Partnerships for Change: Transforming Research on Emergent Learning Technologies

By the Center for Integrative Research in Computing and Learning Sciences (CIRCLS)

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Executive Summary

As researchers seek to build knowledge in their fields and have a meaningful impact on society, the structure of research is rapidly shifting from individual investigators exploring their own questions to collaborations among investigators and partnerships with practitioners. Together, they decide what questions to ask, what data are meaningful, and how to interpret findings. For the last decade, the National Science Foundation (NSF) has strongly emphasized the need for collaboration and has specifically encouraged partnership in research focused on STEM education. Partnerships were at the core of NSF's Math Science Partnerships initiatives and two of its "10 Big Ideas" for future investment – Convergence Research, with its focus on integration across disciplines, and NSF INCLUDES, which catalyzes collaborative work for inclusive change. The EDU Directorate of NSF continues to prioritize partnership as it considers how to advance research to address the issue of the "missing millions" in STEM identified by the National Science Board.

We observe, however, that "partnership" can mean many things – from two universities working on separate pieces of a large project, to a Research Practice Partnership between a school district and an education institute, to an interdisciplinary team of learning scientists and computer scientists, to game designers, students, and researchers co-developing a STEM game. For this report, we are interested in looking at a variety of partnership types, but through the lens of partner contributions leading to transformation, which may be transformation of a design, research questions, or even the research process itself.

This report is grounded in a set of case studies related to Research on Emerging Technologies for Teaching and Learning (RETTL) and similar projects. We chose this focus because the Center for Integrative Research in Computing and Learning Sciences (CIRCLS) hub serves a portfolio of NSF awards focused on RETTL. The theme of how to create effective and lasting partnerships arose as a priority in our last community convening in 2021.

Further, the awards in the RETTL portfolio feature exploratory research – and exploratory research should foster transformation. In fact, the awards require partnerships among computer scientists and learning scientists, and transformative partnership is an intrinsic part of the program. The solicitation states: "Emerging technologies have the potential to transform teaching and learning, in both formal and informal settings, particularly in support of STEM learning outcomes." Shortly thereafter, it states: "Given the complexities surrounding the development of technology and learning environments, high-impact research requires interdisciplinary teams." Going beyond teams only of researchers, the community heavily emphasizes an applied orientation to education in its research and the need to partner with practitioners and other participants through the research process. In short, the CIRCLS community is fertile ground to examine the nature of transformative research partnerships.

What Kinds of Transformations Are Possible?

Across an initial set of four case studies, we uncover how strong partnerships result in transformation of the research vision and initial design commitments, and how they can even lead to considerable reframing of the core research questions at the heart of an investigation. All of these case studies share a commitment to "co-design" – a process in which researchers share power with practitioners to design an exploratory use of technology for learning. Co-design is distinct from light-touch engagement with practitioners that commonly occurs through focus groups or field tests. Through the co-design process, the practitioner's perspective and voice deeply influences the design itself. Below are summaries of these cases.

- Co-Designing an Introductory Coding Platform: To engage more students in learning computer science, a partnership among researchers, local teachers, and a local chapter of the CSTA developed a new vision for a coding platform: a platform grounded in students' creativity, design thinking, and their desires for freedom. The team found ways to refocus away from syntax and toward a problem-centric curriculum, and they learned that incorporating visualizations and non-technology activities was essential to student learning.
- Co-Designing Maker Spaces: As partners sought to create an effective support system for students' self-directed learning in maker spaces, new visions for "documentation" tools emerged with a shift toward design solutions that shortened the distance between physical and digital resources. The case reveals how strong commitments and execution of a well-specified co-design process enabled dramatic changes in the research project, changes that better suited students' needs and learning environments.
- Co-Designing Augmented Reality: As partners explored augmented reality experiences for community college astronomy students, initial presumptions about student roles and the goals of the classroom activity quickly fell away. The design concept and research investigation shifted to focus on giving students "shared representational spaces'' to productively exchange knowledge and make meaningful references to important artifacts and variables across technologies.
- Co-Designing a STEM Learning Game: As game designers collaborated with neurodivergent college students to co-create an educational game about space exploration, the possibilities for what the Principal Investigator (PI) imagined might be up for negotiation expanded substantially. The project team took the time to integrate appropriate accommodations into the work process, enabling full and meaningful participation of all participants, whose voices were heard and whose ideas led to significant changes in the game characters, narrative, and interface.

In these cases, we see that partners transform the core vision of an exploratory research project with emerging technologies, often causing researchers to abandon presumptions about their design and their research questions. As they honor practitioner voices, the researchers re-focus on designs and research questions that are more relevant to practice. Resulting exploratory designs are a much better fit to educational environments and partners' learning goals. In summary, co-design involves sharing power with practitioners so they can play strong roles in reshaping the project vision, its design premises, and the research questions to align with educational priorities.

How Are Partnerships Structured to Be Transformative?

Partnerships can challenge core structural elements of research projects, for example:

- Institutional Review Boards (IRBs): In an exploratory project in which Indigenous communities used technologies to enable families to share knowledge about their connections to the land, the project team partnered with the IRB to define how ethics and social justice could be honored and strengthened through research.
- Advisory Groups: As CIRCLS brought together practitioners to create a framework for school adoption of emerging technologies (such as Artificial Intelligence (AI), Virtual Reality (VR)/Augmented Reality (AR), and use of an expanded set of sensing and visualization technologies), the team re-thought the process for creating and structuring an advisory group in a research project – transitioning away from providing feedback to researchers and toward empowering practitioner voices.
- Interdisciplinary Meetings: An AI Institute encountered challenges in finding common ground among its computer scientists (CS) and learning scientists (LS), and restructured the dialogue between these disciplines. They found that a conjecture map tool helped CS and LS researchers see how their different values and perspectives fit together, and helped them develop "conjectures" about their research that would be meaningful to both groups. Further, the adapted conjecture map helped the interdisciplinary teams consider risks of AI in their exploratory research.

In these cases, we see that in partnerships for change, the partners examine typical infrastructural components of research – the IRB, advisory groups, and interdisciplinary meetings – and then dramatically reframe these roles to enable the infrastructure to more directly and strongly achieve the partners' research and development goals.

How Can Research Communities Build Capacity for Transformative Partnerships?

Demonstrating a commitment to partnerships will require that our community builds its capacity to prepare early career scholars and institutions that do not often receive research funding to engage in this kind of challenging and valuable work. Establishing a set best practices for creating replicable partnership procedures will involve learning what effective programs are already doing. In the final section, we present two cases that illustrate how to build capacity for partnership.

- Among early career researchers: In the first piece, we learn about a project that co-creates technology enhanced math activities with and for a variety of informal STEM organizations. The lead researchers on this project describe how they structured research opportunities to prepare early career researchers to be good partners with community-based organizations and engage in high-quality partnership research. We also hear from the graduate students who were trained in this project, including what they learned about partnership research from their experience engaging with community organizations and youth.
- At Historically Black Colleges and Universities (HBCUs): In the second piece, we learn about an HBCU with close ties to its local community that brought together high-tech industry, research, and workforce development partners to co-create a robotics and data science program to inspire high school students to see pathways into the STEM workforce.

These pieces provide concrete examples of how working with partners, especially community-based partners, is essential for building future capacity for rigorous and meaningful research on emerging learning technologies.

Recommendations and Next Steps

In reviewing all of the cases of partnership presented in this report, the editorial team generated six recommendations for structuring, sustaining, and building capacity for transformative partnerships in our work:

1. **Establish partnerships before developing projects**. Researchers should establish partnerships early in project development because these relationships will change their vision for the work.
2. **Allocate time and attention to establishing equitable procedures for doing partnership research**. Authentic involvement of a diverse set of partners strengthens our projects, but researchers have to be mindful that structuring equitable and supportive partnerships takes time and effort.
3. **Co-design the ideas for research, development and programs with partners**. Our partners need to be the drivers, not the recipients, of our work and should play a key role in all aspects of the project, including research design and outcomes.
4. **Establish the emerging technology as a place for dialog and synergy, where all partners have something valuable to contribute.** It is essential for teams to create open and accessible technologies so that teachers and students can contribute as

much to the design of new learning technologies as programmers or graphic designers.

5. **See changing the research designs, questions, and processes based on partner input as a feature, not a bug**. We engage with partners, especially practitioner and youth partners, not to get their approbation on our designs, but their honest opinions based on the experiences they have using them in real-world situations.
6. **Build capacity for valuing partnership research**. Partnership research is not what many research communities or academic disciplines understand as "research," but it is essential for creating effective designs for technology-enhanced learning.

The CIRCLS team and its community look forward to continuing our progress toward understanding transformative partnerships in our upcoming convening and in our community's future work. The approaches outlined in this report can lead to innovative exploratory research with emerging technologies and concrete strategies to bring the "missing millions" into STEM by partnering with stakeholders, often in historically marginalized communities. We hope these examples will encourage dialogue with other NSF initiatives as well as others who are exploring how research partnerships can be transformative.

Introduction

The community of researchers served by the Center for Integrative Research in Computing and Learning Sciences (CIRCLS) designs and studies emerging technologies for teaching and learning, often in close collaboration with youth, practitioners and multidisciplinary partners. In this Community Report, we explore how such partnerships have enabled research projects to respond to educational needs, focus on capacity building, and pursue transformative visions for teaching and learning. Our intention with this report is to share examples of how members of our community have employed strategies for engaging in productive and impactful partnership research.

The innovative, interdisciplinary researchers who make up the CIRCLS community explore the potential that cutting-edge technologies have for creating exciting new learning experiences. Through solicitations such as Research on Emerging Technologies for Teaching and Learning (RETTL), the National Science Foundation (NSF) has encouraged this research community to take chances and propose bold ideas to move the field forward. Because the community is deeply committed to equity and to understanding how innovations can work in real educational contexts, many in the community have developed partnerships to achieve goals that include translating research into practice, collaborating across disciplines, and co-developing programs with diverse communities.

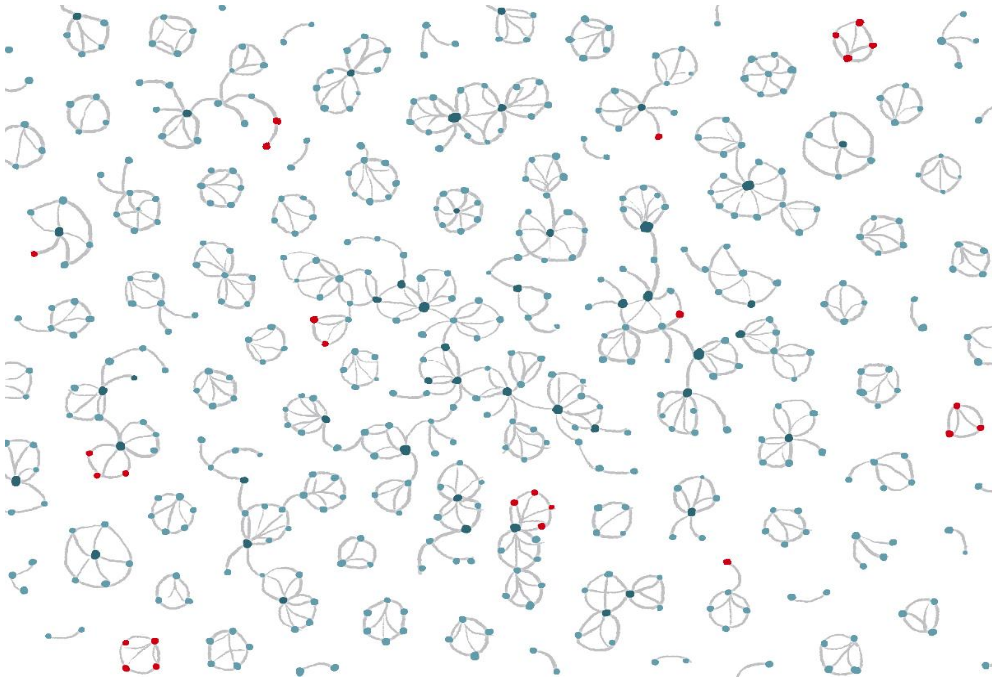
Researchers rarely get a chance to write about their experiences with their project partners. In developing this report, we asked our contributors to do just that. We define partnerships broadly. Partners include teachers and administrators, students, community-based organizations, tribal communities, industry representatives, and even Institutional Review Boards. In all cases reported here, the research teams structured processes that enabled them to collaborate meaningfully and equitably with partners – sometimes by co-designing, sometimes by collaborative decision-making, and sometimes by starting a project from a problem of practice defined by a partner and designing solutions around practitioner needs. By sharing these examples, we aim to enable additional research teams to engage deeply with partners as they investigate how emerging technologies can transform learning.

Community Context

At the CIRCLS'21 convening, which had the theme "Remake Broadening," members of this research community, which includes RETTL awardees and others doing similar work on emerging learning technologies, described strategies for having a meaningful impact. CIRCLS staff came away from that meeting with shared core ideas about moving away from the concept of "broadening participation" to one of creating equitable, empowering partnerships. Some of the key areas of focus for creating better partnerships made by the community included:

1. Preparing Researchers: Researchers should be prepared for research that balances considerations of use and fundamental knowledge; prepared to be good partners; prepared for multidisciplinary teamwork; prepared to set and measure equity-relevant goals; and prepared to expand who is included as a researcher.
2. Changing the Design Focus: Future design-based research should insist on accessibility, tackle tensions between realistic and futuristic technologies, develop tools that improve the process of co-design, and leverage platforms so that designs might more readily scale.
3. Improving Partnerships: Researchers should commit to partnerships early in their projects and seek partnerships that last longer than a three-year project cycle; they should listen in order to transform their work; they should value what communities are already doing and use co-design processes to incorporate community assets; and they should value capacity building (and capacity limits).
4. Rethinking Broader Impacts: Researchers need to (1) develop values and norms around ethics; (2) focus on what user communities value most; (3) invest more in emerging scholars; (4) rethink dissemination to give back more to participating communities; and (5) find policy hooks for research insights.

This report builds on what we discussed about the importance of partnerships at that convening and goes beyond the convening by providing clear examples of effective partnership strategies. The cases are grouped under three themes, which follow a preliminary section that provides overall context about the CIRCLS community and their partners based on data that CIRCLS has collected over a number of years.



Existing Partnership Trends in the CIRCLS Community

By Aditi Mallavarapu and Shari Gardner

Our community is formed by the awards made in NSF research programs, and thus to understand the community, it is important to begin with the solicitations (i.e. calls for proposals). The Cyberlearning and RETTL solicitations invited proposals for futuristic exploratory innovations in learning and teaching technology from cross-disciplinary teams with complementary perspectives. In response, researchers from computer science, learning sciences, educational psychology, and many other domains have come together both as project teams and across projects to form a research community over the decade.

To increase our understanding of the research taking place within the community, including the types of partnerships being formed, the CIRCLS team administers a project survey to PIs of newly awarded RETTL projects. Based on the most recent responses from 35 RETTL projects, about 80 percent of projects include collaborations or partnerships. A majority of these projects reported that they partner with educators or practitioners (66 percent). Responses indicated that these projects partner with educators or practitioners to actively engage them in the co-design of new tools, curricula, and technologies; conduct needs sensing to inform development; and to engage educators as research participants in usability or pilot testing and as early adopters of new tools and technologies. Other project partnerships include those with schools or districts (34 percent), community organizations (14 percent), and/or Minority Serving Institutions (MSIs) (six percent) to engage teachers and learners in the iterative design and development of new technologies and/or to be the implementation setting of the formal and informal learning experiences being developed and tested. Projects also indicated partnering specifically with schools or organizations that exclusively serve students with disabilities to engage these students throughout co-design, development, and testing and to ensure that the tools and technologies being developed meet the needs of all students. Lastly, the few projects that indicated that they partner with MSIs said that they are collaborating with these institutions as research partners.

The CIRCLS Community Network

To further characterize the research contributions from this community, the CIRCLS team collected data on project collaborations and conducted an analysis that allowed us to (1) visualize investigator relationships and research collaborations, and (2) map the interdisciplinary contributions.

We used the names of Principal Investigators (PIs) and Co-PIs listed as NSF awardees between 2011-2022 to visualize the research community. The PIs and Co-PIs constitute the nodes, and the collaborations between them are represented as edges (see Figure 1a or access the interactive network here). The network depicts 1133 researchers connected as 279 sub-networks. This includes nine influential members (awarded more than five grants) embedded in the larger subnetwork which connects 62 members together as a subnetwork (see Figure 1b).

To further understand how the community was evolving, we visualized the new members in red nodes. These new members joined the community in teams, and to a lesser extent, as collaborators with existing members of the community. This growth of the network opens possibilities for CIRCLS to integrate these members to form a more inclusive community.

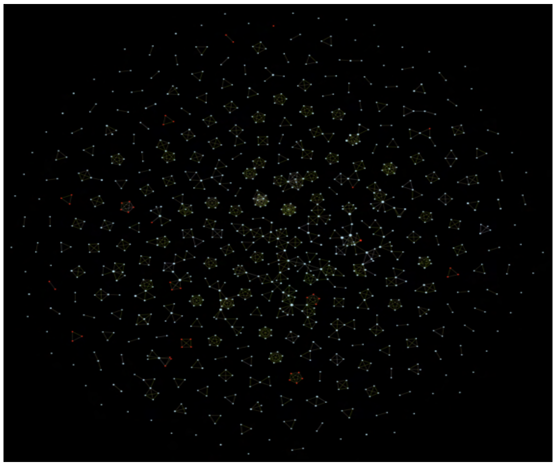


Figure 1a: Collaboration network of CIRCLS community as of 2022. Nodes represent PI and Co-PI, and their collaboration is represented as edges. New PIs and Co-PIs are represented in red.

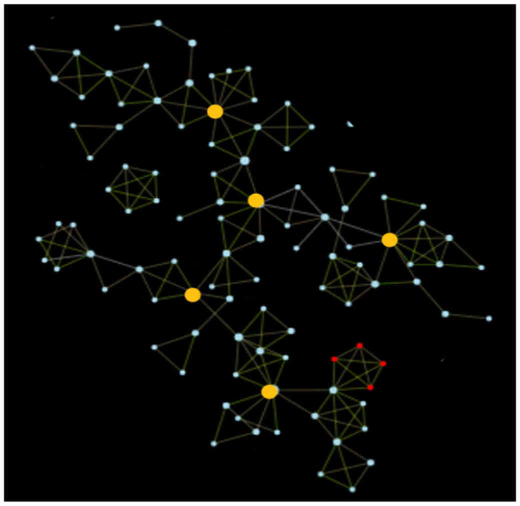
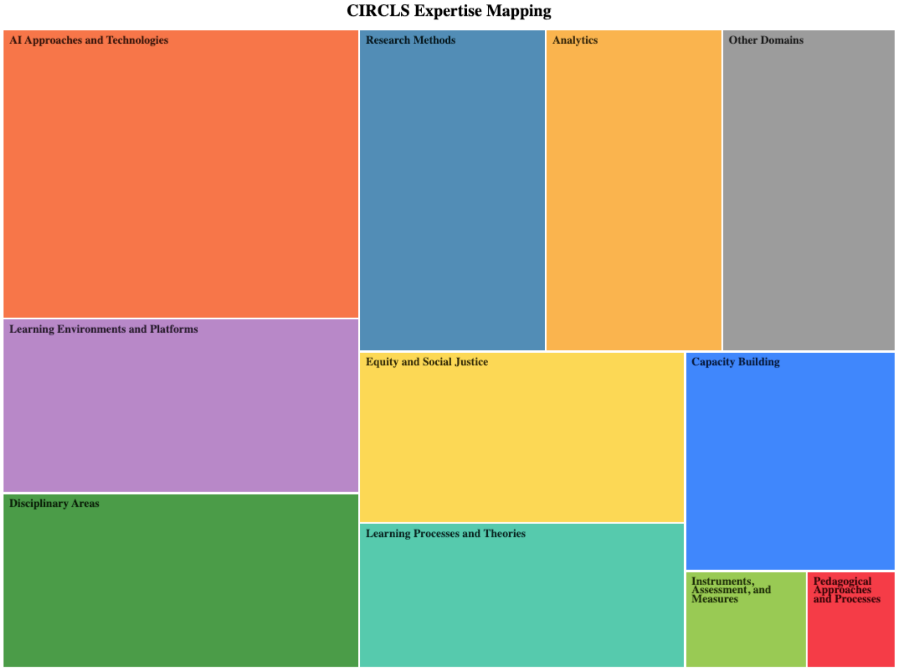


Figure 1b: Representation of the largest subnetwork showing the five influential nodes in yellow

Mapping Interdisciplinary Community Expertise

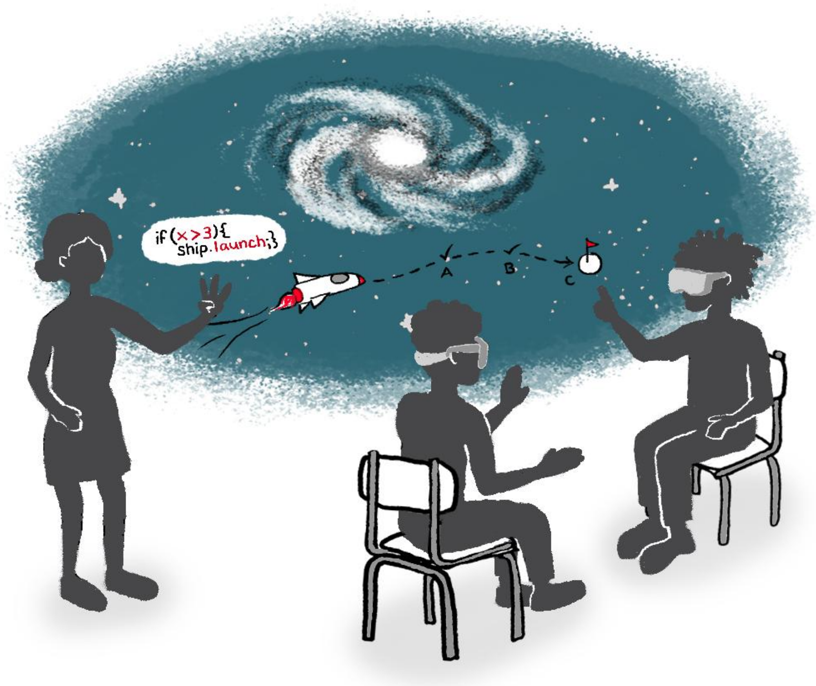


Community expertise treemap. Each tile represents the proportional number of members that contribute to the respective tag, the color of the tile depicts the high-level category of that tag.

To understand the expanse of the cross-disciplinary research contributions of this community, in early 2021 the CIRCLS team developed a tag-based framework, hierarchically arranged within 10 major categories of interest. We manually cataloged research expertise from 145 recent RETTL awardees, from their professional websites and curriculum vitae. We re-coded the collected information using the tag-based framework as a starting point to create a treemap of research expertise of the community (see Figure 2). The treemap shows that 20 percent of the community indicated that they have expertise in AI approaches and technologies (see blue tiles on left), with learning environments and technologies closely following this category at 15%. The community also includes expertise outside of educational research, bringing in domain and state-of-art technology development expertise (see "other domain" block below), while also contributing to equity and social justice oriented projects (see "social justice" block). With the prolific emergence of AI-oriented chat applications, a notable observation is the growing expertise in narrative learning environments, where learning environments mediate narrative-based learning via AI enabled technology.

Future Directions

In future work, the co-occurrences among these tags is being analyzed to understand the different genres of interdisciplinary research in the CIRCLS community. These insights could allow us to (1) understand the nature of the interdisciplinary collaborations within CIRCLS and support it by brokering connections amongst community members, (2) identify the strengths and potential gaps in project areas to suggest exciting opportunities for new investigations, and 3) reveal tag-based similarities and synergies between existing projects.



What Kinds of Transformations Are Possible?

One of the recommendations from the CIRCLS'21 report, "Changing the Design Focus," emphasizes the importance of allowing community and educator partnerships to shape the direction and priorities of design-based research around learning technologies. While RETTL researchers may explore the cutting edge of emerging technologies for learning, they also listen to project partners and thoughtfully reflect on practical issues. These issues include accessibility and the strategic utilization of existing infrastructures present in both formal and informal educational contexts. Researchers weigh the tradeoffs between the pursuit of "futuristic" innovations and finding "realistic" solutions to issues faced by practitioners. Strong and authentic partnerships can be remarkably potent in bringing these practical issues to the fore by centering the voices of practitioners and allowing for rapid cycles of feedback that shape the design process.

This section will highlight four projects that describe the specific ways of working with educational partners that led to a change in the focus of design-based research.

- Designing the Embodied Coding Environment: A Platform Inspired by Educators and Learners presents a novel platform for "embodied coding" that was shaped by deep and frequent discussions with computer science (CS) educators in San Diego who helped the design team understand and focus on the current challenges faced by CS classroom teachers.

- Smart Spaces for Making: Networked Physical Tools to Support Process Documentation and Learning describes how the design process was shaped by long-term partnerships with three different education sites in Pittsburgh that were enacting reflective documentation practices.
- Working with Community College Partners to Create AR Astronomy Learning Activities that are Collaborative and Impactful describes changes to the design of an augmented reality (AR) platform for learning astronomy based on close engagement with community college instructors in Central Illinois.
- UniVRsal Access: Broadening Participation in Informal STEM Learning for Autistic Learners and Others through Virtual Reality describes how redistributing power within a team that includes researchers, game developers, and neurodivergent college students increases the team's capacity for broader engagement and leads to solutions that are reflective of the diversity of its members.

Each project provides important insights into how to cultivate partnerships that will allow for design changes that ultimately lead to more impactful and transformational research outcomes. Key lessons include:

- involving partners from the beginning of the project so that they shape the research and design choices;
- listening to and acting on partner contributions;
- maintaining flexibility in balancing research goals with practical realities (especially important since all of these projects were conducted during COVID restrictions); and
- understanding that learning from partners is a core component of the research-based design process.

Designing the Embodied Coding Environment: A Platform Inspired by Educators and Learners

By Ying Choon Wu, Tommy Sharkey, and Timothy Wood

Key ideas

- Partners provided a new vision of a coding platform grounded in students' creativity, design thinking, and desires for freedom.
- Building from visualizations and no-technology classroom activities enabled a shift away from syntax and toward a problem-centric curriculum.
- "Ecological validity" in educational research means empowering partners to transform research goals.

An Embodied, Augmented Reality Coding Platform for Pair Programming (NSF grant IIS-2017042), based at University of California San Diego, developed an Embodied Coding Environment (ECE) that enables users to create three-dimensional computer programs implemented in virtual reality (VR). The ECE is a programming language created to support learning of computational concepts by leveraging the perceptual and sensorimotor affordances of acting in a 3D spatial medium. Specific design features of this system were motivated by outcomes from a need-finding study (Sharkey et al., 2022) conducted during the incipient stages of the project.

The partners on this project include several local high school CS teachers in San Diego County, whose role was to provide a better understanding of current challenges to CS learning and classroom practices, as well as describing their visions of ideal pedagogical tools and platforms. Another partner was our local chapter of the Computer Science Teachers Association (CSTA), through which the research team organized demos of our prototypes and held informal development discussions with educators throughout San Diego County.

Story of the Partnership

Our CS teacher partners were experts in what high school students need to gain an understanding of computational concepts. Working with our CS education partners revealed the importance of giving learners access to tools that support planning and critical thinking during the process of developing a computer program. This discovery resonated with the outcomes of formal studies of computer science novices (Robin et al., 2003). Virtually all educators who have offered the research team guidance expressed a desire for technologies that empower learners' creative processes, giving them "freedom to build" and scaffolding needed to develop an approach that is grounded in "design thinking." Through these conversations, we developed a new vision of a coding platform where students would be able to visualize their emerging ideas as pictures and engage in rapid prototyping of solutions in response to authentic problems. In this vision, learning tools would offer assistance with high-level aspects of a problem and boost learners' own metacognitive abilities. Preferred programming tools would also allow learners to draw connections between domains, such as block- versus text-based coding, or a piece of code and its output.

Our partners helped the research team place competencies in the foreground and to keep details like syntax in the background. For example, our partners helped us see the degree to which the time and effort it takes to learn different syntax for each code distracts from their desired teaching objectives. We also learned from our partners that the challenges inherent in learning the syntax of various coding languages were frequently viewed as distractions from obtaining foundational computational competencies and programming abilities. As one high school teacher stated, CS tools should allow learners to spend "more time on the problem and less time on syntax." Others pointed out that in the classroom, they guide students first to "solve the problem without even thinking about coding," or to integrate their higher-order understanding of the task with lower-level knowledge of syntax by writing about how different elements of their code interact. Further, another educator expressed the value of drawing connections between specific elements of code in a computer program and its output, as in the case of relating a robot's behavior to the code that controls it.

Another key finding that emerged from conversations with CS educators is their regular reliance on metaphors and visualization, which educators often use to teach challenging abstract computational concepts. Teachers described many forms of roleplay and enactments, such as organizing students to act out the changing values of a temporary variable, to play musical chairs to understand for-loops, and to imagine themselves as functions represented by paper airplanes that they toss between one another. Additionally, our partners reported their frequent use of pictures, diagrams, and flowcharts to communicate concepts and problem solve, as well as their encouragement to students to use visuals.

Through these sustained conversations, our research group realized that visualizations and body movement play several different roles in the process of developing code. They can support planning and design, problem solving and debugging, learning, and communication. Accordingly, tools that support drawing, modeling, and gesture capture are key features of the ECE (Twomey et al., 2022). With analogy to existing 3D modeling and design software packages, such as Gravity Sketch or Tiltbrush, the hand controller can be used as an instrument to create and place 2D drawings anywhere in the environment (Figure 1 left). Moreover, simple 3D models can be generated by extruding 2D objects into a third dimension (Figure 1 middle and right). Alternatively, free assets and models can also be imported from online libraries. Finally, using the gesture capture tool, the path and directionality of the controller in the user's hand can be recorded and visualized in the environment (Figure 2).

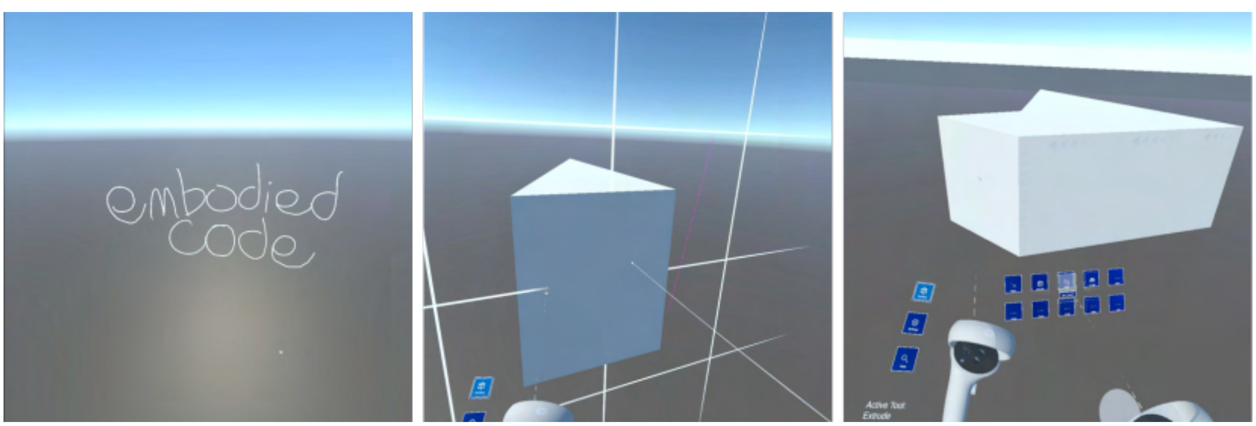


Figure 1. Left: The 2D drawing tool supports free-form sketching and writing. Middle and Right: Procedural 3D models created with the extrude tool. The user begins by defining a 2D shape and then extending it into three dimensions.

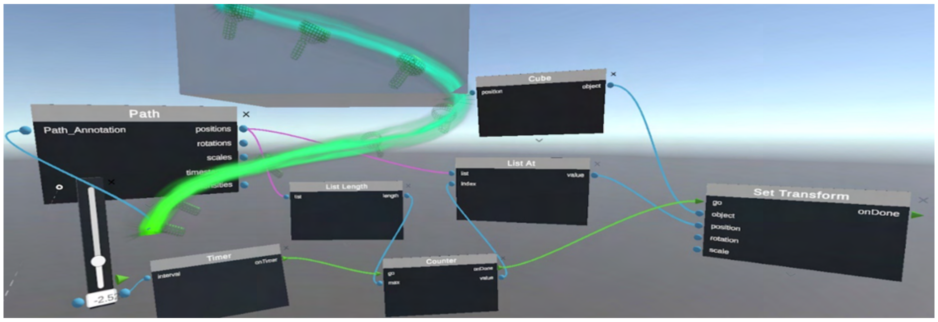


Figure 2. The gesture capture tool records the movement of the user's controller and visualizes it as a trajectory through 3D space. The direction of movement is indicated by the gradation of color from bright to dim. Green lines between nodes indicate event connections, while blue and pink ones indicate different types of data connections.

The suite of tools in ECE serves many key functions within the ECE. First, it supports rapid prototyping and free-form whiteboarding that can foster planning and design in the early stages of code development. Secondly, it supports a radically different method of annotating and organizing code relative to traditional text-based code produced on a computer monitor, which is usually arranged in a linear vertical fashion. Lines of code within traditional text-based computer programs are often ordered in sections according to their function and annotated by comments indicating their function. Embodied coding, on the other hand, enables learners to use their sketches, gestures, models and text as annotations that anchor different segments of their computer programs to different locations in the environment (Figure 3 left).

Imagine, for instance, one's goal is to simulate popcorn bursting. Initial ideation might prompt the user to realize that key programmatic elements will include code to generate representations of popcorn, a timer to control when the bursting will occur, and a random explosion generator. Using the annotation tools, the user is able to quickly sketch out these elements and their interrelationships (Figure 3 left). Next, the necessary nodes and connections are assembled and can be placed near the appropriate annotation (Figure 3 right).

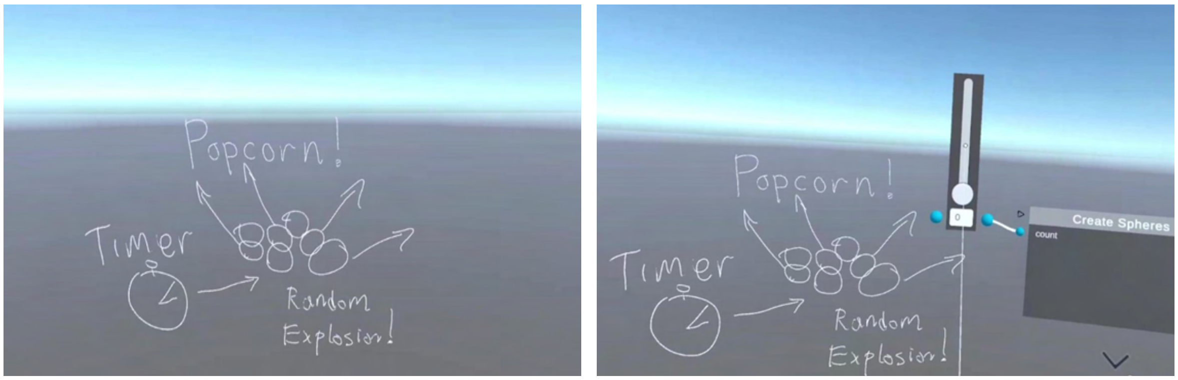


Figure 3. Left: Annotations delineating the key elements of a program designed to simulate popping popcorn. Right: Code is arranged in the proximity of the relevant annotation.

Lessons Learned

Through this partnership, we learned that we have to change the design focus of the project to serve educator goals (e.g. to focus on competencies) and practices (e.g. leveraging metaphor and embodied learning). We also learned about unmet educator needs and now plan to design additional resources for the educators. Finally, we came to a deeper understanding of what "ecologically valid" design entails.

Our partners have contributed invaluable insight to guiding the evolution of the design and implementation of the ECE. Their suggestions motivated our team's focus on creating built-in features to support problem-solving and learning by simplifying the debugging process and helping learners to ground specific elements of code that they create within a more global understanding of their program. Further, conversations with our educational partners revealed the richness and diversity of metaphors and techniques that are used in the classroom to reason about abstract computational concepts. For this reason, ECE tools have been designed to be used in flexible ways that can allow idiosyncratic mappings to be captured between computational concepts and sensorimotor experience. For instance, if a specific individual conceptualizes a loop as a circular structure or an if-statement as a forked path, annotations can be created that reflect this person's particular understanding.

The voices of our community partners have also impacted many practical considerations surrounding the implementation of the ECE. For instance, our team opted for a flow-based coding system to make learning the syntax of the programming environment more intuitive – as educators tended to view the particularities of learning a new syntax as a distraction from the process of learning basic computational concepts. Central to the ECE is a library of nodes, which can be thought of as functions, and by creating a pathway of node-based functions, various programs can be created that generate, manipulate, animate, constrain, or transform objects in the environment. Event connections create the order of execution and can be user-generated events, such as interacting with a UI element, controller events, or timer-based events. Event connections are green and show the general structure of the program (Figure 2). Data connections are blue (or pink for arrays) and transmit program values between nodes (Figure 2). Data and event connections define dependencies that are needed before a node runs on the main event pathway.

Working with our educational partners has served to reinforce our view of the value of ecological validity in design. Ultimately, reaching any particular community of learners – in this case, CS novices from backgrounds that are typically underrepresented in STEM – requires the designer and researcher to gain an understanding of the dynamics that inform learning and motivation within that community. While our educational partners have offered crucial insights in this regard, we also hope to deepen our knowledge of these dynamics through direct exchanges with underrepresented learners.

Next Steps

In conversation with our strategic partners, we are currently developing a library of tutorials and guided activities for use in the classroom or after-school contexts. One challenge to this process stems from the question of engagement; that is, what kinds of content and projects are most likely to motivate learning through the use of the ECE? We are currently developing learning materials with particular attention to the empowering potential of computing, which can enable users to adopt new perspectives and insights that may not have been imaginable on one's own. Our partners have pointed out that focusing exclusively on game development can lead to unintentional biases contributing to gender inequity, as boys tend to enjoy games more than girls. Instead, several educators suggested creating content that is oriented around authentic global or community problems and the role of computing in solving them. Examples could include exploring how 3D modeling can be used to develop solutions to climate change or the COVID-19 pandemic. Additionally, one of our partners suggested applying embodied coding to tackle themes related to the UN's sustainable development goals. Moving forward, as our team progresses through the transition from creating a functional programming environment to making it usable in diverse learning contexts, we will continue to explore what captures the interest of the underserved learners who are the target of this study.

Moving forward, we envision that the role of our partners will evolve as the focus of our project expands from design and development to testing in real-world learning environments. To navigate this transition, we are leveraging the expertise of our educational partners to integrate the ECE into the classroom and after-school activities. We are also forming new partnerships with a focus on reaching learners from underrepresented backgrounds. Our ultimate goal is to test the impact of Embodied Coding on motivation, interest, and computational concept learning in novice coders at the secondary school level.

Resources

- This website contains general information about the Embodied Coding Platform, tutorials, announcements, and more. https://embodiedcode.net/
- This video explores the Embodied Coding platform. https://stemforall2022.videohall.com/presentations/2278
- This video explores the rationale and design concepts motivating the Embodied Coding platform. https://stemforall2021.videohall.com/presentations/2000).
- This website contains general information about projects led by Dr. Wu. https://insight.ucsd.edu

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Smart Spaces for Making: Networked Physical Tools to Support Process Documentation and Learning

By Marti Louw and Daragh Byrne

Key Ideas

- The partnership led to a new vision of 'documentation' tools that support students as they engage in self-directed learning activities.
- Transformation is enabled by a strong focus in the participatory design process on hearing from partners, designing with partners, and creating appropriate ways to rapidly prototype designs with partners that enhance existing valued practices rather than introducing new ones.
- Successful collaborations require that partners create timelines that account for the resources, time, and effort needed to undertake the complex work that benefits everyone.

Smart Spaces for Making (NSF grant IIS 1736189) began as an exploratory design-based research project to examine how emerging technologies can be used to address the challenge of helping students easily and consistently document their work process in creative educational environments such as project-based, maker, and self-directed learning experiences.

To explore documentation both for assessment and as a creative practice, the Pittsburgh-based project brought together a multidisciplinary group of researchers from Carnegie Mellon University (CMU) and the University of Pittsburgh with practice partners in an extended learning design inquiry process. The research team included expertise in design and design research, learning sciences, human-computer interaction, interactive computing, and the internet of things. Building on existing relationships and past projects, we developed close collaborative relationships with three sites, whose instructional leads and programs deeply valued hands-on creative inquiry and were curious about how to better integrate documentation into creative learning experiences (Stol et al., 2023).

Specifically, our partners are pictured in Figure 1 below.

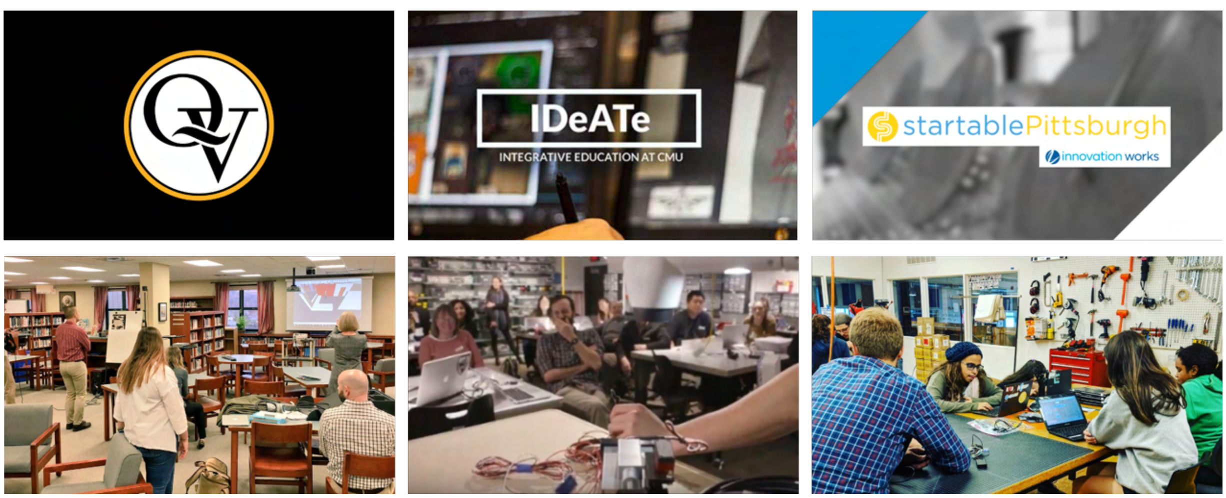


Figure 1. The three partner sites and their creative, collaborative learning workspaces that we grounded our work on. Bottom Left: The library which houses a makerspace and careers education at Quaker Valley High School. Bottom Middle: The Physical Computing Lab is used for in-class and out-of-class experimentation with creative electronics and interactive hardware devices at Carnegie Mellon University. Bottom Right: AlphaLabGear's makerspace is used to support innovation and entrepreneurship summer programming for urban youth.

Story of the Partnership

Most researchers come to partnerships with beliefs, usually research-informed, about what good learning looks like in a certain domain; and often have an associated design conjecture in mind. In addition, researchers often have pre-existing commitments to a particular strategy, tool, system, or approach to try to reach their goal, for example, to make learning happen more reliably, for more people, more of the time. We had a strong hunch that documentation was vital to good learning in creative learning settings. So in seeking to develop good partnerships, we needed to be clear about those beliefs and commitments; then be truly open to changing them as we negotiated, shaped, and gave shared language to the form that the research and design inquiry would take with our practice partners. Our negotiation process unfolded through a series of carefully crafted generative design workshops and lo-fi prototyping engagements. We also kept a dialogue open with our partners to ensure mutual benefit outcomes were centered as the relationship and project evolved.

To open up the research space, we drew on a co-design process and participatory methods to engage educators, stakeholders, and the research team in imagining and defining together what documentation is, why it matters for creative learning, and how we might encourage youth to come to value it as a creative practice, not just as a required assignment or formative assessment. Only then did we begin collectively exploring possible ways to support documentation practices through a series of generative and syncretic practices: (a) workshop engagements, which begin with space tours and inventories; (b) framing activities to identify pain points and values; (c) generative workshops to ideate concepts; and finally (d) collectively choosing concepts for prototyping based on promise and feasibility.

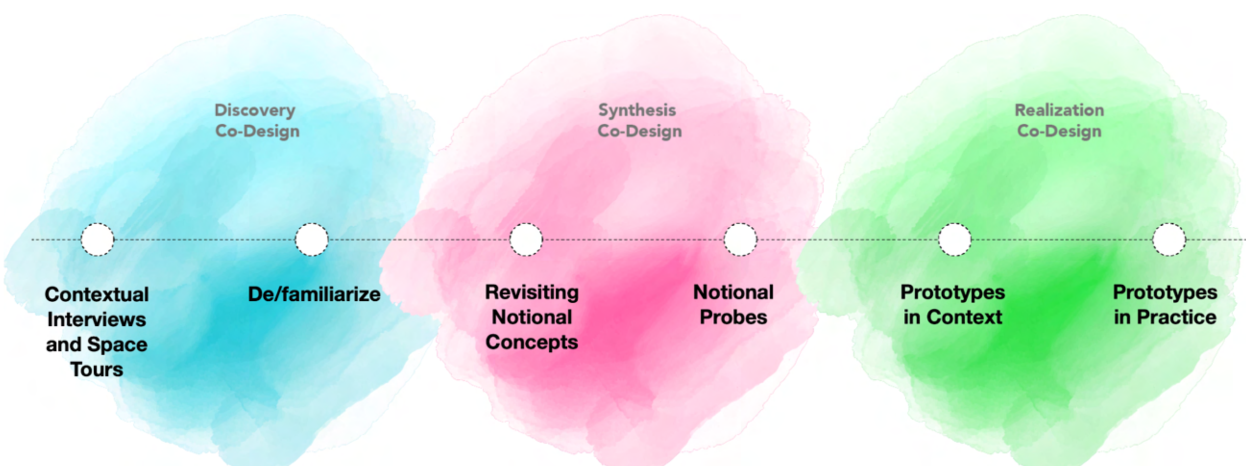


Figure 2. The phases and key activities guiding our co-design process.

Core to our engagement approach is a carefully orchestrated set of co-design activities that sought to solicit concepts and possible design enactments in a process summarized in Figure 2. Conducted in a workshop format, the activities were iterated and refined with stakeholders across three contexts. Participants included instructors, program coordinators, staff, and in some cases administrators. We began with the aim to build a shared understanding of documentation (both as a noun and verb), discussing how it benefits their curricular programming and capturing the type of challenges encountered when facilitating documentation practices in the educational setting. The workshops then transitioned to exploring relatively familiar, low-cost technologies and imagining together ways that these could be used to scaffold documentation practices. The remainder of the workshop was dedicated to a series of guided ideation activities that encourage educators to speculate on the ways in which various inputs and outputs (e.g., cameras and timelapse/video capture, live-scribe pens, thermal printers, NFC tags, smart home products, etc.) could be deployed to augment existing or foster new documentation practices in their classroom spaces. At the end of the activity, groups reported on and prioritized concepts supporting learning in technology-enhanced makerspaces. These concepts were carried forward as notional design concepts to further probe and later prototypes (see Figure 3).

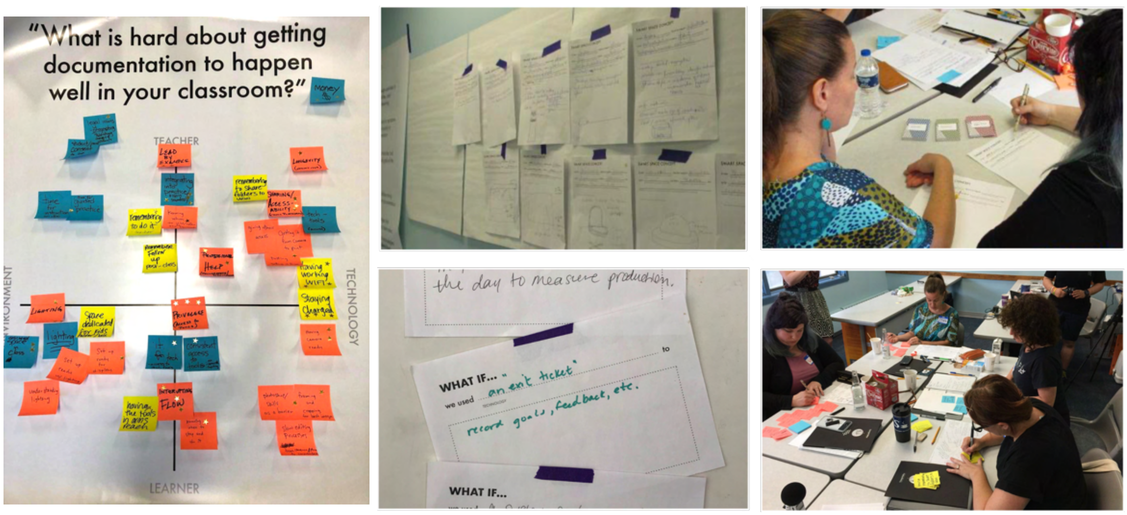


Figure 3. Participants in the co-design workshop initially identified shared values and challenges (left). This grounded a generative card activity designed to help imagine IoT-enabled solutions that support documentation practices and address challenges in maker and project-based learning contexts.

The focus on relatively familiar, under-utilized technologies in education also benefited our co-design approach. Within this work, we consciously chose to avoid more complex, futuristic technology possibilities to bring educators into the cooperative design of more tractable, near-term technology solutions that respond to pragmatic, immediate problems of practice that educational teams faced in their learning spaces.

In deployment, the creative adaptations of 'tried-and-true technologies,' like thermal printers and NFC tags, allowed us to rapidly prototype and realize notional solutions for early consideration. The focus on low-cost, robust solutions allowed us to be agile and respond quickly to shifts, uncertainties, and sudden changes in instruction. During the pandemic, we could quickly produce interventions that avoided complex assembly and uncertain technical infrastructures. These solutions had built-in consideration for students learning in widely diverse settings with varying access to technologies, toolkits, and support.

A related benefit was that our students, who were funded through an NSF Research Experience for Undergraduates grant, were able to team together to develop these relatively simple prototypes over the course of a semester or summer project and gain experience in a full research-based learning innovation cycle.

Practice partners were re-engaged through synthesis workshops to share back insights, clarify design directions (see Figure 4) and decide the next steps. For example, at the high school site, participants prioritized three concepts relating to ways in which augmented tools and materials themselves could help students learn how to use them effectively by documenting past interactions with (other) learners. A concept from one participant imagined a smart parts bin where "[a]s a user comes to materials, [the device] tracks materials they look at and take/put back. Students then "get a list of considered/used/returned materials" to help them identify relevant online tutorials and guides, and to support the creative exploration of parts as they apply to assigned project work. Educators voiced a second, and similar, concept: the design of a parts bin that would help students to "understand the purpose of complex parts and their effectiveness" by allowing a student to select materials or parts which would trigger "text and describe the use of parts and materials through video and images." This concept also included the idea that students could add to these descriptions based on how they had used the tool, giving richer resources to the next student to use the same material or part. These concepts were grouped as "tools with histories" and were prioritized by educators as one for further iteration.

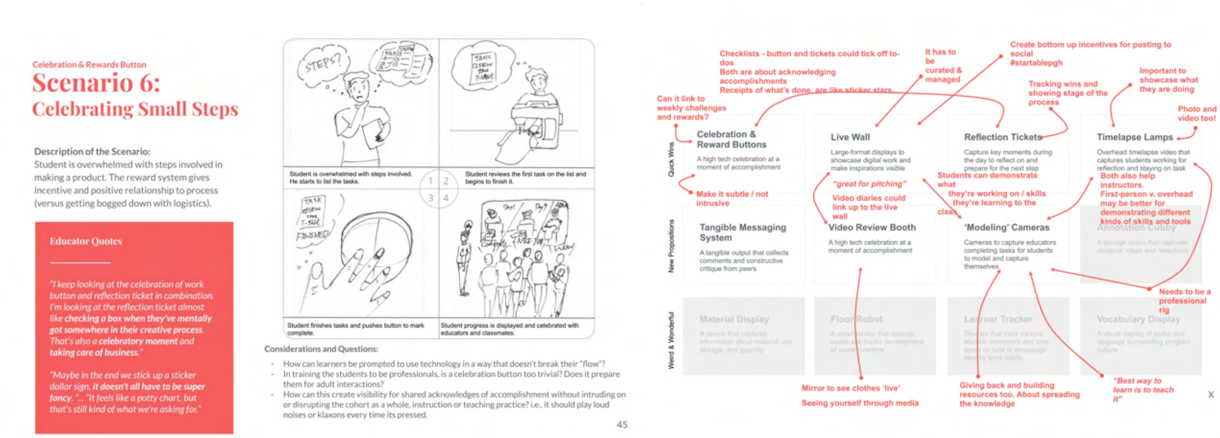
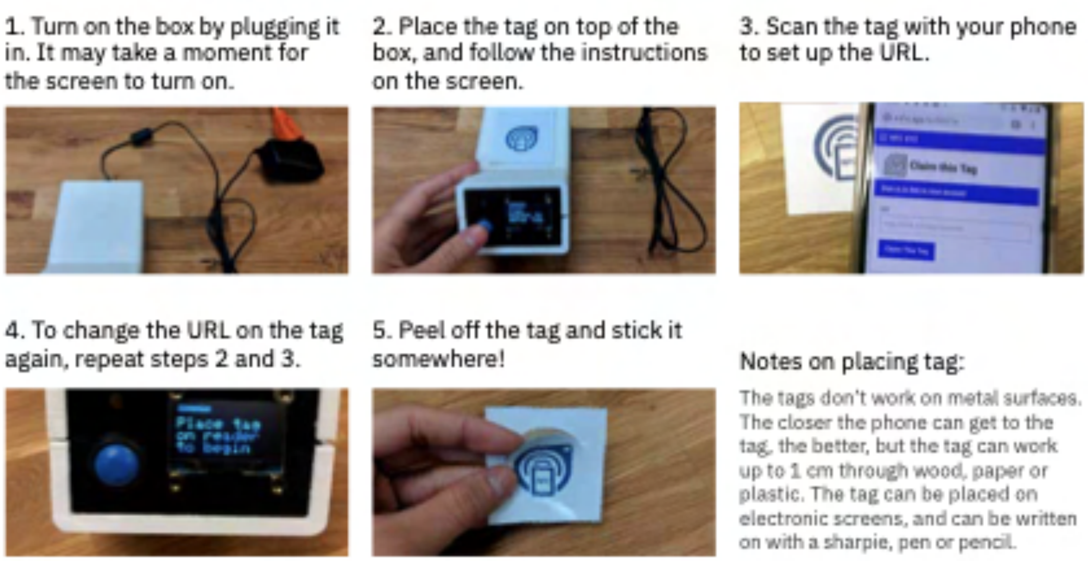


Figure 4. Synthesis workshops presented initial concepts and scenarios based on the generative workshop (left). Instructional teams were invited to share responses, clarify needs, and refine implementations by marking up the concepts (right).

Moving to the next phase of co-design, we rapidly prototyped initial versions of the potential tools envisioned for the instructional teams to encounter. Prototype review sessions allowed educators to experience and respond to material embodiments of the design concepts selected (see Figures 5 and 6).

Figure 5. At Startable, we presented a series of early functional prototypes to a group of educators and students within the program.



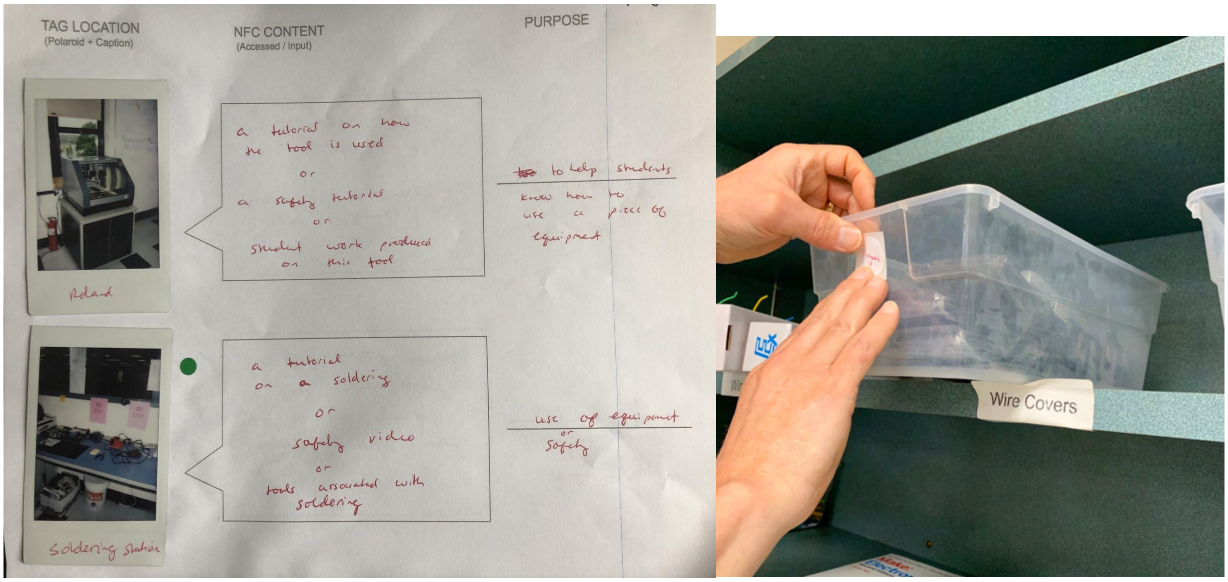


Figure 6. Prototype example for the 'Tools with Histories" concept with an NFC tagging system to allow objects within a makerspace to be quickly annotated with digital information. Each tag can be configured to redirect to a web resource (e.g. an instructable or guide) or to a wiki page that can be collaboratively edited by the learning community. Top: Step-by-step set up of an NFC tag. Bottom: A synthesis workshop where educators brainstormed opportunities and deployed tags in the makerspace

Lessons Learned

Our goal was to translate selected concepts into situated encounters with prototypes in the learning spaces. It was, however, disrupted by the pandemic. Working closely with our practice partners, we rapidly shifted the design focus from adapting documentation-related priorities to something that could be deployed in remote and hybrid learning contexts. Collaborating online throughout the summer and fall of 2020 with our practice partners had some surprising upsides; online meetings were normalized and increased the ease and frequency with which we could gather for decision-making, iterations, and tracking how the learning interventions were being adapted in the pivot to remote instruction. The products piloted included the Self-Directed Learning Kit and ioRef: Electronic Parts Cards, illustrated in Figures 7 and 8, which were deployed to students throughout 2020 and 2021.

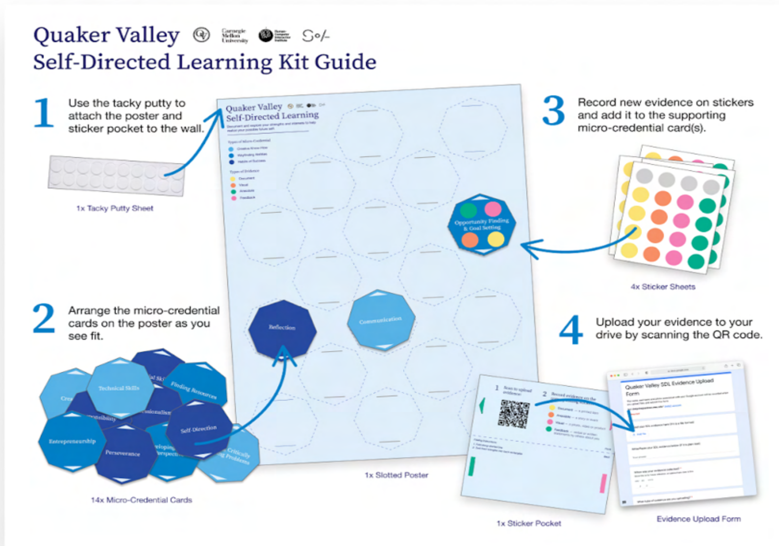
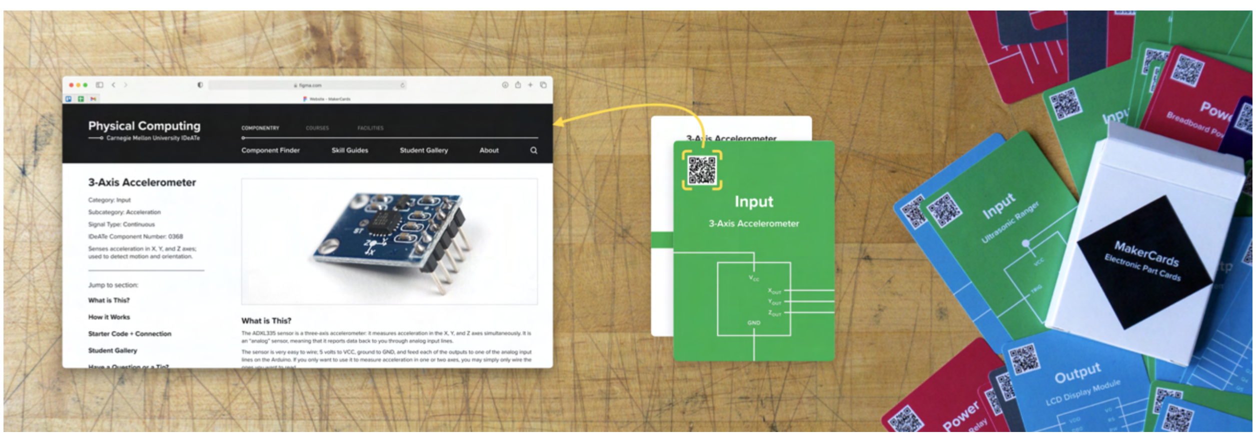


Figure 7. Above: The Self-Directed Learning (SDL) kit is a documentation toolkit for high school students that spans home-to-school settings. The SDL documentation poster kit integrates a visual progress tracker linked to a digital system for uploading, tagging, explaining, and curating evidence. Findings on student use and teacher insights from our Spring 2021 deployments to more than 60 students found it enhanced articulation and reflection on evidence of learning.



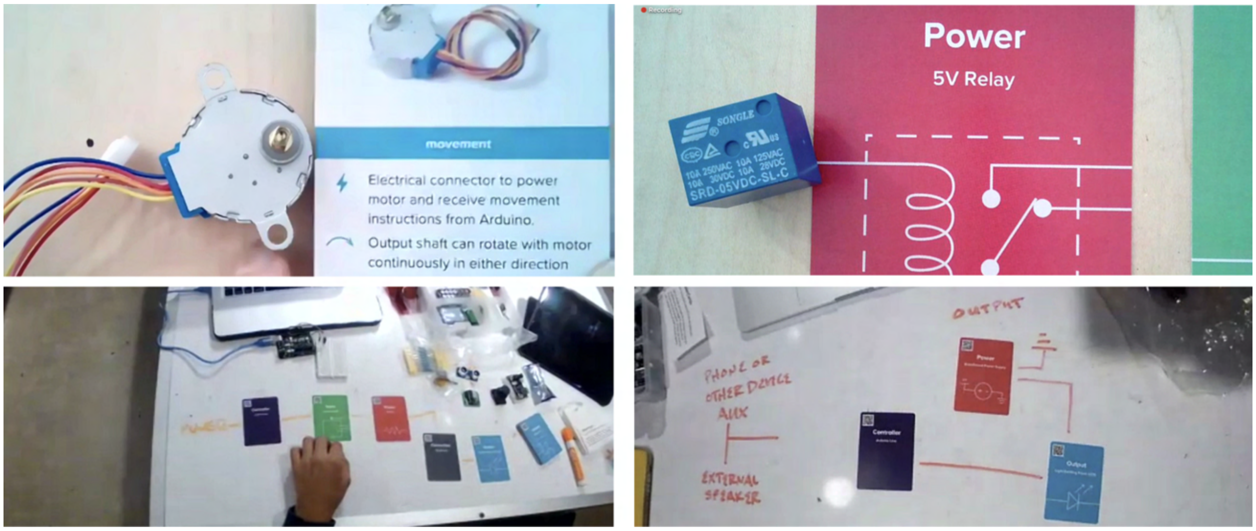


Figure 8. Above: IoRef is an instructional and creativity support tool for introductory physical computing courses. It adapts the 'tools with history concept' and builds on a QR-code-enabled card deck illustrating electronic parts and categories linked to an online knowledge base to help bridge access to creative know-how. Below: Through deployment in five courses, we found the IoRef documentation system to be a versatile resource for learning to recognize electronic components, enhanced communication in early designs and in debugging, and aid in schematic diagramming.

We've just provided an overview of an intensive, involved, cooperative design process that was deeply engaged with a series of practice partners over multiple years, sites, and program instances. This work reemphasized for us the importance of creating timelines that recognize the funding and labor needed to undertake slow, deliberate work open to shifts in priorities and pragmatics. Our partners appreciated sharing of well-designed communication materials and opportunities to showcase the joint work in their professional circles, as well as opportunities to contribute to our publications and presentations.

The project was also a reminder about how important it is to identify valued practices, and in this case, layering onto the existing cultures of documentation at each site, rather than trying to inject new approaches or tool adoption routines. We see co-design as a vital learning design research approach that needs to be better understood and practiced. Co-design offered us a means not only to arrive at highly valued learning interventions but ones that recognize, support, and amplify practices at each site. Co-design also offered us a means to intentionally shift the design focus and consider more fully how technologies can support key learning practices through documentation activities.

Next Steps

This experience has led us to reflect on our co-design practice. One insight is that we need to develop workshop arcs with partners that more fully include and recognize the ways that diverse practitioners and professionals want to participate in research-based learning innovation projects. The work has served as a reminder to us that if co-design is promoted as a more ethical, equity-centered, and justice-oriented way to engage in educational research innovations, then we need to pay much closer attention to the subtle and nuanced ways in which co-design is conducted. The prompts and forms of playful activity, the materials and skills used to creatively ideate, and the facilitation styles and timing of workshops, to name just a few considerations, can unintentionally exclude people from full creative participation in the design work. When successful, co-design methods create spaces and repeated opportunities for all participants to feel heard, energized by the possibility of mitigating persistence problems of practice, and to be fully seen as creative agents and innovators able to shape alternative educational futures.

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Working with Community College Partners to Create AR Astronomy Learning Activities That Are Collaborative and Impactful

By Robb Lindgren and James Planey

Key Ideas

- Partner contributions led to two key shifts in the goals of the learning experience: (1) from an applied task to foundational astronomy skills; and (2) from separate roles for students, toward giving small groups of students an authentic challenge.
- Developers created a narrative-centered learning experience in which students could choose AR for its unique benefits or continue with familiar software.
- Transformation occurs when researchers honor practitioners' educational knowledge and design ideas (including pivoting away from original research proposal

commitments), and yet also point out to practitioners insights that emerge from the research.

The CEASAR Project (Connections of Earth and Sky with Augmented Reality) (NSF grant IIS-1822796) was conceived as a way to integrate cutting-edge technologies, such as augmented reality (AR) headsets, into laboratory activities for students. Headset-based augmented reality has recently become accessible in the form of technologies like the Microsoft HoloLens. Applications of the technology have so far largely been for medical, engineering, and design students in university contexts.

The project involves a partnership between researchers at the University of Illinois Urbana-Champaign, technologists and curriculum developers at Concord Consortium, and astronomy instructors at institutions of higher education in the Champaign-Urbana area, including Parkland Community College. We began the partnership by reaching out to the director of the Staerkel Planetarium located on the Parkland College campus in Champaign, Illinois. Shortly after the CEASAR project was awarded, the director announced his retirement and he introduced us to two Parkland astronomy instructors who for several years have worked with us closely to explore the capabilities of headset-based AR, design the CEASAR environment to broadly support their learning goals, and then utilize the platform in their courses.

The CEASAR project aims to create an exemplar for a vision of broader and more diverse use of AR, such as with community college students who would otherwise not have access to the technology. The goal was to explore how immersive technologies could potentially add value to collaborative learning activities and reinforce knowledge and skills that were consistent with already established course objectives. Ostensibly, the aim was to bring the immersive experience of the planetarium to the social environment of the astronomy classroom by leveraging the specific affordances that AR headsets provide in allowing for simultaneous interaction with digital content and other students.

Story of the Partnership

The CEASAR project was conceived as a design-based research project. We expected that when we started working with our practitioner partners, our initial assumptions and priorities would shift. This certainly proved to be the case, and the best two examples of this were (1) in our approach to designing the collaborative tasks and (2) what we believed the technology could do to support the way the groups work together.

We knew from the outset that we wanted to give students ample space to explore the simulated night sky environment and to motivate them to investigate the spatial relationships between the Earth, the sun, and other visible stars in the sky. We initially proposed to accomplish this by creating 'solar engineering' tasks, such as determining optimal locations and angles for installing solar panels. We also proposed that all students would be wearing AR headsets but that they would be situated into different roles which meant access to different digital resources and personalized in-simulation supports. Both of these design goals were challenged once we entered into concerted discussions with our astronomy instructor partners. The partners had done similar engineering activities in their courses previously, but often near the end of a course or in more advanced courses.

After collectively reviewing course progressions and learning goals, our partners suggested more purposeful and problem-centered activities. These activities emphasized fundamental astronomy skills of observation and calculation, such as establishing cardinal coordinates and determining one's location based on a view of the night sky. The instructors also nudged us away from creating explicit roles for our learners. They argued that explicit roles could inadvertently lead to siloing of knowledge, limiting the flexibility of the tasks to adapt to changes (e.g., absences) and discouraging collaboration. They instead suggested an emphasis on designing a clear and accessible problem that all members of a group could pursue using the available devices. So rather than giving all members of the group an immersive headset, we would develop a simulation that could be viewed either within an AR headset or using a tablet computer; students within a particular group could choose which devices to use and when. This approach addressed another concern expressed by our partners that equipping all students in a class with an AR headset was neither cost-effective nor particularly desirable given space constraints and individual students' preferences (e.g., some students not wanting to wear a headset, simulation sickness concerns, or physical limitations). These early interactions with our instructors were absolutely critical and set the stage for CEASAR to pay attention to the pragmatics of classroom implementation as we continued to prototype and test our technologies.

We tested the resulting design in numerous undergraduate classes. The design was a locally networked simulated night sky that could be accessed from multiple devices, both immersive headsets and tablet computers. Networked software enabled all group members to annotate and highlight information in a way similar to a collaborative online document. Prior to the commercial release of the Microsoft HoloLens 2, we used VR headsets for early pilots, but in all iterations, there were two tablet computers and one immersive headset available to each group of three to four students (Figure 1). Either device could access CEASAR's star and constellation database, with the ability to change location and time as needed, and both devices allowed students to make annotations on the night sky (i.e. sketching lines), highlight specific constellations, share location information, and jump to another group member's location and perspective as they work. While both tablets and headsets allowed for some similar views and access to commensurate information, the devices afforded different kinds of interactions. For example, the AR headset enabled hand and gesture detection, and this allowed students to "air-tap" or pinch to select and reposition holograms. They could also perceive an embodied first-person "horizon view" of the sky as if standing on Earth. Figure 2 shows the three simulation representations available in the system and a comparison of the three views in the tablet versus the AR headset.

Figure 1. A group of three students working on the Lost at Sea task using the CEASAR simulation platform (one AR headset and two tablets).

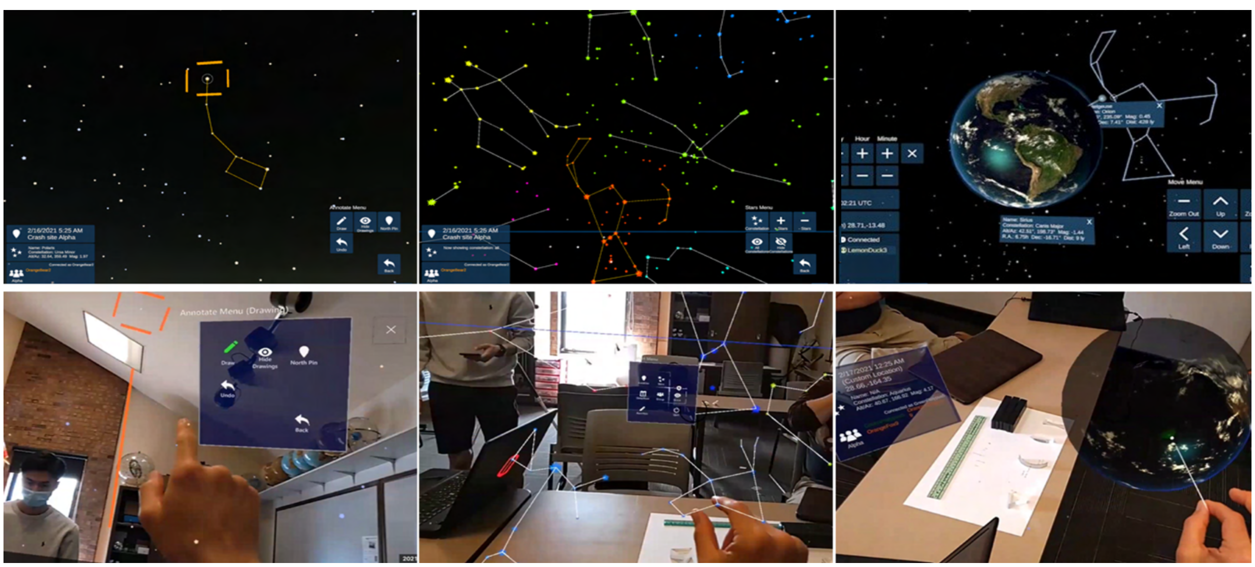


Figure 2. Left: “Horizon view” provides the user with a first-person view of the sky as if standing on Earth. Center: “Star view” removes the horizon limitations from the perspective, giving the user access to the full celestial sphere and constellation catalog. Right: “Earth view” places the user in orbit above the Earth with the ability to place location pins with which to change their position on the Earth or confer with other users about potential sky-viewing locations.

The specific task we used for data collection, which was also co-created by the research team and instructional partners, was a multi-part problem-solving narrative called "Lost at Sea" that prompts students to use star data to find their location on Earth. In the narrative that was used to frame the problem, a space capsule has crashed down at night in an unknown ocean location and students are tasked with using their night sky knowledge to determine the approximate latitude and longitude of the crash. Broadly, the task was designed to contextualize and promote software-group interactions by establishing the need to use the simulation across both AR and tablet interfaces to search, share, and establish consensus around pieces of information that help attain task objectives. The core learning goals were set after reviewing and discussing the curriculum of the cooperating teachers' introductory astronomy courses, with the aim to take foundational skills (i.e., observing and identifying stars and constellations in the night sky) and extend those skills to tasks that pushed students beyond the content engaged in the course (i.e., estimating latitude and longitude based on star observations).

Working with our instructional partners made salient many of the practical issues of using immersive technology in real educational contexts, which led us to design in a way that was maximally flexible and focused on attainable learning goals. For one, it provided valuable information about student skills and preferences that we did not anticipate, such as students' willingness to use headsets for a lab activity and implicit comparisons that students would make between the CEASAR platform and other astronomy software packages. This information made it possible for us to design an accessible immersive simulation experience that enhanced what was possible with laptop astronomy software and which students were likely to choose to use during the task because it offered interactions and information that tablet and laptop technologies do not have. Second, the partnership strongly improved our ability to navigate the inherent tension between "futuristic" and "realistic" technology designs. Without frequent check-ins with our community college partners, we could have veered toward a design that overprivileged the AR perspective. This would not have met the needs of learners who could not, or did not want to, engage with the AR technology. Because of our partnership, we are much more confident that we have implemented a design solution that is transferable to other tasks and even other science domains and educational contexts.

The rapport that developed between the research team and the instructional partners meant that design discussions were productive and grounded in the reality of achieving instructional goals. For example, very early in the design process, one of the instructors described the challenge that many of his students have in "adopting an effective visual perspective" for making sense of large-scale phenomena such as the movement of the Earth relative to the sun. He thought a technology such as AR could deliver an embodied perspective that would allow students to make sense of this positioning relative to one's location on Earth as opposed to thinking of it as an abstract spatial positioning problem. We were able to create a concrete design based on the instructor's intuition that was well-received by students. At the same time, our instructor collaborators allowed the research team to push for interaction schemes, data presentations, or task goals that extended at times beyond established classroom expectations or learning goals, with the shared understanding that the value in exploring a particular task or design decision was worth the complication to the instructional process.

The challenges we have faced in our partnership are relatively minor compared to some of the pragmatic challenges we have encountered, such as a delayed rollout of our preferred hardware platform (the HoloLens 2) and limitations to our ability to test the intervention given the pandemic. We were able to overcome the initial limited access we had to the HoloLens and begin to engage in productive task and technology development through a combination of paper-based task prototypes as well as the development of a VR software prototype. These allowed us to bring both the task as well as similar immersive technology into the classroom and begin to gain critical knowledge about the classroom implementation and data collection processes. Once the AR headsets were finally in the hands of the research team, we already had gained a solid understanding of how students approached the Lost at Sea task as well as the logistics of deploying and managing immersive technologies in the classroom. This gave the entire CEASAR team the confidence to make innovative changes to the system to support AR, as well as integrate Lost at Sea as a full lab activity within the curriculum.

Still, there were occasionally times when the objective of surfacing clear research findings was not aligned with the immediate instructional goals of our partners. For example, we found over several iterations that students tended to be more successful with the CEASAR activity if they had time to orient and explore the novel technologies that comprised the CEASAR platform. However, these kinds of introductory activities took time, and it was not always easy to find available time in a packed semester of content and labs. We found having an understanding of our partners' course schedule requirements and aligning those with data collection plans early in the research process was helpful in avoiding these challenges. It also required mutual flexibility, such as researchers being willing to collect data in non-optimal configurations or instructors allowing for alternative activities or using alternative tools to try and reach the same learning goals.

Lessons Learned

First and foremost, our experiences on the CEASAR project have strengthened our belief that practitioner partners on technology innovation projects need to be positioned as co-creators and as designers as opposed to simply being users or contexts for testing. Even if the partners are not intimately involved in the technology development, the ultimate product of these kinds of design endeavors are learning experiences that go far beyond simple interface engagements; they are complex, system-level interactions that necessitate deep content-expertise, pedagogical knowledge, and an understanding of how small groups of students will perceive the task and work together.

Second, the design focus has to be broader than the technology. Thus, when we worked with instructional partners on the CEASAR project, rarely did we focus only on what the technology should look like or what it would do. Rather, we discussed what we wanted the students to see and what kinds of problems we wanted them to struggle with, and what we wanted them to discuss with each other. Near the end of the project, we began referring to our learning goals in terms of creating "shared representational spaces" where students could productively exchange knowledge and make meaningful references to important artifacts and variables across technologies.

Third, research teams should spend time reconciling perspectives. In many ways, our goals for the students who used CEASAR were similar to our own design process; in both cases, a team benefits by reconciling diverse perspectives to come to a shared understanding of a complex environment.

Next Steps

Based on our success in this project, we will continue to center partnerships in our research. Further, the ways we center partnerships, such as how we frame team meetings or how we empower our partners to be creative and assertive with ideas, will surely continue to evolve. Our partnership work on the CEASAR project has affirmed the transformative potential of strong and equitable collaborations, and it has raised the bar for us on what kinds of partnerships we aspire to have in our work.

Resources

- 2022 STEM for all video showcasing the CEASAR project: https://stemforall2022.videohall.com/presentations/2595
- The Embodied and Immersive Technologies (EmIT) Lab CEASAR page: https://emit.education.illinois.edu/projects/ceasar
- 2022 AERA poster on the design of the CEASAR interface: https://drive.google.com/file/d/1v4il1qMvrUoI__X6Re6hovxCStcO-IMI/view

UniVRsal Access: Broadening Participation in Informal STEM Learning for Autistic Learners and Others through Virtual Reality

By Teon Edwards

Key Ideas

- Successful collaboration requires scaffolding the process of working together, such as by making the choices, taking the time, and finding the tools that enable each team member to engage in a manner that works and is comfortable for them.

- For the UniVRsal Access project, the co-design process and especially our neurodivergent team members shaped the development and research of the STEM-based VR game Europa Prime in unexpected, exciting, powerful, and occasionally challenging ways.
- What brings stakeholders to a project are not the only things stakeholders bring to that project.

The project UniVRsal Access: Broadening Participation in Informal STEM Learning for Autistic Learners and Others Through Virtual Reality (NSF grant DRL-2005447) was developed (a) to design, develop, and research a VR STEM-learning game for use by a broad audience that includes learners with autism and other sensory, attention, and social (SAS) differences and (b) to provide VR developers and learning technology designers and researchers with additional knowledge about the affordances of VR for STEM learning and design choices that consider autistic learners and those with other SAS differences.

The partners on this project are the Educational Gaming Environments group (EdGE) at TERC, Landmark College, MXTreality, and Knology, as well as various informal science (ISE) organizations, including the Museum of Science, Boston. EdGE and Landmark College – a postsecondary institute exclusively for students who learn differently, including students with a learning disability (such as dyslexia), ADHD, autism, or executive function challenges – worked together on the game co-design process. EdGE and MXTreality, a development company that creates VR "tech for good," are developing the actual VR game. Knology, a collective of scientists, writers, and educators dedicated to studying and untangling complex social issues, is serving as the project's external evaluator. And the ISE partners are hosting the research and assisting with recruitment of neurodivergent participants.

The goal of UniVRsal Access is to broaden participation in informal STEM learning by using VR to create accessible, immersive science learning adventures that are designed with and for neurodivergent learners. "Broadening" means expanding to encompass more; "empowering" means transferring the authority or power to do something, as well as making (someone) stronger and more confident. For UniVRsal Access, broadening is part of the goal, involving neurodivergent learners in the process and designing for a broad audience that includes neurodivergent learners. And empowering takes this further, involving choices, attitudes, and scaffolds, many related to supporting a wide range of communication needs and preferences, but others related to shifts in control.

Story of the Partnership

The partnership between Landmark College and EdGE at TERC involved two intensive years of co-designing a STEM-based VR game called Europa Prime with the goal of engaging a broad audience, including neurodivergent players. The co-design team consisted of eleven members who identify as neurodivergent learners and three who identify as neurotypical learners. Ten were undergraduate interns from Landmark College, involved for a semester, a year, or two years. Four were education developers and researchers from EdGE. In our view, co-design is designing with, not just for, target communities and stakeholders. It's about focusing on stakeholders' needs and interests by having them be full, authentic members of the team who not only inform the process but who are also empowered to truly shape it.

> *Working in the co-design team was very different from what I expected... I did not expect to be treated as a complete equal in any internship, and yet throughout my time working with everyone on the team, I never once felt less than anyone else on the team – Landmark or TERC – I never felt like I or my ideas were ever disregarded, even bad ideas were always discussed and valued. That respect that everyone had for each other on the team meant and means a lot to me, and it created an atmosphere when working together that felt just like some group of friends deciding to do a fun project together, not as much like a job/internship.*
>
> *— Becky Scheff (Co-Design Team Member, Landmark Intern)*

Co-design serves its stakeholders both through the final products – in this case, the STEM-based VR game Europa Prime – and through the process itself. The acts of working on a team; learning about game design and education research; being involved with and conducting research; designing the game; and building other social and professional skills (such as clear communication across barriers) allows a reciprocal learning experience for everyone involved.

> *I want to get into game design for a career... From being excited about a video-game field internship period, I really enjoyed that my ideas were being taken seriously and seeing them also being expanded upon by other people in the co-design group. ...It's like I'm being treated like a professional adult ... It's very validating.*
>
> *— Katherine H. (Co-Design Team Member, Landmark Intern)*

Photo credit: Teon Edwards

Some of the Landmark co-design team members on the rare occasions, during COVID-19 restrictions, where they got to explore virtual reality.

Some of the Landmark co-design team members on the rare occasions, during COVID-19 restrictions, where they got to explore virtual reality.

Europa Prime has been shaped by the co-design process in ways not originally envisioned, which was both wonderful and scary.

> *I have had to take risks and give up some of my control. If the members of my co-design team, especially the neurodivergent members, were not empowered, then I wasn't living up to the project's goals. And if they were empowered (as I hope they have been), then my role was to put some of my own ideas aside so I could embrace where we were going, together, and help facilitate the path to getting there.*
>
> *— Teon E. (Co-Design Team Member, EdGE at TERC)*

The specific goals of the co-design team were to design pieces of a game that were fun, involved interesting STEM content and skills, and addressed SAS differences, as well as were engaging for the team members involved.

> *This co-design project is focusing on accommodating many gamers with LDs (or learning differences/disabilities) and the best way to have the game available and ready for everyone is to have input from gamers that have LDs and what they could do to make the game more accessible to everyone.*
>
> *— Gerald B. (Co-Design Team Member, Landmark Intern)*

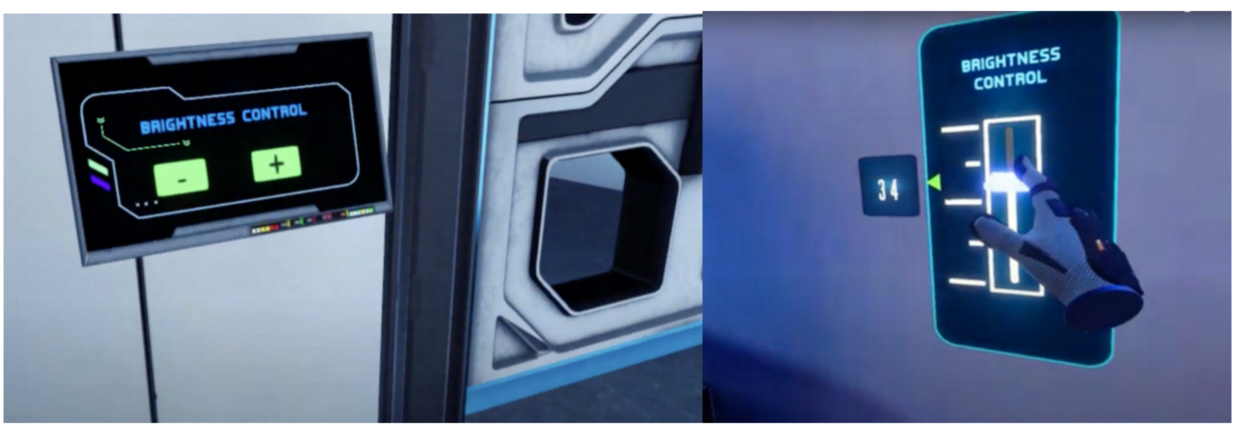


Photo credit: MXTreality

Early VR builds with functional in-game brightness controls, empowering the player to make the environment comfortable without needing to go to an options or settings menu

The UniVRsal Access co-design process involved weekly all-team meetings, weekly pair or small group meetings, a limited (because of COVID) number of in-person interactions, and a wide variety of between-meeting design and research tasks. These meetings and tasks were carefully crafted to make sure everyone had the tools, means, and opportunities to be "heard" – even when verbal and/or written communication was not preferred, as was the case for several team members. The extensive involvement of neurodivergent team members highlighted the need to not just involve stakeholders in the process, but also to learn what the team members' communication and executive function needs are, to design the work process to meet those needs, and to check in on a regular basis to ensure that the process is working well for each team member.

> *The part of the process that I enjoyed the most is bouncing ideas around and seeing where to go. I'm a very discourse-based learner on top of being a visual learner, so having the ability to take in most information that way was extremely helpful.*
>
> *— Daniel L. (Co-Design Team Member, Landmark Intern)*

Week-by-week and semester-by-semester, team members worked together on different elements of the design. We pursued both team-wide objectives and individual passions to create character designs, backstory elements, individual puzzles, user interface elements, iterative artwork feedback, and research instrument design. In parallel, EdGE designers worked to guide the process without oversteering it, to meld and interweave the different ideas together, to structure the research, and to keep the project goals in sight.

Very early in the co-design process, two neurodivergent team members offered a new interpretation of designing for sensory differences, shifting to the broader idea of exploring sensory tolerances and feelings of being overwhelmed. Eventually, this grew into a design feature that brought sensory differences into the game explicitly. The game design already included sensory-related design choices (such as color and scene complexity choices) and already offered integrated user controls (such as noise and brightness controls). With the input from neurodivergent team members, however, the game narrative now also has sensory differences as part of the story, presenting an in-game challenge for every player – neurodivergent and (so-called) neurotypical alike – to confront. This is just one of many examples of how co-design shaped the game in unexpected and potentially powerful ways.

> *We've explored themes in the game around communication and difference that we initially hadn't thought about including… because the neurodivergent co-designers are part of the core design team and not merely a group we get feedback from on an occasional basis.*
>
> *— Ibrahim Dahlstrom-Hakki. (Co-Design Team Member, EdGE at TERC)*

Photo Credit: MXTreality

VR design of a Minos, the main lifeform in the game, attempting to communicate with the player.

UniVRsal Access and the EdGE-Landmark partnership has not lacked challenges. Because it was funded during the summer of 2020, the entirety of the project has been conducted under COVID. This restricted the team to mostly remote-only interactions and very limited opportunities to get anyone – co-design team members and research participants – into VR headsets. We had to figure out how to collaborate, share, and conduct remote design meetings with members who didn't know one another and who had very different communication styles and abilities. We, like so many others, figured out the tools and approaches that worked for us, shifting and adjusting them to fit the needs and preferences of members over time. For our team, this included:

- extensive use of Miro, a digital "whiteboard" and collaboration platform, where ideas could be captured simultaneously with little writing (so no voices held too much sway, and no "voices" were drowned out, even if members were not comfortable speaking; also, so members with dyslexia and other writing challenges weren't at a disadvantage);
- use of chat (where agreement with an idea could be "voiced" with just a thumbs up icon, a member could be privately informed they'd be called upon next so they weren't taken by surprise, etc.);
- the deliberate use of names when referencing and building upon ideas (so there was a sense of legacy and ownership, as well as appropriate credit); and
- carefully constructed agendas that included time for tangents (as structure and clear expectations were needed, especially by some team members, but some team

members also had trouble not going off on tangents and needed this to be honored; moreover, wonderful ideas often arose when we were "off topic").

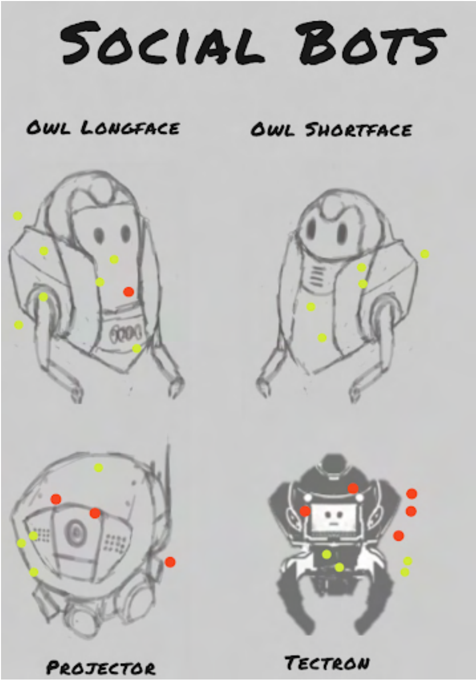
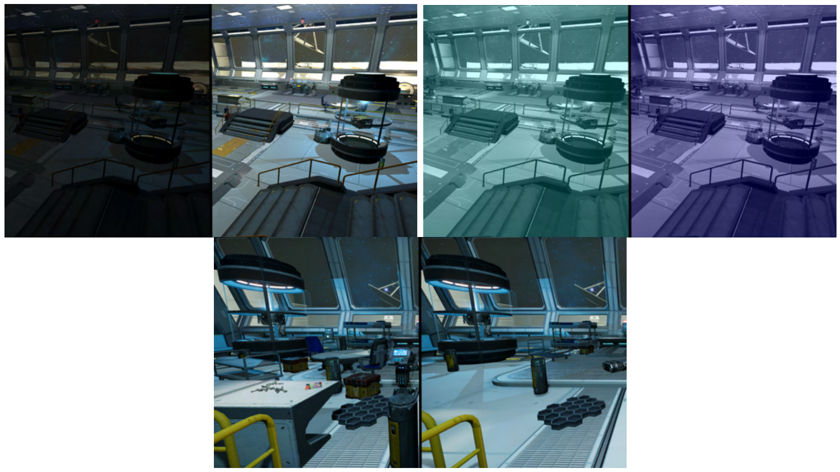


Photo credit: MXTreality and UA Co-Design Team
Example Miro Board, where the co-design team provided feedback for social bots.

With no willingness or ability to get people into headsets due to the pandemic, we shifted our early research questions online. We used pairwise images of different brightnesses, hues (colors), and amounts of clutter to answer questions about the preferences of (by self-report) neurodivergent and neurotypical participants, building to a later round of research conducted in VR, looking at brightness, clutter, and noise. While far from ideal, this still helped us address design research questions and make progress toward our longer-term goals.



Example pairwise images, used as part of a research study conducted during COVID restrictions, exploring neurodivergent and (so-called) neurotypical learners' preferences in terms of brightness, color, and amount of clutter.

By embracing co-design and truly empowering the team to shape things, we created challenges for ourselves. The original premise of the game had the player alone on an abandoned space station of Europa, an icy moon of Jupiter, faced with a mystery to solve. Aspects of this premise stayed the same, such as the player being alone on the space station; however, through co-design, the mystery, as originally envisioned, was allowed to shift. This resulted in additional work to make sure the new story ideas came together and the new story arc felt cohesive. Co-design team members were encouraged to work on ideas even when the connections to neurodiversity were unclear. This encouragement was vital to member agency and resulted in some wonderful ideas, but which also broadened and shifted what was being designed. Sometimes this meant less attention on a sensory or attention-related element than originally envisioned; other times it meant a rich idea that added to the game but might be less connectable to the research. These are challenges of positive opportunity, but they are still challenges.

Lessons Learned

The Landmark-EdGE co-design partnership has deepened the team's expectations and hopes for what collaboration can be and what collaboration may entail.

One lesson involves having stakeholders help shape a project from its inception. When the co-design process began, the UniVRsal Access project and its Europa Prime game were not blank slates. As part of a pilot project, a basic premise for the game had been established and a prototype developed and tested. Then, during proposal writing, areas where it seemed vital to have solid, extensive design input from neurodivergent learners, such as user interfaces, puzzles, and supports for sensory, attention, and social differences, had been identified. Landmark was part of crafting the proposal, but no interns were involved. In the future, whenever we can figure out how to fund it, we want collaboration and co-design, not just an agreement on a partnership and crafting of a proposal, to start as early as possible.

> *As I think about partnerships, collaborations, and co-design, I try to remember these, as in other things, need to be something that comes from and is shaped by the collaborators together. What they mean to me is important, but that's only part of the picture.*
>
> *— Teon E. (Co-Design Team Member, EdGE at TERC)*

The second lesson relates to understanding that it takes a great deal of time and planning to create respectful and effective co-design procedures, but they are well worth the effort. The most impactful elements of this project, in terms of how we will center partnerships in our future research and design efforts, are related to expectations about the amount of work required to support a successful collaboration, and how we should treat team members.

> *Every week, a major part of my work was focused not solely on the design of the game or the related research (though I did this, too); instead, much of my time was focused on planning and scaffolding the co-design process itself. It was absolutely necessary for me to do this in order for the process to work, and the valuable design input I got back from the team made all of this more than worthwhile.*
>
> *— Teon E. (Co-Design Team Member, EdGE at TERC)*

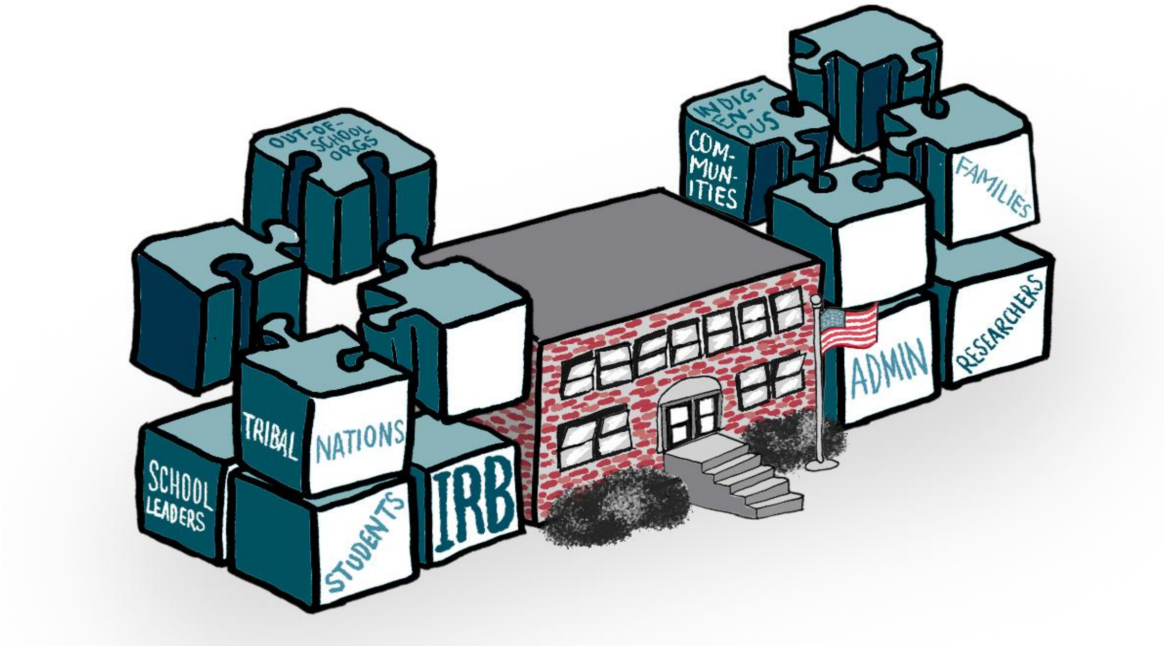
The final lesson relates to not constraining the roles of stakeholders, but instead honoring all that team members bring to the co-design process. It should go without saying, but too often it does not, that people are not unidimensional. In the case of UniVRsal Access, the stakeholders were chosen because they were neurodivergent learners. Landmark College is a partner on the project because it exclusively serves students who learn differently. And the interns were on the co-design team because they are neurodivergent and could bring that vital perspective and expertise to the project. However, the roles of the neurodivergent members of the co-design team were not and could not be constrained to what they brought as neurodivergent learners. They were bringing many aspects of themselves, and the project and everyone involved needed to embrace and honor that, at exactly the same time we were valuing neurodiversity.

Resources

- Educational Gaming Environments (EdGE) Website — https://www.terc.edu/edge/ This is the website for EdGE, which designs and studies STEM-learning games and technology tools for differentiated and adaptive learning, with information about our team, projects, games, publications, opportunities to be involved, and more.
- TERC Website — https://www.terc.edu This is the main website for TERC, a nonprofit made up of teams of math and science education design and research experts, with information about the organization, our projects, products, and publications, our blog

(see "More Than Who’s at the Table: Co-Designing a STEM-Based Virtual Reality Game with Neurodivergent Learners"), and more.

- STEM For All Video 2022 — https://multiplex.videohall.com/presentations/2335?search=a1e8805e8fab2518fc835cddf2f245c820e8a03f Check out our video "Co-Design of a VR Game with the Neurodiverse: Year 2" to hear co-design team members reflect on what the co-design process has meant to them and how it has shaped the project.
- STEM For All Video 2021 — https://multiplex.videohall.com/presentations/2155?search=a1e8805e8fab2518fc835cddf2f245c820e8a03f Check out our video "Co-Designing a VR STEM Mystery Game with Neurodiverse Learners" to see and hear about an earlier stage of the game design and the importance of the co-design process.
- Paper: Inclusive VR through Inclusive Co-Design with Neurodiverse Learners — This IEEE paper reports on the first semester of the game co-design process, sharing feedback from the first co-design participants.



How Are Partnerships Structured to Be Transformative?

The CIRCLS'21 report states that to design useful emerging teaching and learning technologies, researchers need to empower their partners. "Partner" was defined broadly as learners, teachers, parents, policymakers, school leaders, community center leaders, museum staff, and others who use, implement, or make decisions about the technologies being developed. Researchers must engage partners early and often in the research process, listen to partners and yield more power to their voice, learn about what partners have already accomplished, engage in co-design to utilize partner assets, and give back to partners by building capacity in areas that are important to them.

This section highlights different approaches to ethically and successfully engaging partners in three research projects.

Building Ethical Infrastructure for Community Partnership Work: The 'How to Engage Your IRB' Edition focuses on an important, yet often overlooked, partner: the Institutional Review Board (IRB). In this project, the research team sought a successful long-term partnership with K-12 schools and educators, Tribal Nations, and Indigenous communities. Many researchers view the IRB as a box they need to check off versus a valuable partner and resource for ethically building community partnerships. This piece includes the perspectives of researcher Breanne Litts and IRB representative Nicole Vouvalis, as well as commentary by researcher Melissa Tehee. The three authors share how meaningfully engaging the IRB as a partner early on – as well as having open and honest conversations about research goals – can lead to more ethical and impactful community partnerships that truly honor the voices of participants.

Emerging Technology Adoption Policy for Educators discusses how researchers and educators, school leaders, and emerging technology experts worked in collaboration to develop a novel evaluation framework to inform the adoption of new technology by districts and schools. This piece speaks about the importance of listening to the voices of teachers, administrators, and experts when designing an evaluation framework that can be adopted in U.S. classrooms in an organic and culturally responsive way. Pati Ruiz and Eleanor Richard highlight three critical elements that they relied on to create an intentional and meaningful partnership between researchers, teachers and administrators to develop a novel evaluation framework.

Conjecture Mapping discusses how conjecture maps can be a helpful tool for structuring discussions and goal setting across partners from different disciplinary backgrounds. An AI Institute used this tool to help computer scientists and learning scientists draw connections between technical elements of a project design and the learning goals. They also found the tool to be useful for mapping ideas imagined by youth participants as they designed norms for what they defined as a just community. The maps gave a structure to their dreams, highlighting what needed to change for the dreams to be realized.

Building Ethical Infrastructure for Community Partnership Work: The 'How to Engage Your IRB' Edition

By Breanne Litts, Nicole Vouvalis, and Melissa Tehee

Key Ideas

- Our community needs to rethink the relationship between researchers and IRBs.
- Partnering with communities means doing more than inviting them to provide data to researchers for their projects.
- Research should make sense to and benefit the communities in which it takes place.
- Research must not be harmful to communities, and the community should decide what is and is not harmful.
- The definition of "research" in an IRB process should be broadened.
- A key goal of bringing your IRB to the table is to increase mutual accountability among partners.
- Researchers and IRBs can unite under the shared values of relationality, reciprocity, and respect.

As principal investigators and researchers on several projects that aim to explore collaborative approaches to research, we maintain a range of partnerships, such as K-12 schools and educators, Tribal Nations and Indigenous communities, and out-of-school organizations and educators.

Many of our projects seek to design and develop school curricula or community programming and culturally sustaining technologies and resources. One example (i.e., https://www.daigwade.org/shoshoneplants) is a collaborative effort toward designing a new family program. The family program seeks to reconnect the land with people through sharing and preserving knowledge with original and digital technologies.

While each project and partnership is unique and special, one overarching relationship that heavily shapes what is possible with our community partners is between our research team and our Institutional Review Board (IRB). The IRB is a mechanism required for all federally funded research that collects data from or about people. While this relationship may remain largely invisible to non-university collaborators on a team, it is irresponsible to ignore the ways in which IRBs shape partnerships among researchers and community partners.

The story we share is the journey that Breanne Litts and Nicole Vouvalis took toward building infrastructure at Utah State University (USU) that honors tribal sovereignty. Breanne Litts is a learning scientist with expertise in designing storytelling technologies for learning with Indigenous communities. Nicole Vouvalis is a research administration professional with expertise in law, human research protections, DEI, and higher education administration. Melissa Tehee, an internationally recognized research ethics scholar with decades of experience serving Tribal Nations, served as an advisor to Breanne and Nicole throughout the process. Melissa provides commentary to bring to light the nuances of partnering with Indigenous communities on research projects.

What Counts as Research?

Breanne: I first approached the IRB prior to receiving any funding or even proposing any grants. I had been working with a Tribal Nation for a year or so and we had begun working together toward building family programming for their community. In my field, the process of partnership and design is of high scholarly value. The Tribe I was working with had a vision to share our work not only with other nations but also with other researchers. I had asked around to learn how others had navigated their institutions' IRB at this stage and was shocked to learn that many institutions did not consider this work research, and thus, their partnership had no oversight. So, I reached out to Nicole Vouvalis, who is director of our IRB at USU.

Nicole: People who work with and for IRBs, myself included, are trained in a very particular way of thinking about what "research" with a "human subject" is. I think that if you brought any of Breanne's projects to an IRB at a university with a medical school, you'd get the response Breanne noted: this isn't research and it doesn't fall under our purview. If I'm being honest, I think some of that is because this work is intricate, complex, and iterative. If there's a way to wash your hands of it and justify that to anyone who might come knocking, you might take that "out." (And resource constraints, systems constraints, and lots of other good reasons that could be at play!)

For my part, I try to deeply consider all of the principles in the Belmont Report in terms of my office's operations. The most important to me and to my office is "Justice," though "Respect for Persons" and "Beneficence" both also feature prominently in our work. For me, to enact the principle of "Justice" means not telling a Tribal Nation and their collaborators what research does and does not look like. If Breanne and her research partners come to us saying they've worked out a research partnership, we're going to treat it that way.

Melissa's commentary: When engaging with community partners, defining "research" is imperative. Generally, partnership projects may be shaped by various stakeholders involved in the work, however, rarely the team, as a whole, steps back to define what research is in the first place. Additionally, when working with Tribal Nations, we must recognize and honor Tribal Sovereignty and uphold Tribal views of what constitutes research, which may begin with developing the relationship long before what the federal definition would deem as research. For example, in building relationships, Tribal entities are often opening up their space and ideas but the potential researcher is not as vulnerable in the beginning and thus holds the power to decide when to engage an IRB. There can be harms that occur during relationship-building and idea-generation phases when there is no oversight or accountability for the researcher.

Honoring All Voices

Breanne: As I continued discussing possibilities with Nicole, I was also in conversation with the Tribal Elders working on our project who wanted to be active members of our research process and wanted to leave the door open for other tribal members to become researchers as well. I began to realize that current infrastructure gives researchers the power to make the determinations of who counts as a researcher, yet this concentration of power is antithetical to the collaborative research process we were working to define. When I first approached the IRB, the question was, "Is this research?" But after a lot of back and forth, I realized the question needed to be: "How do we protect community partners and honor their sovereignty and self-determination in the research process?" At the end of the day, I really did not care if it's research according to some obscure definition, and rather, I wanted to be held accountable to my values of maintaining reciprocal and respectful relationships with the community partners working with me. Thankfully, Nicole was very open to this reframed question.

Nicole: In the moment, one of the reasons I took to that reframing of the question was partially, "If not us, then who?" This partnership did not have another IRB or research ethics oversight committee to go to, but the direction of their work made it clear that this could be necessary to meet their goals. Why shouldn't we be that? Utah State University is Utah's land grant institution; part of the mission of everything everyone does here should be about how we support and better our communities. In talking more with Breanne and learning more about the project, my perspective became broader. We're a justice-centered IRB. That's the vision for this work and this office that I articulated when I was hired, and I made clear that if that wasn't the direction USU wanted to go, they should find someone else. Like Breanne, I want my work to be accountable to my values, the vision I prioritize for this work, and the mission of our institution. The opportunity to not just oversee, but partner with Breanne and this Tribal Nation is in line with those values, my vision, and the institution's mission.

Melissa's commentary: Researchers have inflicted horrible atrocities on Indigenous people in the name of "science" and these are why Tribes have sought to have oversight of research being conducted with their citizens. When considering community and partner-based research, there are very few written procedures and guidelines from IRBs that require input from the communities or partners. Those from outside the academy are often not reviewing the protocols submitted to the IRB, nor is there follow-up with them unless someone has reported an issue. Having worked with many university IRBs, not all know about when they need to consult Tribes to see if the Tribes view the activities as research or if they would also like a say in the activities or oversight of the research, in which they may have procedures or a Tribal IRB. Indian Health Services and many Urban Indian Centers also have research policies and mechanisms for engaging with research activities. I have had to engage in uncompensated work to educate both PIs and IRB staff on this topic.

Breanne: The paradigm shift from "Do we need IRB?" to "How can the IRB help us enact ethical and cultural values in our work?" opened up a flurry of possibilities, but also united us (my team and the IRB) under the shared values of relationality, reciprocity, and respect. These values not only grounded our partnership with the Tribal Nation but also opened the door to a new kind of partnership with the IRB. Building upon these shared values, we could now define how the IRB can be a fundamental partner in shaping structures to support ethical and culturally respectful engagement with not only Indigenous communities but all community partners.

Nicole: While IRBs operate in different ways and according to different ethical principles, most IRBs in the United States choose to enact the principles of the Belmont Report. The three primary principles articulated in that report, which is a culmination of the yearslong study of abuses in federally sponsored research, are Respect for Persons, Justice, and Beneficence. In talking more with Breanne about the ways we could support this partnership, I learned that those map pretty well with the values Breanne articulated above reciprocity, respect, and relationality. Because we chose to abandon the question of whether IRB oversight was required, and shifted our perspective to a justice-based approach, we began to think about what an infrastructure (largely free from the constraints of other regulations and rules, since an argument could be made that IRB oversight wasn't strictly necessary) that centered those values could look like. That was a really exciting time.

Melissa's commentary: From an Indigenous perspective, we are taught to engage with the world (which includes partnerships) with Relationality, Reciprocity, and Respect. We are all interrelated to one another as we share land, an environment, a community, spaces for learning and working, and are all in relation to one another. Our relationality goes beyond humans and "living" beings and includes all beings, which is often overlooked by the larger society. Values are often more expansive than principles, but the foundational value of Relationality most closely represents the ethical principle of Respect for Persons and Peoples. We come from a worldview that is community-focused and not focused solely on the individual. We consider how decisions and actions will affect the community, thus never focusing on benefits to just ourselves. There are no decisions that only affect the individual making the decision, thus we value and recognize the ways in which we are all connected. Our value of Respect closely aligns with the principle of Justice. When we enact respect, we are showing that we value different ways of knowing and being, and this includes valuing community knowledge and approaches. Our value of Reciprocity ties in with Beneficence, though it does go beyond "doing good." A few of the ways we enact reciprocity are making sure everyone has the opportunity to contribute; balancing the give and take; and sharing both contributions and benefits.

Building Ethical Infrastructure Together

Breanne: With the foundation of shared understanding and values, we got to work on the following:

1. In collaboration with the IRB, we developed an MOU between USU and the Tribal Nation. The MOU was critical to honoring the Tribe's sovereignty and tribal members' self-determination. It established a system of accountability for me, as the PI, to engage in ethical research and to dismantle systems that have been historically used to harm communities. It also included a structure for tribal members to self-determine their own level of participation in the work (from none to participant to full investigator, or both participant and investigator).
2. We designed a video-based research ethics training (integrityinresearch.org) for community partners who want to engage as co-investigators. We designed the free video-based training in response to the Tribal Elders' thought that it was important that tribal members had a basic understanding of research and ethical stewardship of data if they were going to participate at the level.

Essentially, rather than adopting the existing binary research frame (e.g., yes this is research/no this is not, or you are a participant/you are an investigator), we crafted infrastructure together that allowed for plurality of meaning and participation, which mirrored the actual human experience of participating in research, especially education research. At the end of the day, humans are messy and imperfect. Therefore, we need a flexible and fluid infrastructure to support ethical partnerships.

Nicole: We decided not to assign partners to particular boxes; instead, we discussed that we also needed to set the partners up for success, no matter the roles they chose or moved into as the project went on. This brings us to Breanne's second point, the video-based training. While there are other fee-based trainings available (CITI, rETHICS), part of the purpose in engaging in this new, specialized structure was to make sure that we, the IRB, were sharing our resources with our partners. Another purpose, though, was to make sure that those resources were centered in our values. We didn't see CITI and rETHICS meeting those needs. So the team developed a new training, so that we could be certain that the whole structure we were creating spoke to those values and set everyone up for success. Once that was complete, I incorporated the values and actions into a draft MOU (Breanne's first point); we revised it many times over before distributing it for execution, to make sure that (like the training), we were developing an infrastructure for everyone to be successful in contributing to this partnership.

Melissa's commentary: When considering ways to be more inclusive to community and Tribal partners in research, you must consider the value and cost with adding more requirements for the participants. The typical research ethics training is formatted in an academic way, which might not be the best way for those outside of academia (or inside) to learn. For those outside of University systems, there is often an additional monetary cost, along with a time commitment, that is usually uncompensated. We didn't agree with this cost structure, so we designed a free training. The needs and purpose of the research ethics trainings are different for different types of research and different investigators. The training developed by Breanne and her team uses best practices from the learning sciences to present the information in accessible and relevant ways to both community and Tribal research. With Nicole contributing to identify needed knowledge and competencies to meet IRB requirements and the IRB then adopting this training as another option, they are sending the message of valuing Tribal and community contributions.

Moving Toward Adaptive and Responsive Partnership

Breanne: I often conduct research that requires IRB oversight and find that conversations with IRBs can be challenging. For example, if you go into an IRB office and ask for help collecting video data of children, all sorts of red flags go up for them. You've stepped on an ethical landmine and you might not even know it. I've watched this happen to some of my students and colleagues in their IRB consultations. What has been refreshing, though, is how engaging the IRB according to our values of relationality, reciprocity, and respect has shifted our partnership toward an interdependent and mutually beneficial goal of doing ethical research. I don't think this is the easy path to research but the deeper our partnership gets the more I realize this is the ethical path and the result is better for everyone involved, especially community partners. We are inviting people to do the work necessary to protect the partnership through establishing accountability toward ethical research processes. This is even more critical in technology development projects when working with communities that have not only been harmed by research but also technology.

Nicole: For me, our relationship provides a model for our IRB's work with researchers who approach us about their research partnerships from the get-go. I deeply appreciate what Breanne said above about setting up a structure for engaging communities without involving them in those conversations. I remain surprised at the number of research projects we see where all these plans are laid out for the research approach, without any evidence that the community has been contacted or has a say. And, since we work with these projects from the start to the end, we also see where those kinds of projects falter. Having engaged in this process with Breanne (and a handful of other researchers at USU, though not to this extent!) allows us to demonstrate what can, indeed, be done with some advance planning and a meaningful, dedicated approach to centering research participants.

Resources

- Integrity for Partnership Advancement: Ethical principles for indigenous community collaborations. This training is a pathway for community partners to serve as investigators on research protocols at Utah State University. https://integrityinresearch.org
- Centering Culture is a journey toward developing cultural competence across context through building awareness, knowledge, and skills of our own and other cultures. http://centeringculture.org
- The Braiding Knowledge project is a collaboration between Dr. Melissa Tehee, Dr. Breanne Litts, and Dr. Rogelio Cardona-Rivera that seeks to create new forms of technology that support Indigenous perspectives. http://braidingknowledge.org

Emerging Technology Adoption for Educators

By Pati Ruiz and Eleanor Richard

Key Ideas:

- Bringing together school leaders, teachers, and emerging technology experts to create a framework for adopting emerging technologies in schools led to new solutions not imagined by the different groups on their own.
- Working intentionally to gain common understanding of goals while allowing differences in perspectives helped the group move forward.
- Structuring the group into various configurations, sometimes small group meetings, sometimes individual, enabled everyone to participate.

Research has shown that the evaluation of emerging technologies, including those that involve artificial intelligence/machine learning (AI/ML) systems, often requires a significant amount of expert knowledge and historical context (Mohamed et al., 2020). Yet school leaders often must evaluate and make procurement decisions about AI/ML-enabled tools and systems without adequate training and guidance. We aimed to design an evaluation tool that would be useful for emerging technologies, both for researchers and educators.

To date, a number of AI/ML evaluation tools have been created (Holmes et al., 2021; The EdTech Equity Project, n.d.; The MITRE Corporation, 2019; Connor and Nelson 2021); however, few of them are specifically designed for U.S. school districts, and none of them have been widely adopted in the U.S. To address this issue, CIRCLS established the Emerging Technology Advisory Group for PK-12 to develop a framework for schools to evaluate and make procurement decisions about emerging technologies, including AI/ML systems. The advisory group worked together to identify needs and create tools for educators in U.S. PK-12 education settings. The overarching research question addressed by the group was:

What knowledge do school leaders, educators, parents, and emerging technology experts believe is needed when making decisions about the adoption of emerging technologies, including AI/ML, in U.S. PK-12 education settings?

Story of the Partnership

We begin with an overview of the partnership's work from beginning to end. Throughout this work, we created a partnership among researchers, teachers, and administrators who are passionate about reviewing and assessing the emerging technology that enters schools and classrooms. We recruited school leaders, teachers, and emerging technology experts through the CIRCLS newsletter, which currently has more than 3500 subscribers. For all interested participants, we asked about their connection to PK-12 education and why they were interested in and felt they would be able to support this work. From these answers, 11 participants from diverse U.S. school districts were selected, including representatives from large public school districts, small public school districts, independent schools, and higher education. All participants had strong connections to PK-12 technology. They also all had knowledge and experiences that would contribute significantly to the creation of a framework that considered diverse perspectives and was designed for U.S. education settings.

In between advisory group meetings, participants were asked to read scholarly and media articles about emerging technology and AI/ML-enabled tools in PK-12 education. Based on discussions of the readings, consideration of artifacts prepared by participants, and additional collective work, the advisory group drafted a framework. Once a draft of the framework was complete, we shifted from group work to one-on-one conversations to finalize it. Members of our advisory group reviewed the framework and suggested modifications to the framework through comments or in interviews with researchers. Researchers met individually with group members to resolve the comments and suggestions. The final product from this work at the time of this writing is a preliminary draft version of the emerging technology adoption framework, and we welcome comments and recommendations for modifications of this draft framework.

Now, we will proceed to describe stages of the partnership in more detail, describing (1) launching the partnership, (2) valuing what the communities are already doing and building off of those practices and knowledge, (3) listening to all members of the group with a goal of transformation, and (4) valuing capacity building as well as the limits experienced by our participants. In the next sections, we will describe how we did this.

1. Launching the Advisory Group

Our partnership was very intentional about creating an explicit agreement defining how the group would work together. It took several meetings to agree upon our project's overarching goals communally. Our effort to reach a partnership consensus allowed all of our members to share a common belief in the value of our work. Additionally, our partners were asked to contribute their expertise and experiences within their unique contexts to make sure that we developed a broadly applicable product. We additionally allowed for the variation of our community members and their experiences to challenge or push forward the groups' ideas. For example, when partners within this work had differing beliefs about the collection, use, and dissemination of different types of student data, we discussed each of these perspectives and worked to include them all within our framework, allowing districts to evaluate emerging technologies and make their own decisions. The partners on this project brought their perspectives and approached the process of creating solutions in different ways, and that variety significantly enhanced our work.

2. Valuing What Communities Are Already Doing

Within this project, we worked to center the expertise of our advisory group members from the onset. To do this, we explicitly asked participants to share experiences from their local context of procuring and integrating emerging technologies, including challenges that they faced within the technology procurement process. By making connections to what our advisory group members were navigating within their contexts, we were able to see commonalities, such as a desire to balance ease of use with data privacy and student needs. We also noted a repeated concern over whether or not funding for new technology initiatives would allow for continued use of new technology for many years. Further, there were recurring concerns about policies that don’t explicitly block technologies without appropriate data safe-guarding practices.

Examining what these school communities were already practicing in regard to procuring and integrating emergency technology also allowed us to see commonalities and differences. Some of the differences we noted were the duration and level of detail required within the vetting process of new technology, the level of accepted involvement of administrators and school boards, and what types of data are determined to be acceptable for technology to collect (visual data, location data, biometric data). We were able to identify a large number of commonalities and differences within the practices that communities are already doing because we recruited administrators and educators on the ground who have diverse experiences with technology procurement within varying types of schools.

3. Listening to All Members of the Group

In an effort to listen to all members of the advisory group, two cohorts were formed, with each meeting twice a month for five months. The cohorts were co-led by the authors. The first meeting was held in June 2022 and consisted of introductions, the co-creation of group goals, and norm development. The overarching goal was to understand how schools and districts evaluate and make procurement decisions in relation to educational AI systems and create tools to assist in these processes, while paying attention to ethical questions about how student and family data is gathered, used, and stored as well as how AI/ML-powered educational tools and systems are based on data gathered from previous learners and not always designed to work for diverse users (Lecher & Varner, 2021; Wang, 2021).

The smaller cohorts allowed participants to have a chance to share their voices and knowledge through specific examples. One participant, for example, was able to share how their school had been provided with facial recognition surveillance cameras and how they had ethical dilemmas with implementing that type of emerging technology in their settings. All participants in the cohort were able to share their perspectives on the ethics of this surveillance technology and how their districts might be equipped or not to handle a similar adoption. After these sessions, one participant reflected: "I am excited about working and learning with people from different backgrounds." Another commented, "This was fantastic! Look forward to future conversations."

Our time with the advisory group led to the creation of a preliminary version of the emerging technology adoption framework. The League of Innovative Schools is an organization of 125 districts serving more than 3.8 million students. As part of their 2022 Fall Convening, we invited League members to comment on this preliminary framework during a 45-minute session as well as through individual feedback forms. As a result of this feedback, the Emerging Technology Adoption Framework: For PK-12 Education was modified. Feedback and comments are currently being accepted by the community regarding the framework as well as its implementation. The team's next step is to test the framework with a district and integrate the various forms of feedback in ways that transform the framework into a more useful tool that is adaptable in a variety of communities and settings.

4. Valuing Capacity Building and Limits Experienced by Our Participants

While the cohort model allowed us to provide a variety of meeting times for our advisors, we also provided individual meeting options for advisory board members when they were not able to join the larger group. We followed up with advisors via email after every meeting to request additional written feedback, and we also kept a copy of all of that information on an unlisted webpage on the CIRCLS website. At the request of our advisors, we made adjustments to our meeting plans, including adding more individualized check-ins about the framework towards the end; advisors found it easier to meet with the authors and talk through different framework sections while we listened rather than giving feedback with the whole group present. Advisors also requested that we invite outside experts and researchers to give perspectives that might be missing from the group, so we invited a researcher to one of our meetings and also shared drafts of the framework with a range of outside experts, including policy experts, researchers, technology integration specialists, and educators in different contexts.

In the process of creating our advisory group partnership, we encountered some challenges. With so many group members with different contextual needs and within different time zones, finding time to meet among competing priorities was difficult. To overcome this challenge, we asked for detailed weekly availability from each member, then made two smaller working groups and allowed members to switch to the other group if needed due to scheduling. We also adjusted participation to include asynchronous feedback sessions.

The nature of our virtual meeting format might allow participants to multitask rather than focus on the task. To overcome this challenge, we worked to make meetings concise and applicable to the contexts of all members and had individual meetings with advisory board members who seemed distracted or were off task to see how we might better support their participation. To determine that all partnership members were invested and felt this work applied to their contexts and beliefs, we communally agreed upon the goals of the project. Reaching consensus among the participants took time and several meetings; however, once consensus was reached, all members shared a unified belief in what we were attempting to accomplish and supported our work.

Another challenge we faced throughout this project was addressing the needs of all types of contexts (large/small districts, rural/urban/suburban needs, family/community engagement, and independent/public schools). This challenge highlighted that different contexts sometimes have competing needs and desires for technology tools, and school technology ecosystems may be compromised by incompatible tools. While we were able to consider many of these issues in our work to create a framework, we acknowledged within our partnership that some elements of the framework may apply to some contexts more than others.

A final challenge was that we found that districts had varying levels of acceptance of the collection, use, and dissemination of different types of student data; that is, an emerging technology that was considered acceptable in one district may not be acceptable in another. We are still working to address this challenge within our larger partnership.

Lessons Learned and Next Steps

We convened a diverse group of individuals over a five-month period to develop our emerging technology framework. Above we provided extensive details about how we structured the meetings, as a way of providing an example for the field of what it looks like to organize meetings with practitioner partners. As we reflected on our process, we identified the following key ideas for our successful partnership among researchers, teachers, and administrators:

- collectively agreeing on goals as a starting point for creating working partnerships;
- asking partners to share specific examples of what they have experienced in their local contexts;
- identifying commonalities and differences;
- building off of what is already being done while also allowing for variation across contexts; and
- using flexible grouping strategies to accommodate various preferences for remote work.

By employing these strategies, we were able to produce a draft framework that can be applied in a multitude of settings and include many context considerations. Through our work with the advisory group, we saw the significant value of districts bringing ideas and proposed changes to their local contexts, and saw value in reflecting as a group on how the implementation is going and what changes might be beneficial. Our future research and design will incorporate both of these practices.

Resources

- Distributed AI Research Institute: https://www.dair-institute.org/. The Distributed AI Research Institute is a space for independent, community-rooted AI research, free from Big Tech's pervasive influence. They have a newsletter and share research on their website.
- Educator CIRCLS blog: https://circls.org/educator-circls. Educator CIRCLS aims to bridge research with classroom practice and broaden the community of people involved in CIRCLS. If you are interested in joining, please fill out this form.
- EdSAFE Insights Newsletter: https://www.edsafeai.org/insights. Newsletter that unpacks complicated and complex issues to make them understandable and tangible with simple calls to action and implementation suggestions.

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Conjecture Mapping

By Michael Alan Chang

Key Ideas

- Conjecture maps can help research partners from different disciplines find a shared language for identifying common goals and expectations.
- Conjecture maps can help youth and researchers collaboratively illustrate hopes and dreams in an actionable format.

Recent work in the learning sciences (Gutierrez & Jurow, 2018; Garcia & Mirra, 2023) and technology (Dunne & Raby, 2013; Dombrowski et al., 2016; Wong & Khovanskaya, 2018) recognizes the transformative and political nature of our collective work, which involves making a powerful call to the community to surface joyful, expansive, equitable futures imagined by non-dominant communities. Yet we do not dream for the sake of dreaming; we dream to understand how this work meaningfully shapes our research and design work in the present. In considering the role of emergent technology in this mission, it's difficult to imagine computer science alone in bringing about the necessary institutional change that movement towards expansive equitable futures often requires. If the community of computer scientists and learning scientists work together toward constructing these expansive futures, deep collaboration between the computing and learning sciences is absolutely critical. Our work as a partnership shows that conjecture maps (Sandoval, 2013l) can serve as a meaningful first step toward engaging computer scientists and learning scientists in the making of imagined futures (Chang et al., 2022c).

Conjecture Maps to Support Partnerships

Conjecture maps are a tool from the learning sciences that support the design-based research approach. Using conjecture maps, researchers establish theory-supported connections between tangible learning designs and desired learning outcomes. Recent work extends conjecture maps so that computer scientists can meaningfully participate in creation of the tangible learning designs, starting from the insight that many technical decisions made by learning scientists do not fit within the bounds of the learning sciences (Chang et al., 2022b). A key affordance of conjecture maps is that they allow computer scientists and learning scientists to draw connections between technical components and more traditional learning interventions. By explicitly highlighting the necessary learning interventions, designers additionally make transparent the essential institutional change that must occur for the technology design to make the expected impact.

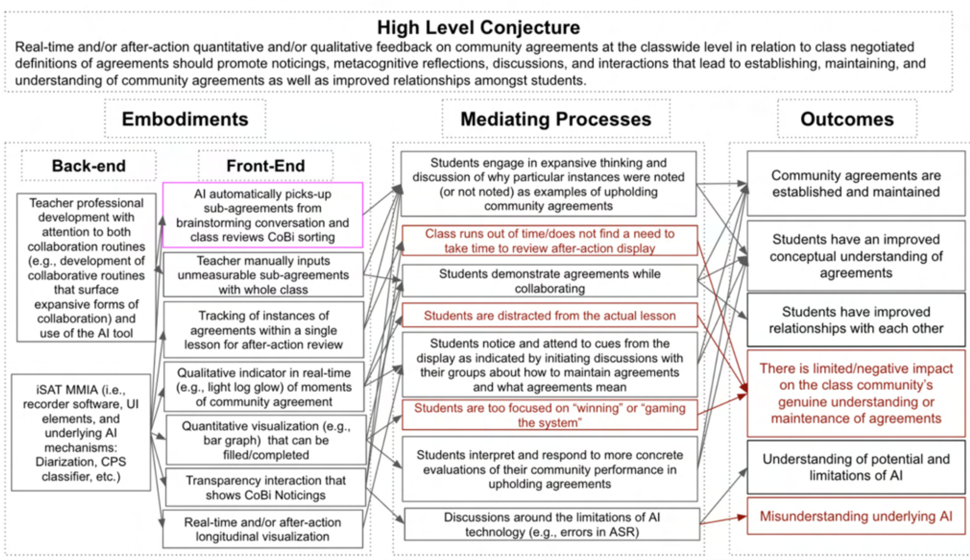

Figure 1: Extended conjecture map of the iSAT Community Builder.

Conjecture maps have played a central role in work in the interdisciplinary NSF National Institute for Student-AI Teaming (iSAT) (Chang et al., 2022a). Our Learning Futures Workshop (Chang et al., 2022) surfaced the hopes and dreams of youth of color about ideal collaboration with peers and educators in and out of school, and the role of artificial intelligence in making those dreams a reality. In our workshop space, youth rejected an AI approach that policed their behavior, and instead proposed a Community Builder. The Community Builder would support youth in collectively creating community collaborative norms and holds them accountable to these norms. Rather than simply building out the technology, researchers in iSAT used a conjecture map to interrogate how to create the necessary classroom conditions to realize the youth's complete vision. We show the completed conjecture map in Figure 1. Conversations held by computer scientists and learning scientists over the conjecture map supported a major realization; because youth-driven community agreements deviated from well-established practices in the schools we are partnering with, learning scientists would have to develop specific community building routines (Reiser et al., 2021) and train teachers in professional development settings in order for the Community Builder to be used in the way that youth dreamed about.

We are still early in our journey, but we have seen how conjecture maps are one powerful tool that supports an interdisciplinary team of researchers in identifying necessary institutional changes and technical developments to help make those dreams a reality. To learn more about how to work across interdisciplinary teams to build conjecture maps, please reference our conjecture mapping primer, which can be found here.

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How Can We Build Capacity for Partnership?

Our community recognizes that partnerships are essential to good research and practice. However, many researchers are under-prepared to do this work. Learning how to be a good partner is not something that most scholars are formally trained to do at large research institutions. Indeed, most programs that train researchers value individual scholarship rather than working with either researchers from other disciplines or participant communities. Conversely, institutions such as Historically Black Colleges and Universities (HBCUs) have strong ties to community organizations that serve local needs, yet often do not receive the research funding to investigate emerging technologies for learning with their community partners.

Below we present two projects that demonstrate how to build capacity for partnership research among early career scholars and HBCUs.

We highlight the first project Seeing the World through a Mathematical Lens: A Place-Based Game for Creating Math Walks (MathFinder) from the perspectives of both the PIs and the emerging scholars who worked on the project, describing how early career researchers are being prepared to be good partners with community-based organizations.

The second project, SACS Summer Data Science Academy, shows how an HBCU was able to bring together high-tech research and industry groups with community partners to design experiences that make advanced technologies relevant to the lived experiences of youth and inspire them to see themselves in high-tech STEM careers.

Seeing the World through a Mathematical Lens: A Place-Based Game for Creating Math Walks

Key ideas:

- Working at multiple sites helped emerging scholars see how to identify strengths of partners and draw on their contextual knowledge to shape program designs.
- Exposure to diverse research sites allowed emerging scholars and senior researchers to identify issues and fill in gaps across the contexts.
- In trying to build on K-12 students' funds of knowledge, emerging scholars learned how challenging it is to design interest-based math problems that are relevant to them and convince staff to let students take ownership of the activities.

The goals of Seeing the World through a Mathematical Lens: A Place-Based Game for Creating Math Walks (NSF grant DRL 2115393; also known as "MathFinder") are: (1) the development of a mobile app that allows youth to create and use "math walks" at informal learning sites, (2) research on how math walks can be best designed to enhance student outcomes, and (3) the development of a network of community-based organizations engaged in informal mathematics education. This project is a partnership among Southern Methodist University (both the Simmons School of Education and Human Development and Guildhall program for video game design); talkSTEM, a community-based nonprofit organization; WestEd, an education research nonprofit; and nine informal learning partner sites in Dallas. These partners include the Dallas Museum of Art, Dallas Arboretum, Dallas Zoo, Frontiers of Flight Museum, Girl Scouts of Northeast Texas, Voice of Hope Community Center, Twelve Hills Nature Center, St. Philip's School & Community Center, and the Girls in Engineering, Mathematics and Science (GEMS) camp. The partner sites are widely varied with regard to their structures and sizes, the complexity of their administration, the number of youth served annually, and their physical locations.

The MathFinder partnerships are grounded in a five-year NSF Advancing Informal STEM Learning grant, which launched MathFinder, a community math walks initiative. Mutual trust and understanding developed between SMU and talkSTEM as they collaborated. Collaborations between the School of Education at SMU and the Guildhall at SMU were also established over this period, as the two groups began working on educational game projects together. The relationships with the nine informal learning partner sites were developed between talkSTEM and most of these organizations, both previous to the start of the project as well as over the period of time, that the MathFinder initiative was launched. Many of these partner sites were interested in implementing math walks at their sites or training their personnel in math walks even prior to the start of this project. The MathFinder project enabled us to build on these long-term collaborative relationships.

To explore the details of how this project prepares early career researchers, we continue with two perspectives, the PI's perspective and the graduate students' perspective.

Perspective One: How the PIs Designed the Project to Support Student Growth

By Koshi Dhingra, Candace Walkington, and Elizabeth Stringer

As described throughout this report, partnerships are valuable because they increase the richness of the technology being developed, the quality and applicability of the research being conducted, as well as the perceived relevance and value for those with whom the technology is being developed. Since partnerships necessarily involve collaboration across institutional cultures, it is important to build an understanding of and respect for the varied habits, activities, and priorities (i.e., the cultures) that are integral to the identity of each partner organization. A deep understanding of the different organizational structures and cultures is critical because, in the absence of this, wonderful technologies with huge potential go unused. To scale usage, researchers and developers must have a nuanced understanding of the practices of the partner organizations that represent the user population. We sought to involve our early career researchers in developing this understanding.

Children interacting with the app in the current state of development at a recent MathFinder research camp at the Voice of Hope Ministries.

Preparing Researchers to Interrogate What Count as Mathematics

One way that this project prepared researchers to be good partners was encouraging them to ask "what is math?" Math is often defined in one of four ways: (a) academically, or (b) from researcher perspectives, or (c) from math teacher perspectives, or (d) based on policies and standards. In this project, the informal learning sites determine what mathematics is, where it is, and what it can be – based on their experience with visitors and learners. By considering partner perspectives, researchers learn to question their own preconceptions about mathematics and to elevate real-world, place-based activities.

Preparing Researchers to Conduct Research on Partner Contexts to Inform Design

The graduate students who are on this project team are trained to gather insights into the priorities, practices, and perspectives of multiple informal learning sites and their personnel, all of whom operate under vastly different constraints and realities. The graduate students learn to recalibrate their expectations as they move between varied partner sites with different resources and styles. For example, at an after-school club in an under-resourced neighborhood of Dallas, learners in the club already have strong relationships with instructors. Our graduate students observed strikingly different interactions between participants and instructors in a three-day long camp at the Dallas Zoo, where the instructors and youth did not know one another. As emerging scholars work with these different partners they gain experience in learning to listen and adapt to the different and unique values, norms, resources, and needs at each partner site.

Building this kind of understanding increases the likelihood that the technology we develop will successfully engage the groups we aim to serve. As we began designing the app, there was necessarily ongoing dialogue about the needs of each site, the ways in which the programming and the app needed to change to improve usage and outcomes, and constant recognition of and discussion about constraints. These ranged from lack of WiFi capability at some sites, to multi-floor buildings at other sites where GPS coordinates were ineffective in pinpointing specific math walk stops. This also related to the differing structures for the math walk activities used at each site. The activities ranged in the amount of time allocated, the mathematical content, and the existing walk stops. As an example, at the zoo, where a key educational goal is to be screen-free during educational programming, youth observe animals in their habitats. Here, emerging scholars worked with the zoo personnel to imagine a solution where youth would comfortably use the app in a way that does not conflict with their key goal. To do this, we came up with a structure where most of the app usage would be in a separate zoo classroom, at a time when students were not interacting with the animal exhibits.

Children interacting with the app in the current state of development at a recent MathFinder research camp held at Twelve Hills Nature Center in Dallas.

Preparing Researchers to Co-Design With Youth and Informal Educators

This project also prepared researchers to engage in community-based co-design work, rather than design a study and then seek a site for implementation of the study. The co-design process with community sites involved observing youth at their sites going on and creating math walks without technology, led by site informal educators. It also involved focus groups with youth and informal educators at the sites. In co-design, our partners from the informal organizations are seen as researchers too. Design decisions are made in partnership with key stakeholders – including the kids that will use the app and the informal learning sites that will support the app. This positions researchers not as the "authority" who are passing on their innovations to educators and kids, but rather as facilitators who help to support the potential of their partners and allow their unique strengths and resources to truly shine.

Observation and feedback about youth participation at each research site were rich and from multiple perspectives.The team engaged in listening to the feedback and was open to revising major portions of the project. For example, an observation from the informal educators that the youth needed more support posing their questions for their own math walk stops led to the development of additional video resources and app mechanics – even though the original plan had been to make this activity a more traditional, less-guided inquiry.

Lessons Learned

Involving early career scholars in this project has helped them develop an appreciation for the amazing co-design work that can occur among a diverse array of community partners and researchers, and learn how to develop technology-supported activities that helps meet their needs in working with youth, while also advancing fundamental knowledge of how people learn with technology. Our partnership work has further highlighted for the early career scholars the power of emerging technologies to adapt to the varied needs of many different stakeholders in education settings, operating under a variety of constraints and with different goals. Finally, this partnership work has highlighted the important insights that kids themselves can give when asked to help design technology systems.

Just as important, our project has also enabled our early career researchers to have a realistic understanding of the costs of this approach. Activities like reaching out to and meeting with partners individually, engaging in co-design processes, building site-specific capacity through individualized resources like math walk videos and training sessions, and providing encouragement and support to sites as needed, are very time-consuming. In addition, it is important to recognize that in long-term projects such as this, strong and sustained top-down relationships with organizations are also needed, given the complexities of organizational structures, shifting priorities, and changing staff.

Perspective Two: What Early Career Researchers Gained From Their Experience Doing Partnership Research

By Marc T. Sager, Saki Milton, and Anthony J. Petrosino

The first and second authors of this section are doctoral students at SMU working on the MathFinder project. We have received invaluable research experiences, such as the development of complex community-based research designs and experience with implementation, data collection, data analysis, and dissemination of research.

During the first year, we were able to participate alongside the Principal Investigators in the implementation of the research project at three partner sites. As such, we observed "behind the scenes" activities associated with preparing a complex and large-scale research project. The MathFinder project included working with a large and diverse set of individual stakeholders to ensure that we researchers are prepared to use equitable lenses in our research and development. Each researcher also brought their own valuable prior and lived experiences and knowledge to strengthen this project, whether that be work experience, teaching and pedagogical experience, or methodological and data analysis experience.

Learning to Do Partnership Research

Preparing early career researchers requires introducing them to fundamental conceptual and theoretical knowledge and supporting literature, which guides the research. This project drew upon informal math learning and the theoretical concepts that we learned about came from interest theory, problem-posing, and culturally sustaining pedagogies. We were trained to use these concepts to design cycles of participatory design-based research on technology-supported math walks. We hypothesized that math walks may trigger and maintain students' interest in learning mathematics (Hidi & Renninger, 2006), increase math ability beliefs (Perez-Felkner et al., 2017), and lower math anxiety (Bai et al., 2009). The data we collected and analyses we ran helped us connect the literature to real-work experiences regarding these constructs.

The project trained us to use research-practice partnership (RPP) tools and routines from Penuel and Gallagher (2017) to support the partnership's infrastructure, such as: (a) working through the logistics of scheduling meetings and professional development events, (b) using multiple communication modalities (i.e., emails, Zoom meetings, in-person meetings, Slack) to ensure all parties involved were engaged in conversations, (c) setting agendas to facilitate discussions, (d) using both Google Drive and Box to support collaborative efforts and house documents, and (e) establishing formal agreements, including research compliance from the university's Institutional Review Board (IRB).

With this RPP approach to research, we established a process that respected students' funds of knowledge, especially those of students from underserved communities and schools. Doing so helped us implement our project in ways that support learners, to ensure asset-based strategies for accessing the mathematical content and practices being explored at the partner sites. We saw how math walks, facilitated through game-based digital technology that position learners as problem designers, could potentially spark learners' interest in and curiosity for mathematics. These math walks could also act as a vehicle for integration across STEM. This helps students collect and analyze data with a greater sense of alignment with the purpose statement and research questions being investigated. Having the opportunity to engage with ideas at both the conceptual and practical level helped make the theory clearer and more relevant to us.

We both acted as adult facilitators and engaged in video recording for data collection purposes while at these sites. We were able to identify: (1) How the adult facilitators unintentionally influenced students' mathematical learning and problem-posing by replicating school mathematics (Sager et al., in review), and (2) the importance of fully capturing students' embodied actions with the video recordings. Additionally, we have been extensively supported by experienced researchers with our data analysis using methods like interaction analysis (Jordan & Henderson, 1995), conversation analysis (Goodwin, 2007), and thematic analysis (Braun & Clarke, 2006). The greatest takeaway for us was that the conventional way that middle school students learn mathematics in formal schooling adversely impacted their attitudes toward math, anxiety toward math, and efficacy while doing mathematics (Milton et al., in review).

Another skill we gained from working on this project was how to disseminate our work. Both of us authored conference proposals for the annual American Educational Research Association (AERA) conference and the International Conference of the Learning Sciences (ICLS). Currently, we are both preparing manuscripts for high-impact journals using data from the project: Marc's journal article looks at the adult-student power dynamics that influence learning, while Saki's journal article looks at students' attitudes toward math and challenges associated with student group dynamics in mathematics learning during the math walk activities. These articles are not the typical kinds of papers that report on project findings, but ones that reflect on how to structure effective partnerships with youth.

Lessons Learned

As early career researchers, we have learned that being a good partner entails full participation and open communication. The quarterly partner meetings are excellent examples of what this looks like in action. At those meetings stakeholders shared updates from their experiences with the research team, ranging from collaborative data analysis to the latest developments of the MathFinder app prototype. They offered constructive feedback to strengthen the partnership (Wang et al., 2021). In addition, we also had to communicate our findings back to the site to ensure that we were achieving the goals of equitable place-based mathematics. Prior to the MathFinder's program at each partner site, museum staff members received a professional development workshop that centered around the three math themes of the grant, facilitation strategies, and methods for scaffolding to support the fidelity of implementation. However, during our data collection and analysis, we noticed the facilitators influenced students to think canonically and traditionally about mathematics, problematizing place-based ideas. Moving forward, we will work with facilitators to use a more "hands off" approach by focusing on video recording group interactions and discussions, as well as emphasizing students' funds of knowledge to ensure student problem-posing is authentic and of interest to the participants.

Through this experience we have also learned more about how to create and contribute to a collaborative multidisciplinary team. For example, because partner site representatives participate heavily in the data collection phase, in Year 1 they did not participate as much in the data analysis, the app development, or dissemination process. In our next phase of work, we plan to provide more support for partner representatives to participate in these aspects of the project. Our experience collecting and analyzing video data in Year 1 also taught us lessons about how to improve our research and collaboration. After facing challenges with the quality of the video in Year 1, we plan to analyze the video data after each partner site visit and before the next visit to improve our data collection, as suggested by the literature (Anderson & Shattuck, 2012; Brown, 1992; Design-Based Research Collective, 2003; Hoadley & Campos, 2022) and to demonstrate the iterative nature of design-based implementation research.

Finally, our experience engaging in co-design helped us learn that students bring their own cultural and familial capital, communication styles, and prior math knowledge to the learning experience. These characteristics need to be recognized and honored throughout the research process because they can inform innovative learning through the use of emergent technologies like AR and VR.

Resources

From Mentors

- https://gomathfinder.org/ MathFinder website for public view with free access to general information about the five-year research project, personnel involved, resources being developed, and invitation to join the growing MathFinder community.
- https://gomathfinder.org/podcasts/ MathFinder podcast series; each episode allows each partner site to share their perspective on the project as it relates to their site.
- https://gomathfinder.org/videos/ MathFinder video collection; this freely accessible and searchable video collection contains 200+ place-based math walk videos, including all videos produced during the research project as well as videos previously produced by community partner, talkSTEM.
- https://gomathfinder.org/newsletters/mathfinder-community-newsletter-jan2022/ Sample MathFinder Community Newsletter sharing updates and information; available near bottom of "News and Resources" web page.
- https://gomathfinder.org/contact/ Contact page inviting all interested individuals from informal education spaces to connect with us.

From Mentees

- Selected Links to Accepted Papers and Presentations about the MathFinders Project:
- Posing math problems about our community: Investigating the WalkSTEM club (Walkington et al., 2021) - This links to our slide deck which was presented at Southern Methodist University's Caruth Institute for Engineering Education. This presentation highlights this project's early work surrounding math walks throughout Dallas.
- Student-created math walks in informal learning spaces (Walkington et al., 2022). This links to our proceedings from the 2022 International Conference of the Learning Sciences and discusses our preliminary findings from our partner site, St. Philip's School and Community Center.
- Learning when creating student centered math walks (Milton et al., 2023). This links to our accepted paper submission to the annual AERA 2023 conference, held in Chicago, Illinois.

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SACS Summer Data Science Academy: Promoting Data Science with Robotics and NASA Geospatial and Extraterrestrial Big Data for Grades 9-12

By David Lockett

Key Ideas:

- Diverse partners bring unique perspectives and resources that expand what is possible and what can be learned by everyone involved.
- For historically marginalized youth to imagine themselves on STEM pathways, they need to experience how those pathways relate to their communities, and they need to see themselves represented in that workforce.
- Creating real-world scenarios with emerging technologies requires high-tech partners to collaborate with those who understand the lived experiences of the youth who will participate.

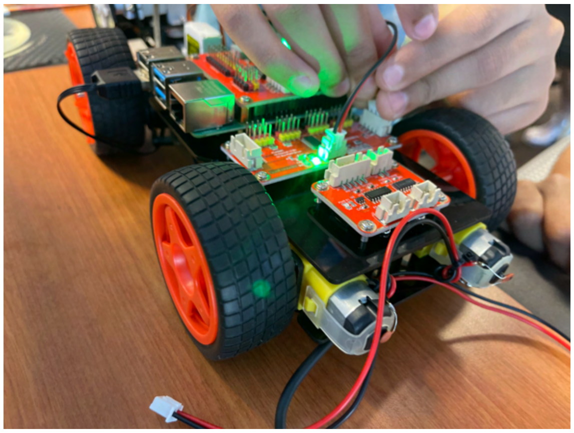
SACS Summer Data Science Academy: Promoting Data Science with Robotics and NASA Geospatial and Extraterrestrial Big Data for Grades 9-12, 22-MUREPPSI-0002, combines robotics and data science, as well as broadening participation in STEM. Meharry Medical College School of Applied Computational Sciences (SACS), an HBCU, developed a free summer program for underrepresented high school students (young women, students of color, and students experiencing poverty) to learn about NASA research and data science tools at our Nashville campus. The key objective of the program was to stimulate curiosity in the cross-cutting field of data science through hands-on STEM activities, deploying real-life application scenarios and industrial-grade robotic systems. Program activities aimed to build statistical and critical thinking skills while inspiring and diversifying the next generation of explorers, researchers, and data scientists.

The partnership for this two-week summer academy included academic, research, community and industry partners. The research partner, the NASA Glenn Research Center, designs and develops innovative technology to advance NASA's missions in aeronautics and space exploration. Our community partner was the Nashville Technology Council, which is responsible for providing workforce training for individuals in the community. We also brought in Stokes Robotics and a geospatial technology firm to introduce high school students to innovative technological tools. The lead partner, the Meharry Medical College School of Applied Computational Sciences (SACS), was the lead who brought all of these diverse partners together to create a program that encourages high school students to understand how data science, computer science, and geospatial technology are relevant to their communities, to experience how to use these technologies to solve problems, and to see themselves represented in the space science and high-tech industries.

Students completed a variety of Spike Prime tasks learning robot design skills and the engineering design method.

Building on Diverse Partner Strengths

Our partnership integrated the strengths of each member. Glenn Research Center, Stokes Robotics, and geospatial industries provided access to advanced technologies for the summer program. To make these technologies meaningful to students, Nashville Technology Council helped us design activities that used those technologies to study our local community together. For example, we collected data on pollution patterns around parts of Nashville using geospatial technology, drones, and Stokes Robotics. We were able to see how certain areas around the interstate had higher levels of pollution than areas that were further away. This helped students get a better understanding of what robotics and big data can contribute to solving problems. While pollution may commonly be seen as an environmental science topic not necessarily related to robotics, this experience enabled the students to draw connections between engineering, data science, computer science, and environmental science and root them in the community.



Students built programmable AI cars.

Building on the initial activities that demonstrated how advanced technologies can address local issues, our partners designed activities that challenged students to imagine how they could use robotics and data science to solve problems beyond their community. One activity had students design a path for a robot on Mars to repair a propeller blade on the NASA Ingenuity helicopter. Students also explored GIS patterns, participated in technology-enhanced escape room activities, and produced 3D models that bridged the connection between the virtual and physical worlds using smartphone data and quadcopter-obtained imagery. These experiences introduced concepts such as computer vision, image processing, spatial positioning, and autonomous navigation, and gave students the chance to apply those to solve real-world problems.

Combining programming and instruction to acquire essential STEM skills.

In addition to providing opportunities for the youth to participate in high-tech workforce scenarios, we also hosted special sessions featuring Black professionals in data science and robotics so that the students could see people of color represented in those careers. Kenneth Harris, the deputy lead integration engineer for the NASA James Webb Telescope's Integrated Science Instrument Module Electronic Components was one visitor. Another was Dr. Sian Proctor, the first Black woman to pilot a spacecraft. These two offered their insights and expertise about career opportunities in science and technology, inspiring the students to build on the strengths that exist in their communities and develop a mindset that they can ultimately do anything.

SACS graduate students mentored high school students wanting to pursue a career in computer and data science.

Lessons Learned

In terms of capacity building, we observed that this project enabled all of our partners to learn from one another and learn from the student participants. The NASA Glenn Research Center and our industry partners introduced SACS, Nashville Technology Council, and the students to exciting new technologies, methods of data collection and analysis, and real-world applications that we could not have imagined prior to this partnership. Together, we developed the following aspects of capacity for doing partnership work:

- Community expertise and insight
- Improved impact
- Enhanced credibility and legitimacy
- Mutual learning and growth

Further, by working together with high school students, the project team had frequent "aha" moments that led us to pivot or think about how to design and implement the program in new ways. College professors who had never taught high school students had to adjust their teaching style to make it more interactive for this younger population. We gave students more time to ask and answer questions, and more opportunities to put what they were learning into practice. We listened to the students to meet them where they were in terms of skills, interests, and content knowledge to adapt the experiences so they were relevant as well as challenging.

Next Steps

This partnership has deepened our expectations of what collaboration can be and ensured that every participant gains inspirational and transformational experiences and encourages them to consider a STEM career. Based on what we learned from this first project, we applied for and received additional funding from NASA to continue the partnership. We're excited for the next iteration of this program and to continue our work to broaden participation in STEM and who has access to pathways for careers in data science, robotics, and beyond. As we aim to continuously improve, we want more students to see themselves and experience themselves learning and working with these technologies.

Resources

- https://sacsmeharry.org/blog/meharry-data-science-summer-academy-opens-students-eyes-to-bright-future/
- https://www.nasa.gov/press-release/nasa-helps-fund-minority-institutions-preparing-students-for-college
- https://my.matterport.com/show/?m=DHCHJmbzeMU
- https://sacsmeharry.org/blog/nasa-grant-funds-new-meharry-data-science-summer-academy/
- https://www.nasa.gov/feature/stem/nasa-awards-hbcus-and-pbis-funding-for-summer-programs
- https://www.nasa.gov/content/data-sciences

Conclusion

This report has explored the transformative ways in which CIRCLS community members have engaged in research with a variety of partners, including educators, administrators, youth, community-based organizations, high-tech industries, and IRBs. Their stories exemplify how to engage deeply with partners to conduct ethical research and development that results in technology-supported learning experiences that benefit the communities. All the stories focus on structuring the work to ensure that educators, community members, and students have power to decide how cutting edge technologies can help the learners they are being designed to support. Although each of the cases in this report has its own unique characteristics, taken as a whole, there are a number of lessons that can be learned from them about productive partnerships.

Establish partnerships before developing projects. Researchers should establish partnerships early in project development because these relationships will change their vision for the work. As we saw in Louw and Byrne's piece, they wanted to focus on the issue of documentation in self-directed learning. By inviting interpretations of documentation from the perspectives of practitioners and youth, the researchers changed their vision of what meaningful documentation can be. Litts, Tehee, and Vouvalis's piece also speaks to the need to focus on partners before conceptualizing research projects. Because IRBs often require research approval before "recruitment" begins, research needs to be designed and planned prior to partner involvement. Defining what is research and who are partners/participants in collaboration with an IRB is an innovation that others can replicate.

Allocate time and attention to establishing equitable procedures for doing partnership research. Authentic involvement of a diverse set of partners strengthens our projects, but as both the Edwards and Ruiz and Richard pieces argue, researchers have to be mindful that structuring equitable and supportive partnerships takes time and effort. Partners come from various cultural and professional backgrounds and can have a wide range of needs, interests, limitations and expectations. Edwards describes many practical considerations that guided how she structured interactions with neurodivergent co-designers during COVID restrictions to ensure everyone was comfortable and their voices were heard. Ruiz and Richard also provided advisory group partners the time to define their collective goals and share their experiences, and were proactive about structuring virtual meetings so that everyone could participate in ways that made sense for them.

Co-design the ideas for research, development and programs with partners. Our partners need to be the drivers, not the recipients, of our work. In authentic partnership work, there should be no need to create "buy-in" among practitioners for the outcomes of a project or innovation, because the practitioners will have suggested it. Lindgren and Planey's piece provides a good example of this. These researchers co-created the technology-enhanced experiences with community college instructors from the early stages of development so that their knowledge of what students need drove the design. Locket's piece describes a program that none of the partners could have designed alone. Working collaboratively, the project drew on the strengths and connections of all the partners to provide a unique opportunity to youth.

Establish the emerging technology as a place for dialog and synergy, where all partners have something valuable to contribute. When a project involves novel technologies, it is typical that some members of the team are positioned as experts on those technologies, while the rest of the team are "users" or "adopters." In the projects described in this report, partners were more frequently positioned as equal contributors, not just to the research or activity design, but to the technology itself. It is essential for teams to recognize that teachers and students have as much to add to the design of new learning technologies as programmers or graphic designers. However, establishing this equal-footing requires more than simply stating so at the onset of a project – design spaces need to be open and accessible. In other words, when a technology design suggestion gets made, the process for implementing that change should be made visible (what resources are required, what side effects it may have, etc.).

See changing the research designs, questions, and processes based on partner input as a feature, not a bug. We engage with partners, especially practitioner and youth partners, not to get their approbation on our designs, but their honest opinions based on the experiences they have using them in real-world situations. All of our co-design case authors were honest and open about the changes that they needed to make to their designs based on practitioner input. Wu, Sharkey, and Wood describe how their computer science teacher partners made many significant contributions to the design based on their deep understanding of what students know and how a 3D coding system could help them express what otherwise they could not. Chang shares a tool that can facilitate change by enabling partners to map their assumptions, conjectures, and possible outcomes and identify where contradictions might arise.

Build capacity for valuing partnership research. This report makes clear that partnership research is challenging but also well worth the effort in creating effective designs for technology-enhanced learning. While many in our community have embraced, or at least attempted, this way of working, we need to acknowledge that this is not what many research communities or academic disciplines understand as "research." One way to help make partnership research more accepted is to be part of the transformation. The MathFinder contributors demonstrated how they are working to transform the culture to value this kind of research. The PIs made sure to give many opportunities for emerging scholars to learn how to do this work. The new scholars have entered into it wholeheartedly and are in the process of sharing their experiences through publications and conferences.

All members of this community can be a part of this transformation. We are the reviewers of journal manuscripts, conference abstracts, and proposals. We are the academics and project directors who mentor early career researchers and make hiring and tenure decisions. We develop new projects, suggest special issues for journals, and attend and host conferences. We are the ones who communicate with, and sometimes become, members of the funding community. Most importantly, we are the ones who have relationships with practitioners, community-based organizations, cultural institutions, developers, industry representatives, and IRBs. The CIRCLS community has already started to transform research on learning technologies by forming valued partnerships and engaging in innovative, groundbreaking work. We can learn from these examples how to empower those who have not traditionally had easy access to innovative technologies to decide how such innovations can enhance their lives. The most important thing we have learned together by preparing this report is about sharing knowledge: detailed stories of research partnerships have been hard to find. We learned that partnership stories offer compelling and surprising details. To grow research communities that proceed through deep, lasting and successful partnerships, we need to make the detailed stories of partnership more readily available.