Co-Design: Success, Challenge, and an Inclusive Design Future for PhET Interactive Simulations

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The PhET Interactive Simulations project conducts and investigates co-design of multimodal features for science and mathematics simulations with learners with disabilities. These efforts are part of a larger initiative to shift our design processes to create a more inclusive future. Through these experiences we have encountered successes and challenges, and share a selection of these from three different perspectives: facilitating inclusive co-design; developing learning resources; and researching inclusive design and inclusive learning resources. We share these as potential topics for further discussion with the inclusive design community.

CCS CONCEPTS • **Human-centered computing→Accessibility design and evaluation methods; *Accessibility systems and tools*.**

Additional Keywords and Phrases: Participatory design, co-design, disabilities, science education

1 INTRODUCTION

Researchers at the PhET Interactive Simulations project are investigating effective ways to design inclusively with learners with and without disabilities, to advance our design processes towards a future inclusive and open learning tool ecosystem. We have engaged in different inclusive design activities with children with learning disabilities (primarily dyslexia and dyscalculia) [3] and with visual impairments [14], each focused on designing sonifications (non-speech sound) to existing PhET simulations. Through these experiences we have encountered successes and challenges, and share some of these as potential topics for further discussion with the inclusive design community.

1.1 Overview of our Inclusive Design Experiences

In this paper, we focus specifically on co-design sessions with children with disabilities experienced by the inclusive design team within the PhET Interactive Simulations project [3, 14], a research and development group in the department of physics at the University of Colorado Boulder [9]. The PhET group conducts research on the design, development, and use of interactive science and mathematics simulations, published as Open Educational Resources (OER) [8].

Since 2014, PhET's inclusive design team has conducted design-based research on the design, development, and use of inclusive features for interactive simulations, such as interactive description [11], sonification [12], alternative input [7], gesture and tangible device input [5], and others. While conducting this work, we have included learners with disabilities and their teachers into the process in different ways, and are continuously striving to increase opportunities for further involvement by learners and teachers with diverse needs. Most relevant to this work are the following co-design sessions:

- **2018-19 School Year:** Researcher embedded within a private school serving students with significant learning disabilities, primarily dyslexia and dyscalculia [3]. Weekly 90-min sessions throughout the academic year with 11 student participants, supporting an introduction to design and sonification of *Balloons and Static Electricity* [1]. Researcher co-designing the classroom activities with the classroom teachers and co-facilitating alongside teachers.
- **Summer 2019:** Researchers visiting a residential summer program for learners with visual impairments [14]. Twelve 2-hour sessions over three weeks with 6 participants. Two researchers facilitating co-design of sonification for *Balloons and Static Electricity* simulation [1].
- **Fall 2019 / Spring 2020:** Researcher leading multi-week, one day per week, co-design sessions within a private school serving students with significant learning disabilities, primarily dyslexia and dyscalculia. In Fall 2019, weekly 1-hour sessions over four weeks with one group of 10 participants (grade levels 5-10). Facilitation by one researcher with three teachers supporting an introduction to design, physical experimentation with friction and waves, and sonification of *Friction* [2] and *Waves: Intro* [13] simulations. In late Spring 2020, five virtual weekly 1-hour sessions with two groups of 4 participants over seven weeks Spring 2020. One researcher without teacher support, facilitating design explorations of several sims with multimodal features under development at the time: *Friction* [2], *Ratio and Proportion* [10], *Balloons and Static Electricity* [1] and *Quadrilateral* tangible [5].

1.1.1 Co-design

In this paper we use the term co-design to refer to scenarios where two or more people work together to design something, with each contributing to the designed outcome and each fully aware of the shared design goal. The shared design goal may have been collectively determined or not. We include this definition of co-design for clarity, acknowledging and appreciating that others (including ourselves) may use this term to refer to, or be inclusive of, other kinds of participatory design scenarios.

2 INCLUSIVE DESIGN FUTURE IMAGINARY

In homage to the work of Jason Lewis [6], we propose for consideration a description of a Future Imaginary, a mechanism for articulating desired futures to support the process of making them real. In so doing, we provide a future we imagine and are moving towards. In the remainder of this paper, we share a selection of successes and challenges we have encountered in our work with this future imaginary.

A collective of teachers and students propose topics for new PhET simulations. Selected topics are chosen, and each new simulation is co-designed through an iterative series of co-design sessions with learners with diverse needs, their teachers, and PhET team members. The process of designing and creating each simulation serves as a rich opportunity for interdependent learning, for example: students learn about inclusive technology design from technologists; teachers learn about collaboration across diverse needs supported by technology use; and the PhET team learns about student and educator needs and creative solutions. Each iteration of co-design results in a more refined and increasingly multimodal prototype, until the simulation experience includes effective ways to see, hear, and touch or move to learn the focal concept.

In this Inclusive Design Future Imaginary, the process for creating technological learning tools, the resulting learning tools, and their end use with learners are inclusive. Further, the process of design, the development of the tools, and their use positions teachers, learners, and technologists on equal footing as partners, each bringing essential knowledge to be shared and arriving to contribute and learn from every other person. The design tools used are accessible, flexible, and intuitive for use by everyone. The process of design explicitly seeks to identify and meet the needs of edge cases, and to include those "at the margins". The resulting learning tool can be successfully used, adapted, and serve as inspiration as well as a starting point to be directly built upon by others as part of open ecosystem of inclusively-designed inclusive learning tools.

This future imaginary and our inclusive design work takes inspiration from inclusive design as practiced by the Inclusive Design Research Centre at OCAD University [4]. With that in mind, we describe Inclusive Design as a practice that seeks to create flexible technologies capable of simply adapting or being simply adapted to meet the full spectrum of human needs in the interaction. Our work draws from the frameworks and strategies of inclusive design, structured as STEM-centered technology co-design, with inclusive learning experiences and tools as the outcome.

3 CO-DESIGN SUCCESSES

Through our various co-design experiences, we have noted multiple successes. We mention them here as points for potential discussion, acknowledging that we are still early in our path inspired by our Inclusive Design Future Imaginary.

Designing for yourself and others. Rather than facilitating design tasks as designing solutions for yourself **or** others, our co-design sessions emphasize designing solutions that work for you **and** for many others. In so doing, the co-designers can recognize that exploration of needs at the margins often results in better solutions for their own use, and vice versa. We have accomplished this in different ways, for example, by supporting learners in considering the needs of potential learners not present and by supporting learners in considering collaboration with the peers in their design group. Incorporating activities into the co-design process that explicitly encourage reflection on their own lived experience, preferences, and aesthetics have been helpful at surfacing relevant differences even amongst seemingly homogenous groups.

Embracing difference. Emphasis in co-design activities is upon recognizing and valuing differences, through exploration of edge cases and situations where designs might not meet a specific need. Though perhaps unintentional, we have found that more mainstream participatory design approaches tend to result in design discussions that ultimately emphasize addressing "common" or "majority" challenges. Our practice of inclusive design positions the exploration of edge cases and "extreme" users as central, creating an environment where identifying such cases (e.g., difference in needs) is valued and utilized.

Removing distinctions between "assistive technology" and "technology". In co-designing technologies through the lens of identifying our own needs, the needs of others, and the ways technology supports or does not support these needs, traditional distinctions between "assistive technologies" and "technologies" fall away, and recognition that all technologies can be assistive and can be more inclusively designed to benefit more people with and without disabilities emerges.

4 CO-DESIGN CHALLENGES

Experiencing these successes and others fueled our interest to continue developing and expanding our co-design practices. In doing so, we have encountered challenges in our roles as facilitators of co-design, developers of learning tools, and researchers of both. Here we share selected challenges and propose avenues of thought or exploration towards solutions.

4.1 Facilitating Inclusive Co-design

Access to contexts conducive to inclusive co-design. We have exclusively co-designed with single population learner groups, i.e., youth with learning disabilities, or visual impairments. While there is diversity of needs and preferences within these groups, we encounter challenges in naturally surfacing needs beyond the canonical supports for each group. This contrasts with our personal experiences of co-designing in heterogeneous adult groups where the groups' heterogeneity serves as a natural starting point for identifying specific and nuanced design needs and preferences.

We have found it challenging to find or create heterogenous groups with respect to sensory, mobility, and cognitive needs for co-design scenarios. This challenge may be amplified by our specific interest in including learners with low-incidence disabilities in co-design, in particular, learners with visual impairments. One avenue we would like to explore is partnership with other inclusive research and design groups to co-create unique co-design opportunities for participants with diverse needs.

Supporting agency in co-design. Our intent is to have co-design activities involve authentic design of features to be implemented within PhET simulations, with co-designers having agency to change the design of the simulations. Instead, we have been challenged in 1) supporting teacher facilitators and youth in both recognizing and enacting their full agency to create design solutions, and 2) authentically relinquishing agency as "design experts." In classroom settings, it is difficult to convey to learners (and teacher facilitators) that we are not "doing school" under the pretense of design, we are actually co-designing new things to share with the world. In all contexts once facilitators are perceived as "expert" it is difficult to shift that perception. Once co-designers recognize themselves as having expertise and agency germane to the design problem, we have noticed that engagement increases, and the design experience appears to improve.

We have had the most rapid application of agency by co-designers in informal rather than formal settings; in informal settings co-designers opt-in, rather than opt-out, of the co-design experience. We also anticipate that more intuitive and accessible design tools will aid in increasing the "transfer of agency".

Accessibility of structure, tasks, and materials. To begin designing a feature for a PhET sim, co-designers need an introductory level understanding of the following: the science or mathematics concept in the simulation; a framework for "doing design" (e.g., Design Thinking or others); and the modality(ies) being designed (e.g., visual, sound, haptics, or description, etc.) along with the associated design tools. Ideally the structure of the co-design session onboards co-designers in these areas, and then focuses on co-designing the simulation feature(s). All the materials involved need to be accessible and intuitive for use by all co-designers, enabling direct ideating, drafting, prototyping, etc., by the co-designers on-the-fly. To date, we have experimented with activities that introduce: PhET simulation content (with simulation and real-world, hands-on, demonstrations), Design Thinking, and sonification (a subset of auditory display design). It has been challenging adapting these activities for new contexts, particularly shorter duration contexts, where the on-ramping needs to be rapid. Ensuring all design tools and materials are accessible has also been a challenge.

To address these challenges, we have begun developing “sand box” tools to support learners in exploring sound, haptics, etc., on-the-fly. We anticipate that with such tools we are simultaneously increasing accessible design tools and providing contexts for more efficient on-ramping into design.

4.2 Developing Learning Resources

Aligning co-design with production timelines. The outcomes of our work include simulations with supporting resources. We can typically create a new simulation in 12-16 months and can add a new modality feature to an existing simulation in 6-12 months. Co-design of sonification has informed the sound design of simulations, but none of the sonifications designed by co-designers have been published in simulations. Designs resulting from co-design sessions have been incomplete or completed too late in the simulation publication process for inclusion. Thus, the actual design and publication process has always ended up decoupled from the co-design process with youth. The use of “sand box” tools and other resources for rapid prototyping could help address this challenge, though we suspect more nuance to this challenge will emerge over time.

Attribution for Youth Co-designers. In the future we anticipate outcomes from co-design, including ideas originating from co-design sessions to be directly utilized in published simulation features. It is not currently clear how to appropriately attribute these contributions, particularly in the context of co-design sessions that are also research contexts.

4.3 Researching Inclusive Design & Inclusive Learning Resources

Emphasis on interventions and clinical classifications. Our work is often (mis)interpreted through the lens of educational interventions for single populations and critiqued for a lack of specificity in the clinical classifications of co-design participants. From our perspective, we are not developing interventions for single populations. For our purposes, knowledge of a learners’ needs with respect to their technology use is more relevant than their clinical diagnosis. For example, we find it more useful to know that a learner relies on auditory information and no visual information when using a computer than to know their clinical diagnosis of blindness, their visual acuity, or etiology of vision loss. Increasing awareness of inclusive design practices and perspectives, and our own outlets for disseminating findings, etc. could help.

Funding and support for the work. Investigating and conducting co-design is a resource intensive process that benefits from long-term partnerships with the community, while stable long-term funding sources are challenging to secure. Increased awareness of inclusive design and its benefits could increase support for these efforts.

5 CONCLUSION

In our work moving towards a more inclusive future, we are investigating different co-design structures in the development of interactive simulations for learning. We share successes and challenges, in the hope of contributing to the inclusive design community and to serve as potential topics of discussion, brainstorming, and collaborative problem-solving for the advancement of inclusive design with learners with disabilities.

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