Next Generation Challenges for Advanced Learning Technology: Emerging Directions from the Workshop Leaders Summit

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Purpose and Objectives

Opportunities and challenges in the Learning Sciences are rapidly co-evolving, with each technological advance raising additional concerns about equity. Students carry mobile devices with voice recognition, motion sensors, location awareness, and powerful cameras. Within 10 years, learners and teachers will experience Artificial Intelligence (AI) learning agents, social robotics, tangible and embodied computing, and more (Sharples et al., 2016). Simultaneously, learning science theories are expanding to include embodied cognition, identity development, student agency, extended learning across time and place, and many new design principles (Roschelle et al., 2017). Equity and inclusion is becoming rapidly more problematic as we contend with issues of power, justice, privacy and security in an increasingly complex digital domain (Esmonde & Booker, 2016).

To articulate and prioritize research and development challenges for the next decade, the National Science Foundation (NSF) supported nine workshops in 2018 and 2019, each of which tackled a particular theme or vision with a separate group of participants. Per the NSF solicitation, each workshop was charged to "propose a diverse interdisciplinary team with clear potential to: (a) describe the proposed perspective(s); (b) engage innovative design thinking to outline blueprint designs for a future learning environment; and (c) describe any potential theoretical, methodological or programming obstacles that are likely to require further research and development."

After these workshops had occurred, the Center for Innovative Research in Cyberlearning (CIRCL) organized a summit of workshop leaders to discuss cross-cutting findings, insights and recommendations. This report focuses on the connections that emerged across workshops at the Workshop Leaders Summit, which was held on June 6, 2019. (Individual workshops will report on findings and recommendations specific to their theme in separate documents.)

Participants and Process

Leaders from eleven workshops participated in the summit. Nine of these workshops were separately funded by NSF, with two additional workshops held as a community activity of CIRCL. See Table 1 for a list of workshops and workshop leaders.;

Table 1: List of Workshops

Date & Location	Workshop Title	Principal Investigator
Nov. 29-30, 2018 Atlanta, GA	Designing Scalable Advanced Learning Ecosystems	Stephen W. Harmon Georgia Tech
January 15-18, 2019 Seattle, WA	Designing STEM Learning Environments for Individuals with Disabilities	Sheryl Burgstahler University of Washington
February 25-28, 2019 Oracle, AZ	Principles for the Design of Digitally-Distributed, Studio-Based STEM Learning Environments	Jill Castek University of Arizona
March 14-15, 2019 Stanford, CA	Weaving the Fabric of Adaptive STEM Learning Environments Across Domains and Settings	Roy Pea Stanford University
March 18-19, 2019 Ann Arbor, MI	Research Priorities in Learning Analytics	Stephanie Teasley University of Michigan-Ann Arbor
March 29-30, 2019 Waukesha, WI	Digital Science and Data Analytic Learning Environments at Small Liberal Arts Institutions	John Symms Carroll University
March 31-April 2, 2019 Orlando, FL	Digitally-Mediated Team Learning	Ronald DeMara University of Central Florida
May 13-14, 2019 Malibu, CA	Distributed Collaboration in STEM-Rich Project-Based Learning	Eric Hamilton Pepperdine University
May 20-22, 2019 Madison, WI	The Future of Embodied Design for Mathematical Imagination and Cognition	Mitchell Nathan University of Wisconsin-Madison
February 8-9, 2019 NYU Tandon Makerspace in Brooklyn, NY	CIRCL Workshop: Instrumented Learning Spaces	Yoav Bergner New York University
January 24-26, 2018 DeKalb, IL	CIRCL Workshop: Robots, Young Children, & Alternative Input Methods	Yanghee Kim Northern Illinois University

Prior to the summit, workshop leaders met with CIRCL leaders on three conference calls to develop an agenda that would synthesize insights across workshops. At the summit on June 6, Karen Marrongelle shared opening remarks. Dr. Marrongelle, the head of NSF's Education and Human Resources Directorate, commented on why improving and enhancing STEM education is crucial to the economic well-being of the nation. In her view, developing effective digital learning environments is an increasingly critical piece of STEM education. To develop effective learning technologies, designs need to be grounded in research.

Dr. Marrongelle also highlighted the connection of this summit to Big Ideas that are an agency-wide focus at NSF (https://www.nsf.gov/news/special_reports/big_ideas/). With regard to the **future of work at the human technology frontier**, participants could consider how evolving technologies are actively shaping the lives of workers, and then how people in turn can shape those technologies in the world of work. The NSF focus on **harnessing the data revolution** highlights the need for a research-oriented data infrastructure to drive new discoveries about how people learn. With regard to **convergence research,** research teams could pay attention to the importance of merging ideas, approaches, and technologies from widely diverse fields to stimulate innovation and discovery in addressing the challenges of today's global society. Finally, in reference to the NSF **INCLUDES** program, Dr. Marrongelle called attention to the significance of a central focus on equity issues.

Amy Baylor, a program director for NSF who focuses on advanced learning technologies, made three additional points. First, the workshops at this summit were funded through a competitive grant process designed to promote discussion around the topics identified by the field as key to the advancement of cyberlearning research, including identification of design principles that should be investigated in more depth. She added that cyberlearning research is intended to have a long-term focus, so the field should be thinking about both near-term (1-3 years) and longer-term (5-10 year) directions and should include stakeholders from many areas such as education, computer science, engineering, and social sciences. Finally, Dr. Baylor highlighted the importance of work that grapples with the potential and problems of AI in learning, including how AI relates to data collection and use, to novel experiential modes like Augmented Reality (AR) and Virtual Reality (VR), and to newer learning approaches, like personalized and adaptive learning.

Following this, each workshop presented its findings, insights, and recommendations during 6-8 minute presentations. While listening, participants wrote down emerging common themes, opportunities, challenges and design principles on sticky notes. During a gallery walk, participants organized the collection of stickies and began to identify ideas worth pursuing collaboratively. A protocol guided small group discussions on emergent challenges and generated productive discussions on possible strategies for resolution. As a result of these discussions, additional topics were added to the list of potential ideas. Toward the end of the summit, participants voted on the most important themes and worked in small groups to define how to engage a broader audience on those themes.

Findings and Insights

Based on the discussions at the summit, the CIRCL team conceptualized the 11 participating workshops as having three centers of attention— learning environments, research issues, and community building. All workshops featured these three centers of attention, but with different levels of emphasis.

For **Learning Environments** workshops, participants emphasized advanced learning environments such as:

- **Social robotics.** Young children interact with artificially intelligent robots as learning partners, which children find engaging and pushes the boundaries of human-technology interfaces as well as learning theories.
- **Embodied mathematics.** With advanced technology, mathematical experiences can be designed using gesture-based, tangible, and sensor technologies; these experiences drive improvements in theories of mathematics learning as embodied (not only as occurring in the brain).
- **Team-based learning.** Although "personalization" and individualization have been popular learning technology themes, one workshop instead emphasized how learning can be increasingly team-based, across space and time. This calls attention to the need for stronger social learning theories, especially theories that can address learning collaborative learning at scale.
- **Learning across geographic boundaries.** Another workshop featured learning environments that connect learners across distant settings, such as in Africa and the United States. Such learning environments challenge us to develop technologies that are robust in different contexts, and to develop theories about interest-driven creative learning across settings.
- **Studio-based learning.** Studio-based learning brought together maker labs, design studios, and other forms of place-based, interest-driven learning. This workshop featured issues of diversity, equity, and inclusion in studio-based environments.

The **Research Issues** at the center of multiple workshops included:

- **Learning analytics.** How to leverage the learning traces recorded as learners interact with technology to improve the design of learning environments.
- **Multimodal data.** How to combine data streams such as technology use, voice, eye-gaze, gesture, and other forms of learner data in a cohesive analysis of how learning occurs in a complex learning environment.

- **Longitudinal data.** How to collect, organize, and analyze data about an individual's learning across different physical learning spaces and over longer periods of time (e.g. a year or more).
- **Diversity, equity and inclusion**. How to make issues of access, use, and learning for learners from different backgrounds, with different needs, and who may participate differently.

Workshops emphasized **Community Building** in several different ways:

- **Smaller liberal arts institutions.** Engaging smaller liberal arts institutions in learning sciences research and learning technology investigations.
- **Scaling technologies across institutions.** Building capacity across institutions to work together on issues of scaling up promising approaches and technologies.

- **Connecting formal and informal.** Deepening the connections among teams that work mostly in the informal sector and teams that work mostly in the formal sector.

During the initial presentations for each workshop, the audience wrote and posted sticky notes about cross-cutting themes. After the presentations had been completed, all workshop participants worked together to organize the notes and to identify categories . Eight overarching themes and challenges emerged:

Themes

1. **Learner agency**. Technologies and learning environments need to be designed to promote learner agency so that students may become more reflective, self-directed learners with the ability to recognize their own learning needs.
2. **Interest-driven learning**. Interest driven is an overarching theme in many cyberlearning projects, but the field lacks common frameworks, terminology, theories etc. to make convergent progress.
3. **Cross-disciplinary insights**. Participants highlighted how cyberlearning research relies on bringing together insights from disciplines that do not ordinarily work closely together, such as computer scientists, learning scientists, and experts in equity or in particular learning environments.
4. **Equity and inclusion.** Participants were in agreement that designing innovative technologies and learning environments that are accessible and meet the needs of ALL learners is critical, but also acknowledged that there are often many barriers to doing so; Technologies are not necessarily neutral/unbiased.
5. **Non-traditional pedagogies**. Participants were excited to expand the boundaries of relevant existing pedagogies (like project-based learning and collaborative learning) and to envision new pedagogies that become possible through the use of multimodal streams of interaction, embodied learning, machine learning, and AI.

Challenges

6. **Assessment**. These types of learning environments require new models of assessment that examine learner growth rather than mastery and that are accessible and equitable for all learners. There was particular interest in how cyberlearning environments could measure progress towards competencies that have real-world value and how to describe the competencies that educators will need to support learners in these new environments.
7. **Data.** Participants indicated that the limited availability of longitudinal data records can hinder research, and also highlighted the range of pressing data issues in cyberlearning research, such as algorithm bias and lack of awareness around data policies and ethics.
8. **Convergence.** Participants indicated that "boundary crossing" can be difficult when building cross-disciplinary research teams. Specifically, increased collaboration amongst learning scientists and technology developers/computer scientists is needed, and existing collaborations need to be sustained.

Each workshop was charged to share **design principles**. Because of the variability of the workshop topics, a range of frameworks and principles were discussed. Details appear in each workshop report, and here we give examples to illustrate the range of relevant principles that are needed in future cyberlearning research.

- **Accessibility perspective.** Valuable principles arise from frameworks such as Universal Design (UD), Universal Design for Learning (UDL) and the Web Content Accessibility Guidelines (W3C)
- **Studio-based learning perspective.** Important principles elaborate how to support interest-driven learning and how to support learning across distances.
- **Child-robot interaction perspective.** There is a need to articulate principles that address both safety and ethics as well as learning as young children interact with technology in novel ways.
- **Adaptive-learning environments perspective.** New principles are needed that connect learning from one topic or setting to a different topic or setting—principles not just for specific learning experiences, but to connect a range of learning experiences.
- **Embodied learning perspective.** Principles are needed to design gestural interfaces, to connect social emotional and cognitive learning and in the area of distributed cognition.

The range and variation of design principles used in cyberlearning workshops speak to the complexity of learning through technology. This complexity is rapidly expanding as new kinds of technologies and interactions are incorporated into learning environments—existing design principles will not be enough to address the challenges arising in highly novel technologies and forms of learning. Participants at the summit therefore see urgency in focusing now on researching the most valuable design principles *for future learning environments*, not just design principles that can guide the technologies that are mainstream today.

Overarching Recommendations and Next Steps

Each workshop produced its own recommendations to advance future research on learning with technology. These recommendations can be viewed in the individual workshop reports.

Through the process of the summit, we arrived at the overarching recommendations listed below. We looked in particular for directions that go beyond “normal science”—beyond incremental advances in the research already taking place. We asked, based on these workshops and our summit, what might yield a “paradigm shift” (e.g. Kuhn, 1962) in the future of learning technology research?

Recommendation 1. Research proposals should prioritize emerging **learning environments and tools** with the highest potential to drive paradigm shifts in the future of learning, not only learning environments and tools that are becoming widely adopted now.

> Examples of environments or technologies that appear to have this potential include social robotics, embodied learning, team-based learning, cross-domain and cross-geographies learning. Overall, priority learning environments tools would be those that could become widely available in 5-10 years, that focus on a modality of interaction that is relatively novel or under-utilized and might span multiple learning settings. Further, priority learning environments would be those that raise the salience of important issues in learning theory, design, algorithms, models, data or analysis— issues that cannot be as deeply pursued within the technologies already in wide use.

Recommendation 2. Research proposals should seek to advance **research capabilities** that are essential to investigate excellence and equity in both learning across many future learning environments.

> Examples of research capabilities that need more attention include multimodal analytics, defining and measuring competencies, methods for designing and measuring accessibility, equity and inclusiveness in novel learning technologies, ways to establishing design principles so they are integrated within many designs. Overall, such proposals would not only answer specific research or design questions, but also advance research methods that many investigators might use to tackle pressing questions.

Recommendation 3. Research proposals should include contributions to **community-wide activities** that can advance the knowledge infrastructure of the field and thereby accelerate the process of discovery and support achieving broader impacts.

Community-wide activities that need more attention include: addressing ethics of data, building capacity around scale up; moving accessibility and other design principles into use; communicating scientific insights to broader audiences; accelerating knowledge sharing; broadening the range of educational institutions and diversity of individual contributors in research activities; improving our understanding of how to do convergent science; building community roadmaps that help multiple scientific teams to focus towards shared goals. Overall, proposals would move beyond viewing "broader impacts" only as "dissemination" to also seek broader impacts by taking a lead role in a process that addresses community-wide needs.

As a next step, we plan to organize events at relevant conferences where members of the community could engage further with the recommendations of the summit and the individual recommendations from each workshop.=

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