside their teachers, co-create learning communities in two computing classrooms. Findings from this work will inform researchers and teachers about how to better support students in learning to program, together.

Goals and background

Although debugging is an essential computing practice, and computing education has spread widely in PK–12, debugging is rarely explicitly taught, perhaps because the process of learning to debug is not well understood (McCauley et al., 2008). In accordance with society’s individualist conceptions of schooling, students are often taught that debugging is a solitary act of perseverance and grit, and if they are truly stuck, they should consult their teacher (i.e., the “expert”) for help (Price, Liu, Catet, & Barnes, 2017). Running counter to that instructionist conceptualization, social learning theories offer a vision of learning together, where novices work together to develop expertise (Murphy, Fitzgerald, Hanks, & McCauley, 2010; Sawyer, 2006).

However, learning communities are often dependent on learners being able to observe, learn, and ask for help from trusted community members with expertise, such as teachers and experienced peers (Sawyer, 2006). In many K-12 computing classrooms, teachers themselves are often novices (Blikstein, 2018), and young learners’ class and cultural backgrounds can affect whether and how learners might ask for help at all (Jack, 2015). A focus on individual knowledge transmission also runs the risk of taking a deficit lens (e.g., “What do learners not know?”) and ignores collectivist ways of knowing (e.g., “What can learners figure out together?”) (Esmonde & Booker, 2016). To address these challenges, this study focuses on a central research question: “*How do teachers and students co-construct a learning community and deepen their computational fluency?*”

Theoretical framework

Some novice programmers have been found to employ a wide range of both individual and collaborative debugging strategies (Brennan, 2013), but debugging research has often focused specifically on individual learners’ mindsets and errors (Li, Chan, Denny, Luxton-Reilly, & Tempero, 2019), even though social interactions can support powerful learning experiences for novices (Lave & Wenger, 1991). In particular, researchers have suggested the need to make visible the role of intentional teaching practices and structures in learning environments in order to increase equity and access to learning for all students (Vossoughi, Hooper, & Escudé, 2016).

In this study, I consider not only *what* students are learning, but also *how* they are learning and *with whom* they are learning. I draw from socio-constructionist theories of learning that highlight the ways in which engaging in learning communities can support the development of expertise and account for how learning can take place not only from teacher to student (or “expert” to “novice”), but also between peers or near-peers (Lave & Wenger, 1991; Smith III, Disessa, & Roschelle, 1994). This work also addresses the call from Esmonde and Booker (2016) for learning sciences to “necessarily center conceptions of equity, diverse experience, and the dynamics of power and privilege expressed in and through learning environments.” (p.1) Prior work on learning communities and novice programmers has often focused on learners in terms of their computational fluency (or what they do or do not know), without necessarily taking into account the complexity of their held identities and the potential for gendered and racialized pathways in STEM spaces (Vossoughi et al., 2016).

Methodology and expected contribution

Through regular in-depth participant observation, interviews, and focus groups with students and teachers, I will conduct a critical ethnographic study (Carspecken, 1996) of two teachers’ elementary school classroom communities as they pilot new co-designed (Roschelle & Penuel, 2006) computing curriculum materials over the next year. Understanding a learning community requires attention to the subtleties of social interaction, and critical ethnography enables researchers to attend to the ways in which power and privilege complicate social interactions, as well as to work with teachers and students to co-construct knowledge. This work is a component

of a broader project, *Getting Unstuck*, which supports teachers and students in co-developing their computational fluency with and from one another through teacher-facing online professional development experiences (Haduong & Brennan, 2019). With an emic approach to data analysis, I will systematically code observation field notes, interview transcripts, and learning artifacts (e.g., teacher marked-up lesson plans, student design journals, and student projects), prioritizing explorations of patterns around the ways in which a teacher and their students build a learning community and co-develop their computational fluency, as well as working with teachers to co-construct understandings of how their classrooms function as learning communities (Brown, 1992).

Because I will be working with teachers who are already committed to computing as a social practice (since these are teachers who have already participated in *Getting Unstuck*), I expect to be able to document the pedagogical practices teachers engage in to create learning communities within their classrooms, as well as the ways in which students respond to these practices and develop their own means of debugging individually and collaboratively, seeking to understand young people not only in terms of their identity as a computational creator but also the various identities they bring into the classroom. By closely examining the complexities of classroom communities (Brown, 1992), I expect to be able to support researchers and teachers seeking to understand how learners get stuck, get unstuck, and learn together.

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Citizen Science in Schools: Building Mutualistic Partnerships Between Schools and Scientists

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Abstract: Partnerships between schools and scientists, in which students collaborate with scientists on scientific research, can potentially break traditional boundaries between schools, science and society. This study aims to build and support such partnerships on the basis of mutualism and sustainability, and explore how they affect their participants - students, teachers, and scientists.

Research goals

The overarching goal of this study is to explore how school boundaries are disrupted when incorporating citizen science into schools and including scientists as active participants in school ecologies. Specifically, my research aims to: (a) understand how this disruption within the school ecology changes traditional practices and beliefs of students, teachers, and scientists, (b) examine how it affects students' epistemic thinking and science capital.

Breaking the boundaries between school and science

A key idea within the learning sciences is that learning is part of everyday life, and not limited to the classroom. This notion has resulted in conceptualizations and designs that bridge where, when, how, why and with whom people learn (Dierking & Falk, 2016), such as the idea that students should engage in cross-spatial and cross-cultural co-creation of knowledge (Hod, Bielaczyc & Ben-Zvi, 2018). Incorporation of citizen science in schools is a fertile ground for developing such bridging processes.

Citizen science joins audiences with multiple forms and levels of expertise: scientists, communicators, educators and citizens from varying backgrounds. Engaging in citizen science can promote learning of and about science, alter attitudes and practices, and foster scientific identities (NASSEM, 2018), highlighting the potential contribution of citizen science to both formal education and students' science capital (Archer, Dawson, DeWitt, Seakins & Wong, 2015). Of several models for incorporating citizen science within schools, the one based on partnerships with scientists poses particular challenges (Harlin, Kloetzer, Patton & Leonhard, 2018). These include bridging cultural communities and differing expertise, balancing scientific and educational goals, and supporting the blurring of roles that occurs as students and teachers become citizen scientists, and scientists are introduced to the school environment. The interventional approach of this study is based on building and maintaining such partnerships with *mutualism* as a guiding principle. That is, to establish partnerships that provide benefits to all involved parties.

Methodology

This study uses a design-based implementation research methodology, combining iterative design and research processes within research-practice-partnerships (Fishman, Penuel, Allen, Cheng & Sabelli, 2013). I extend the notion of design-centric research-practice partnerships (DC-RPPs; Kali, Eylon, McKenney & Kidron, 2018) to include not only learning scientists and educational practitioners, but also scientists. I am developing and exploring three such DC-RPPs, aimed to design, implement and explore sustainable incorporation of citizen science as a context for learning of various contents, in three schools.

To develop an understanding of how school-scientist partnerships shape their stakeholders' practices and beliefs (research goal A), this study uses an exploratory multiple case study design. Following a pilot with one school, current participants include eight teachers from an elementary school and about 240 4th-6th grade students, and three teachers from a secondary school and about 150 9th graders. A scientist, a doctoral student in ecology, is also a participant. As a member of the DC-RPP, my role as a researcher enables me to collect rich and situated data: research journals, observations of meetings and student activities, informal communications and documents produced by the participants. In addition, the teachers, scientists and a subset of the students are interviewed at several time points, discussing their view of the process and their participation, as well as perceived benefits and challenges. Qualitative analysis is used to seek and characterize emergent themes and patterns (Charmaz, 2006).

To examine the development of students' epistemic thinking about science and science capital (research goal B), I am taking a mixed methods approach, combining quantitative analysis of pre-post questionnaires with Chi's (1997) method for quantifying qualitative analyses of student interview transcriptions. Specifically,

questionnaires including both Likert scale statements and open-ended questions were developed to assess students' dispositions towards science, epistemic thinking and science capital, and administered at the start and end of each intervention. A deductive analysis of both the open-ended questions and the interviews is conducted based on Archer et al.'s (2013) conceptualization of science capital, and on epistemic themes defined by Osborne, Collins, Ratcliffe, Millar & Duschl (2003).

Preliminary findings

Regarding goal A, preliminary findings from the pilot have already been presented (see CV). Together with initial analysis of the current findings, they indicate the emergence of mutualistic partnerships. At this stage, perceived challenges and benefits were analyzed for teachers and scientists only.

Teachers were challenged by allocating time and incorporating the project within the schools' practices and norms, and by communicating with the scientist. The scientist too was challenged by time management and communication issues. However, as the second year of the partnerships unfolded, the scientist is expanding his engagement with schools and other community institutions. One of the schools declared its wish to continue with a multi-year citizen science program that includes other projects as well. Two teachers from this school enrolled in a teacher development program designed to build leadership in implementing citizen science in schools.

We found preliminary evidence that the motivation for sustaining the innovation stemmed from a feeling of empowerment teachers sensed as they realize personal and school-wide aspirations for providing meaningful learning experiences to their students. At the same time, the scientist was satisfied with the students' significant contribution to his research, and with the development of a community that engages with nature monitoring.

Regarding goal B, a significant advancement in 4th and 9th grade students' epistemic thinking about science was indicated by an initial analysis of the questionnaires and reaffirmed by samples of students' interviews. Preliminary findings within this trajectory have been submitted to the European conference for citizen and participatory science (see CV).

Expected contributions

This study explores school-scientist partnerships that have the potential to break school boundaries and bridge over traditionally distinct knowledge-seeking communities. It will determine guidelines for designing and enacting citizen-science-based curricula in schools, in a way that makes students participants in authentic knowledge creation. The study contributes insights on the premise of citizen science to democratize science and make it more accessible to the public.

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The Interplay Between Jointly Constructed Ideas and Identities in Statistical Modeling

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Abstract: My dissertation examines the interplay between students' ideas and identity development in the context of collaborative statistical modeling activities. Viewing both knowledge and identities as jointly constructed, I have developed the ideational and identity artifacts framework to describe and examine this interplay. The framework and its background are introduced as well as an illustrative example for its affordances.

Background and research goals

The overall goal of my doctoral research is to elucidate the interplay between students' ideas and their identities as they engage in the practices of statistical modeling. Adopting the view that knowing, doing and being are inseparable (Herrenkohl & Mertl, 2010), the knowledge one contributes during collaborative statistical endeavors is inevitably linked to who one is, as are the practices shaping their participation. To become a central participant in a new disciplinary discourse, one needs to adopt its values. I envision this as a process of coalescence of two discourses (Lavie & Sfard, 2019)—that of the culture of the discipline of statistics and that which students have adopted through their prior or external experiences such as school narratives, familial culture, after-school activities etc. The latter can be considered as the potential landscape of students' cultural learning pathways (Bricker & Bell, 2014) and central to the joint accomplishment of their identities “between individuals and their interactions with norms, practices, cultural tools, relationships, and institutional and cultural contexts” (Hand & Gresalfi, 2015, p. 190). The focus of my research is on relational aspects of these interactions, manifested in students' discourse and practices, which reveal the norms and narratives they value as well as the incongruences between these and the new culture they enter. A community whose discourse legitimizes the sharing and discussing of these incongruences can promote identity growth. The purpose of my dissertation is to elucidate how students' transforming identities shape the statistical knowledge they jointly construct, and how its joint construction can, in turn, shape their jointly constructed identities.

Inspired by the Popperian depiction of ideas as mental objects in the public realm (1978), my research has hypothesized an identity corollary. From this view, participants' expressions are artifacts that contribute to the community's constantly growing resource reservoir. Other community members can choose to build on these resources, expanding the shared reservoir with their appropriation of these artifacts. While an expression can communicate a person's idea, it can similarly communicate information about their identity. To examine how these may be interrelated, I distinguish between *ideational* and *identity artifacts*. Looking across a relatively long learning sequence, topic-related artifacts can be tracked and identified as ideational or identity themes. Examining how themes concurrently develop can elucidate their co-mediational relationship (Hod & Dvir, under review). While identity themes may vary from one participant to another, focusing on the specific practice of statistical modeling affords the identification of shared, key, ideational themes. I identified two key themes that are aligned with those of an expert statistician, but are also omnipresent in students' articulations. These relate to two types of models students either visually construct or verbally express, distinguished by what they represent: *data models* representing patterns students account for in data they examine, and *conjecture models* representing the data they expected to see (Dvir & Ben-Zvi, 2018). My goal is to explore the interplay between the progression of these two jointly constructed ideational themes and the progression of students' identity themes.

Methods

To research the way students' ideas and identities interrelate, I have been drawing on two main data corpuses, each with specific affordances. The first data corpus was collected from a community of sixth grade students engaged in statistical inquiry and modeling activities (Dvir & Ben-Zvi, 2018). Audio and video recordings of all students' actions and expressions and any online or physical artifact they created were collected. I used an interpretative microgenetic method to analyze these data (Siegler, 2006), resulting in a framework showing two *ideational* themes reflected in students' data and conjecture models.

The second data corpus was collected from a graduate course of a community of learners in an Educational Technologies program. Using the constant-comparative method based on rich data collected from all face-to-face and online meetings, I analyzed the identity artefacts about all of the participants in the course. This led to a framework capturing students' *identity* themes, how these progressed over time, and how these progressions related to participants' changing values.

I am currently rising above these two frameworks to characterize the interplay between *ideational* and

identity artifacts. I employ a method which I developed to untangle students' statistical modeling processes to snapshots capturing shifts in students' ideational artifacts (Dvir & Ben-Zvi, 2018). In parallel to this, I employ a method to capture students' identity themes (Hod & Dvir, under review). I then focus on the interactions associated with each snapshot to examine what identity themes were expressed. Putting these concurrent activities together shows the interplay between the progressions of ideational and identity themes.

Noa and Ido's joint construction of ideas and identity

The story of Noa and Ido, two sixth grade students, shows how ideas and identities are interrelated. A segment of their joint investigation whether it was true that boys run faster than girls illustrates this briefly. This question resonated with Noa, who was goal-oriented, and who set out to "prove the stigma is only half true" stemming from her past experience as the only female member of a regional water polo team. However, the data the pair had collected (a sample size 60 out of 1300 students) showed otherwise. Ideational artifacts that Noa initially expressed were biased data models (claiming the data showed girls run faster), relating to her goal-oriented identity theme. Ido, in comparison, expressed identity themes that were non-confrontational and fairness. These were related to ideational artifacts he expressed such as claiming that a representative sample should include extreme values. In this segment, Fairness can be associated with the ideational theme that Ido attempted to introduce in his data model in which the boys were faster runners. Being non-confrontational, he initially did not counter Noa's objection, but suggested the data they had was insufficient. This suggestion was significant in the pair's ideational progression as it afforded the researcher an opportunity to suggest the issue of sampling representativeness ("can we trust a sample size 60?") to the pair. To begin exploring this new question, the pair needed to create a computerized model of their conjectured population.

They initially created a computerized model depicting the real data they collected, but were then encouraged by the researcher to create one reflecting their conjectured population, aligned with the statistical practice of hypothesis testing. Due to incongruences between the students' views, the collaborative design of their computerized model took four hours of negotiation. Gradually, Noa appropriated Ido's non-confrontational identity theme, showing a shift in her values, as earlier her goal of disproving the stigma was much more dominant. She suggested a compromise that was more aligned with what the data were indicating, implying she came to value data as a means to justify claims. Ido's values changed as well, as his fairness theme manifested in more data-based artefacts, and became more dominant than his non-confrontational theme. These identity changes were accompanied by a significant ideational progression. The resulting model, the jointly constructed ideational artifact, was now more aligned with the statistical discourse representing a null hypothesis. Untangling this interplay shows how corresponding shifts in ideational and identity artifacts ultimately resulted in the building of more formalized statistical discourse.

Expected contribution

This research seeks to contribute to the ongoing conversation about identity and collaborative knowledge building in the learning sciences. My dissertation offers an explanation of how an initial, often naive, ideational artefact can be jointly refined to become more statistical by showing the role students' jointly constructed identities play in this process. The models students construct serve as mediational means allowing students to initially express their existing discourse, and jointly negotiate its incongruences with the discourse of statistics. This suggests that fostering learning communities that legitimize the expression of such incongruences alongside statistical values can promote disciplinary enculturation.

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A Critical Computational Literacy

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Abstract: Like reading, writing, and arithmetic, computational literacy can be a means for empowering children to make sense of the algorithmic world in which they live in the service of unveiling power structures that drive bias and social injustice, and through computational literacy, contributing to a more equitable world. To this end however, computational literacy must not come short of a critical literacy (Freire, 1970; 1972). In my mixed-methods study, middle school aged students will manipulate and revise algorithms in a software environment, deciding over who gets a loan, a job interview, or parole for example. The purpose of this study is to explore how students conceptualize computer algorithms and how their understanding of social justice, power, and positioning shapes and is shaped by their redesigning of algorithms. To this end, I will conduct semi-structured interviews, a focus group, and log data during their gameplay. Janks' (2010) Critical Literacy Synthesis Model which argues for the crucial interdependence of power, access, diversity and design will be the guiding lens in the analysis in this inquiry. This study will help me articulate design principles for creating playful systems that encourage students to assume agency for social change. Additionally, the results of this study should provide practitioners empirical evidence on using technology as a tool for inviting students to examine social injustice.

In our modern era, computer languages, like human language, influence many aspects of our social fabric. Therefore, it is critical that all children become familiar with the foundations of computer programming, not just those who will program computers professionally (diSessa, 2000; Wing 2006). Integrating computer science into US schools is one of the most significant changes being made to K-12 public education in decades (Gardiner, 2014). However, there is disagreement over what and how computer science should be taught.

It is important that we move beyond the mere teaching of coding skills to letting children explore how coding pertains to existing social structures, how code reifies or challenges existing inequities, or how code can be part of addressing these inequities. Only then can children become agents who can act to transform the social situations in which they find themselves today. If coding is treated as anything but a literacy practice, if it is compartmentalized as a tool for a select group of people and a select group of activities, this would prove a significant opportunity cost for computer science education.

Background of the project

Since the 1960s, computer enthusiasts have relied on the concept of literacy to underscore the importance, flexibility, and power of writing code. Perlis suggested in 1961 that all undergraduates should be taught programming, just as they are taught writing in first-year composition courses. In 2015, Guzdial proposed that everyone should learn to code, reasoning that, "the printing press was a huge leap in human history, but that leap didn't happen until many more people became literate" (p. 5).

Vee (2013) however points out that when "literacy" is connected to programming, it is often limited to reading and writing text, "literacy divorced from social or historical context; literacy as an unmitigated form of progress" (43). However, literacy broadly and computational literacy more specifically, is not a neutral activity. And while mathematical concepts that are at the root of these computations may be objective and unbiased, they don't exist in a vacuum but are situated in a social context (O'Neil, 2016).

Freire (1983) stated that "reading the world always precedes reading the word" (p. 5) and in acquiring literacy skills, readers (re)gain a sense of themselves as agents who can act to transform the social situations in which they find themselves. This means that children construct literacy by engaging with the "word" – decoding language, and meaning making – but also by drawing relations to the world in order to explain the world.

Yet children should not only be able to understand, question, and critique established conventions that have been defined by a largely homogenous group of people (Margolis & Fisher, 2002; Margolis, 2008) but, more importantly, contribute to a more equitable world by participating in its production and circulation (Janks, 2010). Janks' (2010) Critical Literacy Synthesis Model will be used as a lens to guide the analysis in my study. This model argues for the crucial interdependence of power, access, diversity and (re)design in critical literacy pedagogy.

Goals of the research

Recent research has focused on increasing children's ability to read and write algorithms – or the computer code that encapsulates them. However, if we want to truly empower children to become agents who can act to transform the social situations in which they find themselves today and in so doing, contribute to a more equitable world by participating in its production and circulation, we need them to understand how algorithms pertain to existing social structures, how algorithms reify or challenge existing inequities, or how they can be part of addressing these inequities. Therefore, further research is warranted to shed light on how a sample group of children understand and use algorithms to challenge what they see are existing inequities in society.

Therefore, the purpose of this study is to explore with 15 middle school-aged children how they conceptualize computer algorithms and how their understanding of social justice, power, and positioning shapes and is shaped by their redesigning of algorithms.

In order to carry out this purpose, the following three research questions will be addressed:

1. How do students revise algorithms that impact social systems to be more equitable?
2. How does deconstructing and reconstructing algorithms affect student's understanding of power and one's own positioning?
3. How does the critical literacy process of deconstruction, reconstruction, and social action in a software environment affect student's role as agent outside of this space?

Methodology

15 middle school-aged students will be recruited from a public school in New York City. Public school was chosen over independent schools because they are the site of Mayor de Blasio's CS4All (Computer Science for All) initiative that intends for each New York City public school child to have a computer science experience.

The study will be organized into preliminary interviews, two separate 45 minute sessions of gameplay activity, and follow-up interviews, with each intervention spaced approximately one week apart; all activities will take place at the school. The last session will also include a focus group with all participating students. The study is planned for March through April 2020.

For this study, interview transcripts, gameplay communication transcripts, focus group transcripts, and logged data will serve as evidence from which patterns will be identified, coded, and categorized. An inductive and deductive data analysis will help examine how students conceptualize computer algorithms and how their understanding of social justice, power, and positioning shapes and is shaped by their redesigning of algorithms.

The inductive analysis will allow me to discover patterns, themes and categories in my data (Lincoln & Guba, 1985); the deductive analysis will allow me to see how theoretically based hypotheses apply in this study (Lincoln & Guba, 1985). Because the theory used in this inquiry is Janks' (2010) Critical Literacy Synthesis Model, the data will be coded based on how they align with the general themes of power, diversity, access, and design. For example, to be coded under the label of 'Power,' an incident has to manifest power relations in terms of personal (e.g. feelings of incapacity in relation to computational literacy), social (e.g. unjust institutional or community practices), or computational practices (e.g. opacity of text/algorithm).

Preliminary or expected findings

I expect to find a shift in the language students employ around algorithms that reflects a change in their conceptualization of computer algorithms as well as their understanding of social justice, power, and positioning as a consequence of their redesigning of algorithms. Jank's (2010) framework will focus my lens on power, access, diversity, and (re)design.

For example, with regard to 'Power,' students expressions may become more personal and in relation to society (e.g. utterances about computational literacy may shift from 'they/others or 'computers' 'to 'I' or 'we'). With regard to 'Access,' students may recognize ways in which algorithms are around them and come in contact with them. With regard to 'Diversity,' students may recognize social injustices and complexities in algorithms. With regard to (Re)Design, students may acknowledge ways in which social or personal justice can be brought about in their algorithmic world.

Expected contributions

The purpose of this study is to explore how middle school aged students conceptualize computer algorithms and how their understanding of social justice, power, and positioning shapes and is shaped by their redesigning of algorithms. I will articulate design principles for creating playful systems that encourage students to assume agency for social change. Additionally, the results of this study should provide practitioners empirical evidence on using technology as a tool for inviting students to examine social injustice.

Modeling Complex and Political Phenomena Across Settings with Preservice Teachers

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Abstract: This proposed research aims to explore how preservice teachers construct an understanding of complex phenomena which are political across classroom and non-classroom settings. Preservice teachers collaborate to modify agent-based models after exploring the phenomena in its physical location. Interaction data will be collected in the form of video recordings which will be transcribed and analyzed using Van Leeuwen's sociosemantic inventory. Findings contribute to demonstrating how understanding complex and political phenomena achieved in interaction

Goals of the research

I have two interacting goals which inform my dissertation research: (a) the practical goal of preparing future educators to use computational models to explore scientific and political issues, and, (b) the theoretical goal of using critical discourse analysis to understand how knowledge is collaboratively built in interaction across time and space.

Practically, I work with preservice teachers to model complex phenomena which are locally relevant, spatially expansive, and political. Inspired by the work of Hostetler, Sengupta, and Hollett (2018), we engage in modeling the phenomenon segregation. I chose segregation because it is relevant to Central Texas, frequently discussed in popular media, and easily demonstrates how to integrate computer science, mathematics, and social studies in teaching. Furthermore, segregation occurs across large spaces and time periods, which makes it challenging to discuss in classrooms. My research explores how preservice teachers engage in model-based learning (Louca & Zacharias, 2015) to critique and revise agent-based models about segregation. Specifically, I am interested in how we can develop preservice teachers' capacity to use, critique, and modify NetLogo agent-based models (Wilensky, 1999).

Distinct from many studies of modeling that use a cognitive approach, I am interested in capturing interactions in real time between preservice teachers and the models they use, critique, and modify. I plan to use critical discourse analysis to trace how preservice teachers discuss complex phenomena like segregation with each other while they use agent-based models. Drawing upon Philip, Gupta, Elby, and Turpen (2018), I am interested in understanding how ideologies come to the surface, interact, and impact the process of modeling a complex phenomenon. Furthermore, many studies of modeling (and learning in general) are conducted in a single site. Since the phenomena I plan to investigate are spatially and temporally expansive, I am interested in how exploring physical spaces beyond the classroom impacts learning about complex and political phenomena. The broad questions guided by my research goals are:

1. How do preservice teachers interact with each other and agent-based models, in and out of the classroom, when attempting to understand segregation?
2. How do models constructed by preservice teachers vary in their representations of social actors and processes involved in segregation?

Background of the project

This project is an extension from a National Science Foundation research project investigating Group-based Cloud Computing (GbCC) and its role in integrated STEM education (Petrosino, Sherard, & Tharayil, in press; Petrosino & Stroup, 2017). GbCC is agent-based modeling program, powered by NetLogo Web, that allows learners to work collaboratively to participate in, author, and share models. I decided to bring this tool into multiple sections of a course designed to prepare preservice teachers to teach STEM to elementary students. Together we used GbCC models to explore ecological change, disease transmission, and traffic. Towards the end of the semester, the preservice teachers I worked with most closely expressed interest in continuing to use the models to explore other phenomena.

In the Fall of 2019, I planned a pilot study to test the waters of engaging elementary preservice teachers in modeling, computer science, and complex phenomena. I planned a three-lesson series using the Model-based Learning (MbL) cycle (Louca & Zachariah, 2015). The MbL cycle follows four stages: (a) observing and engaging in some phenomena; (b) using a pre-created model; (c) evaluating the model; and (d) revising the model based on evidence or new experience. A description of the three-lesson series is provided in Table 1.

Table 1: The three-lesson series, a short description, and the phases of the MbL cycle covered in each section

Lesson	Description of Activities
Exploring the Initial Segregation Model	Participants share personal experiences with segregation or integration, explore multiple maps of segregation nationally and locally, and use and evaluate the NetLogo Segregation model (Wilensky, 1997).
Walking Tour of Local Segregation	Participants engage in a walking tour of campus guided by smart phones which discusses the history of segregation and the build campus environment.
Revising the Segregation Model	Participants work to construct new segregation models, identify sections of code to change, and present their modified segregation model to their peers.

This pilot study represents the first iteration in exploring how preservice teachers engage in modeling to understand complex phenomena. I hope to propose my dissertation in the Spring of 2020 to continue iterating through this MbL cycle to explore the modeling of complex phenomena with preservice teachers.

Methodology

I plan to engage in design-based research with preservice teachers to iteratively refine how to promote thinking about and modeling complex phenomena which are political. Since I aim to trace knowledge as it is produced in interaction, I collect video and audio data, in and out of the classroom. Audio and video data will be transcribed and submitted to Critical Discourse Analysis (Fairclough, 2003), specifically the sociosemantic inventory, a technique developed by Theo Van Leeuwen (1996). Sociosemantic inventory analyzes texts to determine which social actors are included and activated, and which social actors are excluded and passivated. This will help illuminate how preservice teachers think about the agents and actions involved in complex phenomena like segregation and may even support critically challenging narratives built into some models of segregation.

Expected findings and contributions

While I have not begun analysis on the data collected from the pilot study, I did record meticulous field notes throughout the three-lesson series to make quick modifications for the Spring semester. Despite voicing apprehensions about using agent-based models, participants in the pilot study grew more comfortable using the models, making sense of particular parts of the model code, and attempting to redesign the functioning of the model. When participants were tasked with redesigning the segregation model, all participants included aspects of *de jure* segregation, indicating a conceptual departure from the initial model provided to them.

This research has potential to contribute to designing preservice teacher education that makes the social and political aspects of scientific and mathematic phenomena apparent in teaching and learning. With regards to the Learning Sciences broadly, I hope to contribute research which better demonstrates the connection between how people talk in different spaces and collectively construct an understanding (or multiple understandings) of important and politically relevant complex phenomena.

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