Synthesis and Design Workshop: Distributed Collaboration in STEM-Rich Project Based Learning

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This paper reports outcomes from a workshop that took place at Pepperdine University in Malibu CA, 13-14 May 2019. The workshop's theme of distributed collaboration emphasized K16 STEM projects completed by teams whose participants cross geographic, cultural, and economic boundaries to work together effectively. The original motivating scenarios involved middle and secondary school students collaborating with counterparts in other countries, over both synchronous video and asynchronous platforms, to devise and complete STEM projects. The report follows the general format of the CIRCL Center's Rapid Community Reports of addressing four key topics: 1) motivation; 2) starting points and process; 3) insights, issues, and new ideas; and 4) directions and recommendations.

1. Motivation

The original impetus of the workshop was research into the interaction between variables associated with learning, culture, and collaboration when school-age students in after-school STEM clubs carried out digital makerspace projects by working with peers in clubs in other countries. Specific projects involved learners in North and South America, Africa, Asia, and Europe. Such collaboration can only take place successfully through extensive planning and multilayered arrangements. Investigators noted a compelling dynamic that transcended logistical considerations, however. The very fact that students were both so different from each other and so similar to each other (in terms, for example, of STEM interests) fueled a curiosity, appreciation, and desire to communicate and co-create that videoconferencing seemed to intensify. This led to a conjecture that when students can collaborate over video with peers in other cultures from the safety of their own school or home settings, their collaboration can be richer than without video, and their intercultural competence has a greater opportunity to flourish. The proposal's rationale for the workshop included reference to court-ordered mandates for school busing as a controversial and mostly unsuccessful way to physically bring students into physical proximity, a point discussed on page 6. It seems that at least some of the social repair goals motivating those mandates could be within reach high-bandwidth distributed collaboration. In short, could the educational and socio-affective goals of building a simultaneously unified and pluralistic society be advanced through vigorous, high interactional bandwidth and distributed collaboration in STEM projects? Could the activity systems that such collaboration help form ensure not only STEM competences across different populations but also shape prosocial and healthy understandings that students make about those who differ from them?

As noted above, designing distributed collaboration that orchestrates such opportunities for students is a complex undertaking, with a wide spectrum of practical possibilities and interconnections with the existing educational and cultural practices of participants. Emerging cybertools enable distributed collaboration high interactional bandwidth forms that extend significantly beyond those of the past. While distributed collaboration over the internet by school age students has been in practice for a quarter-century [e.g., 1, 2], the advent of reliable and high bandwidth videoconferencing, other advances in communication and cloud technologies, and the concurrent ascendance of the makerspace and social sharing movement have reshaped the distributed collaboration landscape in ways that merit reconsideration of ways to reach some of the most elusive goals of the national STEM education enterprise.

Purpose. The purpose of this workshop was thus to beginning framing a research agenda to articulate both a) foundational research issues in distributed collaboration in STEM project-based learning especially when student backgrounds differ significantly along national, cultural, economic, or linguistic dimensions; and b) important design principles for such distributed collaboration. Potential applications cut across both formal and informal STEM education contexts.

2. Starting points and process

The workshop is one of a series of nine synthesis and design meetings that NSF-funded through a Dear Colleague Letter [3] focusing on issues foundational to future learning environments. NSF explicitly sought ideas for adaptable and distributed digital learning environments that could serve as a forum for active research and development studies in optimizing learning for groups and individuals.

Aspirations for these workshops align with efforts by many organizations in recent years to articulate the shifts which must take place in education. The term “21st century skills” seems dated, now 20 years into the 21st century. Nevertheless, the term has sparked scrutiny globally on understanding and articulating the difference between what education systems prioritized in pre-digital era schooling, and what society needs now and in the future. These efforts yielded important wisdom and directions that continue to unfold. Well-known formulations include the 4Cs of collaboration, creativity, critical thinking, communication [4, 5] and numerous variations of these 4Cs. Each of these, especially collaboration, appears recurrently in different forms in current NSF proposal solicitations. Intel, Cisco, and Microsoft jointly sponsored the 21st Century Skills Initiative [6], which yielded similar recommendations, as did UNESCO’s International Bureau of Education (IBE) with a delineation of seven global competences that educational efforts. These developments have coincided with significantly greater appreciation of the mutually reinforcing nature of socio-affective and cognitive growth [7]. Relatedly, the importance of *help-giving* as a prosocial disposition has been increasingly recognized as crucial not only to positive affect and to healthy personality integration [8] but also, and unsurprisingly, as central to the kinds of collaborative community competence [9] envisioned by this workshop. These themes add to an orientation around *competence* as a stride that includes but extends beyond academic knowledge, and to the holistic exercise of interpersonal faculties, imagination, and determination as crucial markers of competence. Additionally, the rise of social media has created previously unavailable opportunities for adolescents to create and communicate personal meaning [10, 11]. These directions align closely with building distributed collaboration communities. They help set the stage for the workshop’s effort to frame a research agenda usable to articulate foundational research issues and important design principles in contemporary distributed collaboration.

Workshop Details. This workshop included an eclectic and international collection of approximately 25 individuals. Participants included prominent research methodologists, learning scientists and technologists, a highly-regarded education futurist, a university president widely published in areas essential to this topic, nationally prominent experts in computational thinking, and data scientists. Collectively, they represented education service and leadership from the US, Kenya, Brazil, Singapore, and Finland.[1] The appendix details novel steps that organizers and participants took before and during the workshop to elicit thoughtful and productive consideration of how to situate boundary-crossing collaboration into research investments in future learning environments.

The workshop initially entailed three webinars, in February, March, and April of 2019. The webinars helped "set the table" for the workshop that took place on 13-14 May, 2019. The opening session involved a "priming" exercise. Each of three different exemplars of high bandwidth and boundary-crossing distributed collaboration was presented. Then, each of the core team of invitees spent 90 minutes creating a "response" presentation of 20-30 minutes addressing the five questions below. They gave these presentations over the second half of the first day and all the second day, spurring lively discussion and a corpus of inputs for workshop products. This proved an effective approach for sustained and substantive participant engagement. The questions each expert addressed, from the vantage of the exemplar settings and other contexts with which they were familiar, include:

- Insights on how boundary-crossing impacts learning
- Theoretical directions/frameworks ("What existing frameworks that can be built on? How do we develop theoretical gravitas around boundary crossing? Who are most influential thinkers in this area that we have not yet evoked?")
- Curiosity around this topic ("What questions are emerging from these exemplars and your colleagues' presentations?")
- Ideas for future learning environments ("What is the potential for boundary-crossing impact in learning?")
- Intersection of boundary-crossing with current work ("How does your work pertain to, inform, or contribute to synthesis and design of this construct?")

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[1] Participants included: Guadalupe Carmona (University of Texas, San Antonio), Shaundra Daily (Duke University, NC), Brendan Eagan (University of Wisconsin, Madison), Danielle Espino (Pepperdine University, CA), Lynn Frickey (Meteor Education, FL), Beatriz Galarza (University of Texas, San Antonio), Eric Hamilton (Pepperdine University, CA), Erik Huesca (Knowledge & Digital Culture Foundation, Mexico), Seung Bok Lee (Pepperdine University, CA), Chee-Kit Looi (National Institute of Education, Singapore), Ana Paula Luciano (Assessoria em Robótica Educacional Aplicada, Brazil), Arquimedes Luciano (Assessoria em Robótica Educacional Aplicada, Brazil), Rex Miller (Mindshift, TX), Jari Multisilta (Satakunta University of Applied Sciences, Finland), Hannele Niemi (post-workshop) (Helsinki University, Finland), Aileen M. Owens (South Fayette School District, PA), Vitaliy Popov (University of San Diego, CA), Heli Ruokamo (post-workshop) (Lapland University, Finland), David Williamson Shaffer (University of Wisconsin, Madison). Pepperdine University participants included: Lexi Aria, Natasha Brown, Denise Calhoun, Pamela Donnelly, Amanda Lee, Leonardo Minelli, Luiz Oliveira.

Lexicon. Any evolution of learning ecosystems – and distributed collaboration on STEM challenges or projects between school-aged learners is such an evolution – can be interpreted through myriad conceptual or theoretical frameworks, and, in turn, contribute to theory testing that relates to those frameworks. The emphasis in this workshop on boundary-crossing collaboration adds an important dimension to these interpretations, and contributes to the lexicon entries below. In the category of "high level basics," research in this domain should clarify or refine use of any of the following terms.

STEM projects or challenges: This term refers to projects rich in STEM content which are designed to result in one or more artifacts. Artifacts may take the form of physical artifacts, as in the case of makerspaces which are often defined by physicality and by the opportunity they provide learners to manually experiment and construct artifacts that embody social cognition and obligate or spur intellectual growth (Peppler, Halverson et al. 2016). Among the most prominent makerspace domains are robotics, circuit board experiments, and 3D printing. A subset of the makerspace movement, though, involves digital activities. Among the best-known activities involves video making, games, coding, and commercial products such as Minecraft (Rippa and Secundo 2018). The use of the term in this context includes and extends beyond makerspaces. The types of multi-level and game-like challenges of the FUSE Studio [12] at Northwestern University include making, but are more oriented around emphasizing specific STEM ideas. Use of the term also implies recognition of the other disciplines, including Arts, or the well-known STEAM acronym.

Distributed collaboration refers to teams geographically located in two or more venues working on common tasks, with internet-mediated communication. The advent of ubiquitous internet technologies over the past thirty years has reshaped the landscape of distributed collaboration. The interest in this workshop is specifically on distributed collaboration on STEM projects or challenges that involve school-age learners and their teachers.

Boundary-crossing: This construct refers to distributed collaboration involving team members who differ along dimensions of interest—in the case of the workshop, nationality and culture are two such boundaries.

Thus, scenarios of interest for the workshop typically involved teams whose school-aged participants (or teachers) reside in different countries or cultures and who collaborate on specific STEM challenges or projects in the context of formal or informal educational settings [13, 14].

Such collaboration remains relatively impractical in most current school and informal education settings due to logistical, privacy, and technological limitations. Additionally, such collaboration does not currently have the driving force in school practice that characterizes the need for adults to collaborate in the workplace so increasingly defined by globalization. Yet each factor limiting such collaborations between young people in learning settings is manageable, and the expansion of social connections in global society will inexorably drive distributed teamwork in learning settings [9].

Virtual presence: Virtual presence can be treated as the perception that one is in a physical location by dint of being present in that location through communication technologies [15].

Recurring literature contexts include immersive games, simulations and virtual reality [16], and telemedicine [17]. The role of virtual presence in the context of distributed collaboration among school-age participants lags other contexts simply because this context is not very prevalent. As noted earlier, video connectivity fundamentally intensifies the nature of virtual presence [18]. The virtual presence construct gave rise in the workshop to a construct of **virtual migration** as connoting something more than presence, something that is acculturated, acclimated, or at home in the virtual setting.

Interactional bandwidth: Interactional bandwidth has been defined as the magnitude of social and disciplinary content that can be expressed or perceived in a learning setting [19, 20]. It is an as-yet informal or notional construct that is more difficult to measure than electronic data throughput. Interactional bandwidth in a classroom, for example, can encompass everything in a student's field of view, including on a computer screen, a teacher or nearby peer, or visible disciplinary content. A low-bandwidth environment might involve a classroom lecture with minimal student discourse and no media access. A higher interactional bandwidth might involve a classroom with extensive give and take, and perhaps with network communications that allow students to connect with search engines. Earlier forms of distributed collaboration involve interactional bandwidth primarily limited to asynchronous and/or text-based collaboration, at least relative to interactions that students have with each other. The advent of reliable and no-cost or low-cost video communication is a crucial development for the transformative possibilities of boundary-crossing distributed collaboration. It enables richer and visual, live engagement with those from other countries, cultures, and backgrounds. That, in turn, enables richer heterogeneity of perspective to enter into a team's complex problem-solving processes, both fueling development of STEM competences and the sense of community accomplishment.

Social trust: This paper adopts the definition of the Europe Social Survey, of trust as the belief that others will not, at worst, knowingly or willingly do you harm, and will, at best, act in your interests. Social trust can be treated as a property of social systems [21]. The role of social trust in a nation's institutions and general society has gained increased recognition in recent years [22, 23]. The role of social trust in distributed collaboration settings has long been recognized but has had little theoretical or experimental specification [24], especially in more recent environments that allow video virtual presence between school-aged participants.

3. Insights, Issues, & New Ideas

The workshop discussions included articulating the terms above for their relevance and to contribute clarity to their research agenda recommendations. In crafting those recommendations, the workshop attendees elaborated on several themes or observations relevant to the design of distributed collaboration ecosystems.

1. They repeatedly converged on building **social trust** as a crucial or transcendent factor or variance account in successful distributed collaboration, especially when participants differ by the country or culture in which they live.

   In our country's increasingly pluralistic society, and in a shrinking global society, boundary-crossing collaboration teams – that is, teams involving is likely to occur in most distributed collaborative settings around producing STEM artifacts. That is, distributed collaboration with heterogeneous or boundary-crossing teams will be normative as distributed collaboration evolves in STEM education.

2. **Heterogeneous STEM problem-solving contexts** were routinely reported to elicit sophisticated STEM learning and complex reasoning. That is, diversity of participation in trust-rich contexts appears to stimulate diversity of applied reasoning. This corresponds to multiple theoretical frameworks on social cognition [7, 25] and negotiation of shared meaning or intersubjectivity [26]. Computer supported collaborative learning fosters both the engagement and reconciliation of multiple perspectives. This, in turn, prompts not only intercultural comity but intellectual expansiveness in collective problem-solving. In the same way that social trust can straddle being an individual trait and a socially owned trait, social cognition in collaborative problem solving augments and transcends individual cognition to become a collectively shared process that is pervasive in daily life.

3. Virtual collaboration in STEM problem-solving that takes place in ways that lead students to cross new boundaries **routinely elicits complementary sentiments of curiosity, pleasure, and deep enjoyment in learning** - in addition to STEM learning and competence formation. These prosocial dynamics associated with it should be considered carefully. They relate strongly to growing attention in the field to the mutually reinforcing nature of social, affective, and academic growth.

4. **Interest-driven creator theory (IDC)** may prove an important aspect of driving collaborations envisioned as a routine aspect of distributed collaborative learning. IDC is an evolving learning design framework in computer-supported collaborative learning that prioritizes student interest in creating different types of artifacts. An important 2018 foundational article on IDC, with eighteen co-authors led by Tak-Kwai Chan and Chee-Kit Looi, offers IDC as "a theory of learning design for Asia in the twenty-first century." The theoretical connections that it draws, though, with multiple levels of articulation across the constructs of interest, creation, and habit, are not Asia-specific. IDC will contribute to establishing norms for interest-driven work, the fusion of formal and informal ecosystems, and establishing learning trajectories rather than credentials and grades as a means to characterize individual students.

   IDC's importance in discussion of distributed collaboration arises in finding common ground for formulating or designing complex projects. How do collaboration teams select or choose the parameters for any given project? What agency do they have in framing a collective knowledge space? Distributed collaboration as a component of any learning ecosystem promises to facilitate development of the 4Cs through the mediating factor of social connections across geographical boundaries. Except in rare cases, pre-determined school curriculum is likely suboptimal for distributed collaboration projects. Different venues have different curriculum expectations, terminology, and time frames. IDC offers a framework other than pre-determined curriculum as an animating force behind distributed collaboration.

5. **Self-determination theory** [e.g., 27, 28] provides a convenient set of constructs for emphasizing prosocial benefits of distributed collaboration in STEM project-based learning. The theory's emphasis on autonomy, relatedness, and competence [29] as essential building blocks to nourishing personal well-being and social health correspond to the dynamics of forming project-based (e.g., makerspace) communities through distributed collaboration. Project-based learning is inherently oriented around creating artifacts and intrinsically addresses competence. Interacting with others in synchronous and asynchronous forms through a community structure intrinsically addresses relatedness. The emphasis on self-directed project definition and discourse scaffolding that explicitly recognizes and respects cultural differences and similarities addresses autonomy.

6. Tools for **assessing or evaluating distributed collaboration** in STEM projects must encompass not only the constructs of interest such as the 4Cs, engagement, intercultural competence, or academic growth in STEM competence, but the relationships between those constructs. Tracing relationships between constructs can furnish richer and more holistic views of how individuals and groups progress through distributed collaboration. The workshop devoted time to elaboration of quantitative ethnography as a methodological approach to using collaborative discourse to furnish statistically supported and finely-grained visualizations of group and individual progress in distributed collaboration.

7. There are compelling arguments for expanding the use of distributed collaboration with diverse or "boundary-crossing" participant teams. The original proposal cited the example of school busing as a tool courts settled on as a means to repair profound social injustices. The premise of busing was proximity and shared educational experience. If African-American and Anglo students could share the same physical learning environment and the same instructional activities, racial disparities would narrow or disappear, and racial reconciliation would have more promising pathways. In fact, in at least isolated cases, these aspirations were attained . More commonly, though, the cost of entry in the form of social strife across the participating communities sabotaged the courts' goals. Distributed collaboration offers the opportunity to hybridize physical and virtual presence in ways that enable students to work with those from other cultures, backgrounds or countries from the cultural comfort of their own home or school.

   This should be recognized as a transformational opportunity that allows students to invent fresh ways to see and understand those who differ from them, and to align and reinforce cultural norms of listening and respect. The use of a shared activity system – in this case, distributed collaboration over STEM projects, can take the formative role in students' lives of helping to shape or define how that students situate themselves with others who differ from them.

8. Important **philosophical considerations** that are of little relevance in production style and bounded classroom settings become richer and more germane in settings that have fewer boundaries. Participants who did not feel they fit into to the workshop's academic setting and who did not quite understand the role they should assume in the workshop - since papers in advance were explicitly discouraged, and instead created on-site to respond to the exemplars - proved especially engaged and invested in the work of the workshop. This technical detail is a small metaphor of the subject of the workshop.

4. Directions and Recommendations

As immediate and short term follow-up, workshop participants have already sought continued engagement in pursuing the aims of the workshop, initially in the form of **conference symposia** and **grant funding proposals**, and they are exploring development of a special issue or volume to **produce a more comprehensive framework**.

Formal recommendations begin with providing **theoretical specification to the constructs** beginning on page 3, expanding to include **collaborative artifacts and intermediate outputs as boundary objects.** This includes articulating the nature of the collaborative activity, especially how its design fits into the IDC theoretical framework (page 6).

Other recommendations include **testing linkages between cognitive, social, and affective dimensions of the high bandwidth STEM project-based distributed collaboration settings.** Research in lower (non-video) bandwidth distributed collaboration settings and early research in higher bandwidth settings confirm that social connectivity has both positive affective and positive cognitive effects. These can be pursued through multiple avenues; the initial workshop proposal suggested and the participants concurred t**hat ethnographic studies to articulate these connections are essential.** They specifically concurred that the epistemic network analysis tool supporting quantitative ethnography could prove especially useful in this process.

This area is ripe for **social policy research**. The vision of using high bandwidth distributed collaboration in STEM projects as a tool not only for educational goals but for concurrent socialization and cross-cultural learning goals requires **situating such projects in policy and curriculum contexts**. These contexts vary in terms of the types of educational jurisdictions that approve and incorporate the activities. Within-county and between-country collaborations entail different considerations and design parameters, for example. The degree to which schools or school-based informal settings make room for STEM distributed collaboration involving students partnering with peers in other jurisdictions will turn on such research and determinations of the tradeoffs those collaborations entail. There is sufficient basis to explore the viability of such activities, but not yet enough evidence to confirm that existing designs are sufficient or that the resource tradeoffs merit beginning the transition to the more ubiquitous presence that workshop participants envision.

Existing designs will certainly evolve. The attendees noted that **emerging technologies (such as collaborative VR devices, biometric data, sensor-enriched collaborations or internet nodes**) along with the need for greater dexterity in hybridizing synchronous and asynchronous collaboration tools **are part of both near-term and longer-term profiles**.

This material is based upon work supported by the National Science Foundation under grant 1824924. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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