NATIONAL LEADERSHIP GRANTS FOR LIBRARIES

Sample Application LG-260194-OLS-26
Project Category: Applied Research

Indiana University, Luddy School of Informatics, Computing, and Engineering

Amount awarded by IMLS:	$497,065
Amount of cost share:	$0

Indiana University, Luddy School of Informatics, Computing, and Engineering in partnership with Binghamton University will do research toward developing a program that can increase children's (3-5 years) algebraic reasoning, as well as caregivers' and public librarians' self-efficacy in math literacy skills. The project outcomes will be a generative artificial intelligence-integrated curriculum and resources (e.g., stories, play-based math activities, at-home math resources, facilitation guide, webinar, project website), which includes an artificial intelligence chatbot designed to help caregivers and librarians navigate algebraic misconceptions and learn scaffolding strategies they can use with children; a working co design model for generative artificial intelligence–librarian collaboration around early algebraic storytimes; and development of adults' self-efficacy in math literacy skills and children's algebraic reasoning through engaging in algebraic reasoning.

Attached are the following components excerpted from the original application.

- Narrative
- Schedule of completion

When preparing an application for the next deadline, be sure to follow the instructions in the most recent Notice of Funding Opportunity for the grant program to which you are applying.

Mathematizing Public Library Storytimes (MPLS) through Integration of GenAI: Empowering Caregivers and Public Librarians to Develop Young Children's Algebraic Reasoning

INTRODUCTION Indiana University Indianapolis and Binghamton University request $498,967 to conduct a three-year applied research project from September 1, 2026, to August 31, 2029, to develop GenAI-integrated Mathematizing Public Library Storytimes (MPLS) program that can increase both young children's (3-5 years) algebraic reasoning, as well as their caregivers' and public librarians' self-efficacy in math literacy skills. This study addresses NLG-L program goal 1 and objective 1.1 (serve the learning needs of the public through libraries and archives), and responds to the urgent need to develop children's algebraic reasoning from an early age, while increasing adult educators' (e.g., parents, caregivers, librarians) self-efficacy in math literacy skills, and seeks to contribute to the limited evidence-based practices in out-of-school math learning opportunities at public libraries. The MPLS program will be developed by leveraging community funds of knowledge and extending math-focused storytimes to home environments, as well as offering a coaching session specifically for adults that utilizes a Large Language Model (LLM)-powered chatbot developed by the research team to identify caregivers' algebraic misconceptions and provide ways to scaffold children during MPLS. Our partnership includes, but is not limited to, the Indianapolis Public Library, the George F. Johnson Memorial Library, and the Association for Library Service to Children (ALSC), with a team of experts in early childhood mathematics education, AI, and co-design. Our study is guided by the question: **In what ways can MPLS create impactful early math literacy opportunities for young children, their caregivers, and librarians in public libraries?** The intended project outcomes are: (1) a research-informed, nationally scalable GenAI-integrated MPLS curriculum and resources (e.g., stories, play-based math activities, at-home math resources, facilitation guide, webinar, project website), which includes an AI chatbot designed to help caregivers and librarians navigate algebraic misconceptions and learn scaffolding strategies they can use with children; (2) a working co-design model, including design principles, for GenAI–librarian collaboration around early algebraic storytimes; (3) development of adults' self-efficacy in math literacy skills and children's algebraic reasoning through engaging in algebraic reasoning talk at MPLS. This project will lead to a novel understanding of effective mechanisms for mathematizing storytime programs for young children and caregivers and their impact on increasing children's algebraic reasoning and enhancing adults' self-efficacy in math literacy skills.

PROJECT JUSTIFICATION

Need 1: Developing evidence-based practices for early algebraic reasoning into library storytimes. Research demonstrates that strong early math literacy skill at school entry is one of the most significant predictors of eighth-grade achievement, with this finding being consistent for both boys and girls across high and low socio-economic backgrounds [1]. Unfortunately, many children enter school with weak math skills, which hinder their academic success and widen the achievement gap [2]. Public libraries, through their widely available storytimes [3,4], are uniquely positioned to bridge this gap. By Mathematizing Public Library Storytimes (MPLS), we argue that libraries can support children (3-5 years) to develop math literacy skills at a young age. While existing frameworks and ongoing projects (e.g., Libraries Count, Family Engagement Toolkit, Young Mathematicians, Reimagining School Readiness) provide insights on ways to integrate math into library programming and/or strengthen children's early literacy skills, out-of-school math learning in public libraries lacks structured, evidence-based practices to maximize impact. For instance, according to a recent analysis of IMLS-funded STEM education research [5], there is a significant lack of research on math-focused programming in libraries. Current research is limited to showing how regular storytimes provide opportunities to engage in cognitive and behavior skills for school success (i.e., counting, size) [4,6], rather than intentionally mathematizing the library storytimes and understanding the impact of such programs for developing children's math literacy skills.

Our project aims to extend the field's thinking of integrating early math concepts to storytimes even further by moving beyond number, operations, and geometrical concepts to early algebraic reasoning. While mathematical concepts such as numbers, operations, and geometrical concepts are more likely and easily integrated into storytimes, introducing the concept of algebra is less common. Early algebraic reasoning is crucial for young children because it strengthens foundational number skills and helps prevent future math difficulties [7,8]. Yet from young children to adults, research highlights math struggles in understanding foundational algebraic concepts [9,10]. One approach to combat these challenges is to embed algebraic ways of thinking at an early age and move beyond the typical arithmetic-based focus [11,12]. Prior research demonstrates that young children can grasp early algebraic concepts, such as functional relationships [13], the equal sign as relational [14], and algebraic generalizations using abstract symbols [15]. These concepts can be introduced through intuitive experiences, such as children adjusting their balance on a slope to understand variables or using color patterns to represent binary systems, mirroring how algebraic variables interact. While prior scholarship shows promise in terms of early elementary-aged children's algebraic understanding [16–18], less is known regarding the algebraic thinking of preschool-aged children and within library story time. This project addresses this gap by building upon the current scholarship base and previous IMLS projects (e.g., Libraries Count, Reimagining School Readiness, Supercharged Storytimes for All) to move beyond number, operations, and geometrical concepts to early algebraic reasoning. In doing so, we are attending to Cahill et al.'s [4] conclusion: "While research has found that storytimes frequently incorporate opportunities for children to engage with foundational math concepts through counting, and identifying numbers and item amount (Campana, 2018); librarians could expand the mathematics learning environment in storytime by providing opportunities for children to interact with the *wider range of mathematics concepts they are incorporating through hands-on activities*…" (p. 482; italics added for emphasis).

Need 2: Developing culturally relevant MPLS materials while considering resource constraints within libraries. Mathematizing storytime requires intentionally integrating mathematical concepts into the narrative and shared reading experience. One particularly effective way to mathematize storytime is to provide culturally relevant conversations to identify and build upon the math already present in children's everyday lived experiences. While culturally relevant pedagogy [19,20] and the integration of Funds of Knowledge (FoK) [21] have proven effective in making math more accessible to diverse learners [22], developing culturally relevant children's programming materials at public libraries presents a significant challenge given the limited time and resources of public libraries.

Generative AI (GenAI) presents a promising opportunity to overcome these challenges by serving as a co-design partner [23–26], supporting librarians in developing customized library programming materials. GenAI is widely used by educators to support lesson planning and instructional design [27,28], as well as an instructional partner in co-creating digital stories, narrative-based games, and story problems [29,30]. While less is known regarding this scholarship with public librarians and algebraic reasoning, our *working hypothesis* is that GenAI tools (e.g., Microsoft CoPilot, Gemini) will function as both ideation and scaffolding partners in the co-design process with public librarians. Following the successful use of GenAI in lesson planning [31–33], we anticipate that GenAI can assist librarians to mathematize stories in culturally relevant ways, draft MPLS narratives, simplify complex algebraic concepts, and design images for the MPLS narratives. Thus, our project addresses the need to develop culturally relevant MPLS materials by utilizing GenAI tools as a co-design partner for the MPLS curriculum to overcome the time and resource constraints within public libraries, while attending to the need to define a framework for public librarians' co-design of culturally relevant programming materials with GenAI.

Need 3: Providing support for caregivers and library staff to enhance their own math literacy skills by providing a "third space" through the integration of GenAI. In thinking about developing children's algebraic reasoning, it is equally important to consider ways to support the math literacy skills of adults who will interact with children. Prior scholarship highlights how adults often exhibit low levels of math [literacy] self-efficacy [34,35] and high levels of math anxiety [34,36], which may limit how often they engage in math concepts in their home environment [37,38], as well as have a negative influence on children's own math dispositions and performance [39–41]. Adults also hold similar algebraic misconceptions as those held by children [42], with limited awareness of the significance of early algebraic concepts [43], such as equality and variables [9,10]. Guided by prior literature, which demonstrated GenAI serving the role of a low-stakes, non-judgmental mediator for learners to address conceptual misconceptions or sensitive knowledge gaps that they might otherwise be hesitant to disclose in social or formal educational settings [44–46], we recognize the need to explore the role of GenAI in serving adult learners to address their own math misconceptions. Prior literature demonstrates that, during the interaction with GenAI, participants asked questions more frequently [46], particularly around foundational concepts [47], and developed a willingness to seek help without fear of burdening others or appearing less knowledgeable [48]. Based on this body of work, our *working hypothesis* is that providing a safe "third space" through the integration of GenAI for caregivers and library staff in the MPLS program will increase adults' self-efficacy in math literacy skills.

PROPOSED SOLUTION

Our proposed solution is a **Gen-AI integrated Mathematizing Public Library Storytimes (MPLS)** that includes **10 storytime sessions** at the library and **four home-based activities**, along with a **coaching session for caregivers** where they interact with an **LLM-powered chatbot** (*hereafter, we will refer to it as an AI chatbot*) to ask questions about their algebraic misconceptions and learn scaffolding strategies that they can use with children during MPLS to help children make connections with math present in their everyday life (see ***Supportingdoc1*** for an overview of MPLS). To ensure participants' confidentiality, all AI interactions will be conducted through platforms that allow for deactivation of model training to ensure that participant data remains within an encrypted session and is excluded from training datasets. We expect to contribute to math education and public library children's programming research that focuses almost exclusively on GenAI as an automated tutor or problem-generator [49], adding novel understandings on how GenAI-supported public library storytimes can foster algebraic reasoning among young children and develop adults' self-efficacy in math literacy skills.

MPLS will focus on four concepts: (a) equal sign as relational; (b) variable; (c) functional relationships; and (d) exploring the structure of mathematical operations/generalizations. These are concepts that middle school, high school, and post-secondary students hold erroneous notions and inaccurate understandings [50–52], but also core algebraic concepts identified by the National Council of Teachers of Mathematics [53]. Each session will begin with a librarian-led coaching session for caregivers (10 minutes), covering four algebraic concepts and introducing how to use community funds of knowledge to scaffold mathematical reasoning during storytimes. Then, caregivers will utilize the AI chatbot for private, individualized coaching to address personal knowledge gaps and co-develop prompts and questions tailored to their child's unique interests and funds of knowledge, which they can use during MPLS. Then, the storytime (20-30 minutes) will embed math questions, songs, and interactive caregiver-child math activities relating to a story they read together. For each algebraic concept, a home-based activity will be developed that situates an algebraic concept within everyday activities and funds of knowledge. We anticipate that home-based activities would integrate the use of the AI chatbot that we will develop. Light refreshments tailored for young children and caregivers will be provided at each MPLS session, along with other craft materials they need for interactive math activities and home-based activities. The research team and the librarian will provide childcare when caregivers are engaged in the coaching session with the AI chatbot (see ***Supportingdoc2*** for an example curriculum of an MPLS session). We further expect the AI chatbot to be used by librarians as a coaching tool as they familiarize themselves with our MPLS curriculum and address their own algebraic misconceptions.

Theoretical Perspectives: Our project is grounded in the human-AI collaboration theory, positioning GenAI not as a replacement for human expertise, but as a complementary co-creative partner that augments the strengths of librarians and caregivers [54,55]. Human-AI collaboration theory also connects with human-centered AI perspectives [56,57] that assert the importance of designing AI tools that are usable and useful to human needs to amplify human agency. Grounded in these perspectives, we leverage GenAI's capacity to support more personalized and adaptive learning [26,58–60] based on each family's unique funds of knowledge, while ensuring that librarians can apply critical thinking and contextual knowledge to interpret and refine GenAI outputs. Specifically, we will develop an AI chatbot to create a "third space" [61,62] where the "first space" of home-based lived experience and the "second space" of formal algebraic instruction can merge into a hybrid understanding. However, acknowledging that GenAI tools can sometimes produce mathematically inconsistent or culturally generic outputs [63], our study positions librarians as the primary pedagogical authority to validate, modify, and enhance AI-generated content using their expertise and nuanced understanding of their local communities.

In our work, math literacy is defined as an individual's capacity to formulate (recognizing opportunities to provide mathematical structure to a contextualized problem), employ (apply mathematical concepts and reasoning to solve and obtain solutions), and interpret mathematics (reflecting on the solutions in the context of real-life problems) [64]. To mathematize algebraic concepts for children, we adopt the notion of seeds of algebraic thinking [65,66] that recognize pre-instructional cognitive resources that are constructed early in a child's life and become incorporated into later reasoning processes as they interact with the world. Seeds of algebraic thinking pushes researchers and educators to rethink how to support children's early algebraic reasoning [67], and will inform the design of the MPLS and how we understand young children's algebraic reasoning. Our work is further informed by culturally relevant pedagogy [19,20] and funds of knowledge (FoK) [68–70], which is a transformative approach to storytime and is based on a strength-based model of education as opposed to a deficit theorizing model. As noted by Fusco [71], this theoretical framework provides opportunities for children and their caregivers to be givers and engage in learning activities that are often perceived as fake as opposed to community-based projects. Research on FoK highlights the positive impact on children, caregivers, and educators [72–74]. For example, learner outcomes include learning of concepts and skills, promoting sense making among peers, increasing interest, and a positive sense of efficacy in a specific discipline [75–77], including mathematical concepts and processes [70,78–80]. Using family's FoK promotes feelings of empowerment and belongingness of parents and caregivers [74]. Utilizing this framework should also support children, caregivers, and librarians in seeing the relevance of math in their daily lives.

Target Groups: (1) Young children. We anticipate that at least 110 children will receive the educational benefits of the MPLS program by having it implemented across 22 libraries. We expect to recruit at least five children (ages 3-5) per library. **(2) Caregivers.** We also expect to serve the same number of caregivers who will accompany children. We define caregivers loosely in our project to include any adult member who provides care for the child during the time of library storytime, which can include parents, grandparents, and nannies. **(3) Public library staff.** We will work with six librarians in Phase 1, four librarians in Phase 2, eight librarians in Phase 3 (*However, some participate in multiple Phases, so there are 12 unique librarians in Phases 1- 3*). In Phase 4, at least 10 librarians will participate. In total, 22 librarians will participate in this project, and are expected to experience educational benefits from co-designing the MPLS program and/or implementing it.

Beneficiaries: (1) Caregivers and young children. The primary beneficiaries of this project will be the caregivers (i.e., parents, nannies, grandparents) and young children (3-5 years). By developing 10 series of MPLS, we aim to support children's algebraic reasoning while increasing caregivers' self-efficacy in math literacy skills and empowering them to have continuous conversations and play-based activities with their children after MPLS. **(2) Public librarians and educators in early childhood education.** The secondary beneficiaries will be the public librarians and educators in early childhood education who will use MPLS curriculum materials to facilitate children to engage in early mathematics learning and continue to integrate math into storytimes or other play-based activities. **(3) Researchers.** Lastly, we aim to provide knowledge on ways to integrate mathematics learning in play-based activities for children, the role of GenAI as a co-design partner for librarians, and how GenAI may serve as a third space for addressing caregivers' algebraic questions. The expected knowledge produced from this project will provide benefits in the field of library and information science, learning sciences, and mathematics education.

PROJECT WORK PLAN

Our overall research question is: In what ways can MPLS create impactful early math literacy opportunities for young children, their caregivers, and librarians in public libraries?

- **RQ1:** What roles do GenAI tools (e.g., ChatGPT, Microsoft Copilot, Gemini) play in developing a culturally relevant MPLS program through the co-design process between researchers and public librarians?
- **RQ2:** How does MPLS influence caregivers' and librarians' development of self-efficacy in math literacy, and what program components do they perceive as most impactful to this development?
- **RQ3:** How does the quality and quantity of adult-child math talk supporting children's algebraic reasoning evolve?
- **RQ4:** How does MPLS support the development of children's algebraic reasoning?
- **RQ5:** How do public librarians in diverse settings adapt the MPLS curriculum, and what are their perceptions regarding the MPLS's influence on their own conceptual understanding and the subsequent algebraic engagement of participating families?

The proposed study aims to: (1) develop a GenAI-integrated MPLS program; (2) develop caregivers' and librarians' self-efficacy in math literacy; (3) increase the quality and quantity of adult-child math talk supporting children's algebraic reasoning; (4) increase children's algebraic reasoning; and (5) expand the implementation of the MPLS curriculum to diverse library settings. These aims will be addressed through four phases.

- Phase 1: Co-design the MPLS program (addresses RQ1 and Study Aim 1)
- Phase 2: Implement the MPLS program at four local libraries (addresses RQ2-4 and Study Aim 2-4)
- Phase 3: Scale up the MPLS program at two local and six remote libraries (addresses RQ2-4 and Study Aim 2-4)
- Phase 4: Disseminate the research findings and the MPLS materials (addresses RQ5 and Study Aim 5)

<u>Phase 1: Co-design the MPLS program (Months 1-8)</u>

PIs have extensive experience obtaining IRB approval, and we plan to submit the IRB application two months before the project start date (see ***Scheduleofcompletion***). We will obtain feedback on our data collection instruments for all the activities mentioned below from our AB members before conducting the research activities.

(1) Recruitment of co-design team (6 public librarians). A national call will be distributed through ALSC/ALA listserv (see ***Supportingdoc3***) and professional social media channels (e.g., Programming Librarian Interest Group). Interested individuals will be able to access a Google form to send in an application that asks them to share their experience with storytimes, their time availability, general library information, community population, a description of how their values align with the vision of MPLS, and a required video upload to introduce themselves. We will recruit 6 librarians who meet the following criteria: (1) passionate about integrating mathematics into storytimes, (2) works in a public library that provides weekly storytime and has regular attendance of minimum 10 families per storytime session for a sustained period of time, (3) can commit to attending 12 bi-weekly co-design sessions (each 1.5 hours), and (4) can commit to sharing their experience of facilitating MPLS program with other librarians via two Zoom meetings in the future. We will not ask for librarians' prior experience with GenAI during recruitment to ensure that we investigate the effectiveness of GenAI tools during co-design across librarians' varying levels of familiarity, perspectives, and expertise. Additionally, we will ensure that there is diversity in terms of size, location (i.e., at least one rural library staff), service population, operating revenue, and culture (i.e., at least one tribal library staff) in our selection of libraries. We will also recognize the importance of valuing the unique lived experiences of librarians involved in the project. Out of these six libraries, two libraries have already been recruited from IN and NY that are geographically near the PIs to enable in-person data collection activities described in Phase 2 (see ***Supportingdoc4–5***; *Please note that Supporting Document 5 reflects IndyPL's commitment to our project,* *although the title of the project is not correct*). Recruiting six librarians is intentional, recognizing that librarians may not attend all. We plan to provide an hourly honorarium to librarians to increase their motivation to attend all co-design sessions and ensure fair compensation based on their attendance and time commitment (see ***Budgetjustification***).

(2) Online co-design meetings. Bi-weekly online co-design meetings, each 1.5 hours, will occur in Zoom over six months to design a series of 10 MPLS curricula and 4 home-based activities. We will bring in partner libraries' expertise in family literacy and build on existing frameworks and knowledge, such as math-related funds of knowledge [81,82], elements to consider in storytimes and narratives [83,84], and best practices for using GenAI tools for co-design of educative materials (e.g., IMAGINE AI framework) while bringing our expertise around math learning, AI chatbot development, intergenerational learning, co-design, and public library programming to develop MPLS (see ***Resumes*** and ***Project Personnel*** section). Based on our prior experience of co-designing with rural library staff and museum educators, we see the importance of building relationships and situating librarians as equal co-design partners rather than co-design participants. We will leverage previous resources that maximize collaborative idea elaboration and equitable partnership, such as cooperative inquiry [85,86], dimensions of equal and equitable design partnerships for participatory librarianship [87], and IDEO design thinking for libraries. We also experienced that the newest online tools can sometimes be overwhelming and hinder librarians' confidence to participate and openly discuss ideas. As such, we will be careful in choosing co-design techniques [88] based on partners' design experience and need for accommodation. We will use the Learning, Using, Assessing (LUA) framework [89] where librarians first engage with GenAI to practice prompt engineering and understand the tool's strengths and biases. Then, we will move into collaborative discussion and occasional breakout rooms where we integrate community funds of knowledge (FoK), such as family traditions (e.g., cooking) and routines (e.g., grocery shopping), into narrative contexts. Each session will culminate in a "show and reflect" activity to share co-created materials and reflect on how GenAI tools assisted in the co-design.

(3) Evaluation of 10 MPLS curricula. After co-design, 10 MPLS curricula will be evaluated by advisory board members with areas of expertise in co-design, AI, mathematics learning, early childhood, and storytimes. While the full curriculum will be developed through co-design, an example can be found in ***Supportingdoc2.***

<u>Phase 2: Implement the MPLS program (Months 9-18; at four local libraries)</u>
(1) Recruitment of two additional local libraries. In addition to two libraries that have already committed to be part of the co-design, two additional local libraries in IN and NY will be recruited, following similar methods described in Phase 1. Library partners in Phase 1, AB members, and ALSC will also assist with recruitment. **(2) Caregiver and child recruitment:** About three weeks prior to the start of MPLS, a member of the research team will attend regular storytimes at each library site to discuss the project and obtain consent from caregivers (e.g., parents, nannies, grandparents) and assent from children. Given that our partner libraries have had regular attendance of minimum 10 families per session for a sustained period of time, we expect that a minimum of five families will consent to participate. Out of 10 MPLS sessions, research participants will be expected to attend at least four sessions. We have honorarium for each research activity participants complete to support participant recruitment and retention (see ***Budgetjustification***). **(3) MPLS implementation.** MPLS will be implemented at four local libraries by integrating them into existing weekly storytime hours.

<u>Phase 3: Scale up the MPLS program (Months 19-27; at two local and six remote libraries)</u>
(1) Recruitment. Eight libraries will participate in Phase 3—four returning from Phase 1 and four new sites (two local, two remote) recruited via the same methods described in Phase 1. To recruit families, researchers will join existing storytime sessions (in person for local sites; virtually for remote sites). Data collection at local and remote libraries will differ (see ***Research Plan*** section for details). **(2) Preparation for scale-up.** To prepare Phase 3 librarians (n=8) to facilitate MPLS, the research team will provide a coaching session in Zoom, which will be followed by a librarian-to-librarian coaching session led by Phase 2 librarians. These sessions will be recorded and analyzed to develop training webinars for Phase 4. In addition, the MPLS curricula and resources, along with the AI chatbot, will be provided to them in advance for use. **(3) Replication.** The same research activities described in Phase 2 will be implemented. Replication in Phase 3 is designed to maximize adaptability, replicability, and scalability by continuously revising the MPLS program based on evaluations that are built-in to the project on a program-to-program, library-to-library, and year-to-year basis. Every phase of the project is designed to move toward replicability and scalability.

<u>Phase 4: Disseminate the research findings and the MPLS materials (Months 28-36; at minimum 10 libraries)</u>
(1) Finalization of MPLS. Findings from previous phases will be used to develop a research-informed, nationally scalable MPLS program and resources, which will then be evaluated by advisory board members. **(2) Development of training webinars.** To support other libraries to implement MPLS, we will develop a training webinar based on the analysis findings

from Phase 1-3. We will specifically attend to how Phase 2 librarians provided training to Phase 3 librarians and will seek input from AB members. Webinars will be made available on the project website and through ALSC's digital resources (see ***Supportingdoc3***). **(3) Study the impact of MPLS implementation.** We expect public library staff across US to access the MPLS program resources via our website and ALSC's digital resources. To understand the use and impact of MPLS, when public library staff freely access the MPLS program resources, we will distribute a call via our project website and ALSC website to recruit library staff who are committed to implementing at least four MPLS sessions. If they consent to participate, each library staff will complete the self-efficacy measurement survey (used in Phase 2 and 3), complete a program debrief template, and participate in one focus group interview. (3) **Dissemination.** A ready-to-use, open-source digital content for MPLS curriculum, stories, play-based math activities, at-home math resources, facilitation guides, and case studies of MPLS implementation will be publicly available (see more at ***Communication and Dissemination Plan***).

RESEARCH PLAN

We will collect multiple forms of qualitative and quantitative data simultaneously and triangulate them to answer our RQs. Table 1 illustrates data collection methods in each phase by participant type.

Phase	Participant	Zoom recordings	Artifacts	AI Logs	Pre-Post surveys	Focus groups	Algebraic questionnaire	Debriefs	Fieldnotes	Video recordings
Phase 1	Librarian	•	•	•		•				
	Researcher								•	
Phase 2	Local librarian (Intervention)			•	•	•				•
	Local librarian (Control)				•					
	Local caregiver (Intervention)		•	•	•	•				•
	Local children (Intervention)		•	•			•			•
	Local caregiver (Control)				•					
	Researcher									
Phase 3	Local librarian			•	•	•				•
	Local caregiver		•	•	•	•				•
	Local children		•	•			•			•
	Remote librarian				•	•		•		
	Remote caregiver				•	•				
	Researcher									
Phase 4	Librarian	•								
	Researcher	•								
	Remote librarian				•	•		•		

Table 1. Data sources in each phase by participant type.

Theory of change: Grounded in Social Cognitive Theory (SCT) [90], we posit that parents' and librarians' math self-efficacy will increase through GenAI coaching, storytime and home-based experiences, and/or AI–librarian collaboration during the co-design process, leading to more frequent and higher-quality algebraic reasoning talk that, in turn, supports children's algebraic reasoning development. This theory explains learning as a social, cognitive, and behavioral process that unfolds through dynamic interaction between the person, their behavior, and their environment, known as triadic reciprocal determinism [91]. Viewed through SCT, GenAI may function as a social, cognitive partner that models pedagogical approaches or questions to pose, as well as strengthen adults' math self-efficacy [92,93]; yet, where human relationships and supports remain central [94].

<u>RQ1:</u> What roles do GenAI tools (e.g., ChatGPT, Microsoft Copilot, Gemini) play in developing a culturally relevant MPLS program through the co-design process between researchers and public librarians?

Data sources: **(1) Online co-design meetings** will be video recorded in Zoom (approximately 18 hours). Each librarian will spend the last 5-10 minutes of each co-design meeting to write reflections about the role of GenAI tools based on prompts (e.g., How did the use of GenAI help or hinder you to develop MPLS program today? What features of the GenAI helped you the most?). **(2) GenAI log files** during the co-design meetings will be collected. **(3) Artifacts** (i.e., storytime plans, at-home activity designs) will be collected. **(4) Fieldnotes.** After each co-design meeting, two PIs in this study will make fieldnotes to note key discussions and ideas, and reflection on the use of GenAI tools during co-design. **(4) Focus group with the librarians.** After the completion of co-design, librarians will participate in a focus group to share their perspectives on the use of GenAI as a co-design partner, when and how they perceived the GenAI tool as helpful or not, and their initial expectations and goals for integrating GenAI tools in co-design, and how it may have changed. Preliminary analysis of co-design meeting memos and librarians' reflections will inform the design of the focus group protocol.

Data analysis: Co-design meetings will be transcribed and analyzed using qualitative thematic analysis and interaction analysis [95] to characterize the roles GenAI tools played in co-design, what challenges arose in incorporating AI-generated responses in the MPLS curriculum, and how librarians' perceived value of GenAI may have changed over time. GenAI log files will be analyzed in coordination with co-design meeting transcripts to examine how GenAI-mediated ideas are transformed into finalized pedagogical materials, linking GenAI prompts and outputs to ideas introduced, taken up, revised, or set aside during meetings. Artifact analysis will focus on changes in mathematical richness, forms of early algebraic reasoning, and pedagogical features over time.

Expected outcomes: We expect to develop an understanding of how librarians collaborate with GenAI in co-design and how they perceive the value of GenAI as a co-design partner in designing children's programming materials, including ways to leverage community funds of knowledge during the use of GenAI to develop MPLS. Based on this understanding, we expect to deliver a working co-design model, including design principles, for GenAI–librarian collaboration around early algebraic storytimes, extending the existing co-design and human–GenAI co-creation research into a new, underexplored setting [26,96,97].

<u>RQ2:</u> How does MPLS influence caregivers' and librarians' development of self-efficacy in math literacy, and what program components do they perceive as most impactful to this development?

RQ2 is addressed in two ways. First, we focus on understanding *if* MPLS influences caregivers' and librarians' development of self-efficacy in math literacy through an experimental study in Phase 2 (*we note that other Phases are not experimental studies*) via a direct comparison between an intervention group (i.e., MPLS) and the control group (i.e., a traditional storytime). Four libraries recruited in Phase 2 will offer MPLS programs and will act as the intervention group. Additionally, four other libraries in IN and NY that serve similar demographics will be recruited as the control group. For the control group, their regularly occurring storytimes will be attended by one researcher to receive participant consent and administer the data collection methods. The librarian at these libraries will note down which caregiver participated in which storytime session. If caregivers participated in more than four sessions out of 10, they will be asked to take the self-efficacy post-surveys. Next, we will use data sources gathered from local caregivers and local librarians in Phases 2-3 to examine *how* MPLS influences their development of self-efficacy in math literacy. The following data sources are collected.

Data sources: **(1) A pre-post survey to librarians and caregivers.** A pre-post survey, the Self-Efficacy Scale for Mathematics Literacy by Özgen and Bindak [98], consisting of 35 items with a reliability coefficient of 0.942, will be administered to caregivers and librarians. Open-ended questions will be added to the post-survey regarding how the program supported their self-efficacy, or not. On a weekly basis, the librarian will keep the attendance sheet to record who came to which sessions. The pre-post survey will be sent to caregivers who attended at least four sessions to examine shifts in their math self-efficacy**. (2) AI log files.** Phase 2-3 librarians and caregivers at local libraries will engage with the AI chabot. For caregivers, they will use it during the MPLS sessions, while librarians will use it as a preparatory resource for MPLS facilitation. AI log files used by both participant groups will be collected. **(3) Focus group with librarians and caregivers in Phases 2-3.** We will conduct a focus group with librarians and caregivers who attended at least four sessions via Zoom to understand to what extent the MPLS helped them develop self-efficacy in math literacy skills and what program components they found to be most helpful. (Out of 70 caregivers who we expect to participate in MPLS in Phase 3, we expect at least 15 caregivers to sign up for a focus group.) AI log files will be analyzed before the exit interview to identify instances where librarians and caregivers received specific prompts or feedback from the AI chatbot. Using these instances, we will develop a protocol to prompt participants to reflect on those moments of support from the chatbot.

Data analysis: Dependent-samples t-tests will be conducted based on pre-post survey results for librarians and caregivers. In addition, an independent-samples t-test will be conducted to compare post-assessment scores between the intervention group and a control group. To investigate how librarians developed self-efficacy in math literacy, we will qualitatively analyze their responses from the open-ended questions in the post-surveys and the exit interviews.

Expected outcomes: We expect to know how GenAI as a coaching tool serves as another way for caregivers to learn how to facilitate and discuss algebraic concepts, if at all, which will add to our current understanding of supports such as prompts in everyday settings [99], informational sessions [25], interactive apps [100], and side-by-side coaching [101].

<u>RQ3:</u> How does the quality and quantity of adult-child math talk supporting children's algebraic reasoning evolve?

Data sources: *RQ3 is addressed based on data from local libraries. Data collected at remote libraries will not be used.* **(1) Video data during MPLS.** Caregivers and children's interaction and librarian-children interactions during MPLS will be collected through stand-alone cameras focused on each consenting family. The research team will be on-site to record them. **(2) Video data during at-home math activities.** Caregivers will be asked to video record their interactions with their child(ren) during at-home math activities. Caregivers will receive a unique Zoom link from which their at-home interaction will be recorded automatically when they login to Zoom and will automatically upload to the researcher's secure cloud account. **(3) AI log files** during the coaching session and home activities will be collected.

Data analysis: Transcripts will be generated for each video. We will conduct interaction analysis of video records in conjunction with AI log files. Similar to others [102,103], we will quantify math language by computing both the total number of math-related utterances and their frequency per word. Rates of algebraic-reasoning language will then be compared with the rates of other mathematical concept categories, such as numerical language and shape-related language. Quality will be examined by coding the types of questions and conversational prompts posed, the level of cognitive demand, and the degree of conceptual depth reflected in the interaction specific to algebraic reasoning [103–105]. We will also analyze scaffolding strategies such as explanations, responsive feedback, and guided-play prompts specific to algebraic reasoning [106–108]. AI log files will be synchronized with video transcripts to trace how learners' spoken language and actions correspond to specific AI prompts, hints, feedback, and representations presented during the interaction. This alignment will allow us to examine (a) how participants take up, reinterpret, or ignore GenAI-generated suggestions; (b) how GenAI feedback shapes subsequent mathematical talk and reasoning; and (c) the temporal sequencing between GenAI system moves and shifts in learners' algebraic reasoning.

Expected outcomes: We expect to characterize what program components help make the shifts in quality and quantity of adult-child math talk that supports children's algebraic reasoning and demonstrate when and how caregivers and librarians are supported to engage in higher quality and quantity of math talk with children.

<u>RQ4:</u> How does MPLS support the development of children's algebraic reasoning?

Data sources: *RQ4 is addressed based on data collected at local libraries only.* **(1) Children's play-based algebraic reasoning questionnaire.** We will use prior research to develop a pre-post children's play-based algebraic reasoning questionnaire [e.g., 16–18]. We will both pilot the questions with young children and ask the advisory board members to provide feedback. Children who attended more than four sessions will be asked to complete the questionnaire. The caregiver will assist by reading aloud the survey questions and recording answers, making it feasible for young children to complete them.

Data analysis: Analysis will focus on correctness and strategies utilized, which will include drawing on established research to identify known strategies and developing new codes for additional strategies that emerge from children's responses [12]. We will compare results from pre-to-post. We will also conduct interaction analysis to examine caregiver-child discourse, strategies, and multimodal interaction, such as pointing and gesture [e.g., 109], over their participation in at least four MPLS sessions to look for evidence of the development of children's algebraic reasoning across the four algebraic concepts.

<u>RQ5:</u> How do public librarians in diverse settings adapt the MPLS curriculum, and what are their perceptions regarding the MPLS's influence on their own conceptual understanding and the subsequent algebraic engagement of participating families?

Data sources: *RQ5 is addressed based on data collected at remote libraries in Phase 4.* **(1) A pre-post survey with librarians** will be employed. **(2) Librarians' debrief template.** After implementing each MPLS session, the librarian will complete a debrief template to describe families' responses to the storytime, debrief about their own experience of providing MPLS, and share if they discovered any mathematical concepts relevant in everyday life as a result of preparing for the MPLS. Each librarian will complete 4-10 debrief templates (in total, 40-80 debriefs). **(3) Librarians' focus group** will be conducted in Zoom with 10 librarians who participated in Phase 4. Considering there are 10 librarians, we may need to provide two focus group date options. We will ask them to share their experiences regarding the ease of using MPLS resources, the program's overall impact, and suggestions for sharing the curriculum more broadly.

Data analysis: We will follow the same analysis plan outlined for RQ2.

Expected outcomes: By implementing the MPLS program with 70 families across 14 libraries, we will develop a scalable MPLS program and resources. We expect these resources to support other public library staff interested in mathematizing library storytimes to replicate MPLS across the nation.

Contingency Plan: We acknowledge that families may miss a session or leave the study in the middle. We aim to limit these issues by integrating MPLS at existing storytimes that already have regular attendance of minimum 10 families per session for a sustained period of time. To incentivize attendance, light refreshments will be provided at MPLS, and caregivers will receive an honorarium for completing each research activity (see ***Budgetjustification***). In the event that caregivers do not complete the post self-efficacy survey or the post children's play-based algebraic reasoning questionnaire, we will work closely with the librarian to provide reminders and support in completing them. We also understand that families at local libraries may not feel comfortable being video recorded. To accommodate everyone, we will provide separate areas for those who consent to be videotaped, ensuring that all families can still participate in MPLS.

Planning, Execution, and Management of Project
Project Personnel: This applied research project will be led by Dr. **Soo Hyeon Kim** (an expert in family STEM learning, public library makerspace, and participatory design) and Dr. **Amber Simpson** (an expert in mathematics learning, family STEM learning, and professional growth of informal educators). It builds on the successes of the project team's prior research—Family Makers (LG-252377-OLS), At-Home Family Engineering (NSF-1759314), and Failure in Making (NSF-2005927)—and will employ similar data collection and analysis procedures, such as conducting co-design with librarians, interaction and discourse analysis, and surveys. Building on previous research in co-design with rural librarians [110], culturally relevant engineering learning for children and caregivers [111–113], and GenAI for instructional design [114], Kim will lead the co-design, planning, and dissemination efforts, while overseeing and managing the project as the PI. Co-PI Simpson's research expertise is on mathematics learning, examining spontaneous and humanistic approaches to mathematics through other fields, such as archeology and engineering [115–117], Simpson will lead the development of measurement items based on her expertise in mixed-methods approach. Kim and Simpson will collaboratively manage the implementation of MPLS across libraries, and each will oversee the data collection of video records at local libraries in IN and NY. This project will fund one doctoral student at Indiana University Indianapolis and support multiple graduate and undergraduate students at Indiana University Indianapolis and Binghamton University. Two PIs and students will engage in bi-weekly Zoom meetings to make progress on the project (see ***Resumes***).

Senior Personnel with AI expertise: Dr. **Jiyeon Park**, an assistant professor at Binghamton University with expertise in GenAI chatbots, will serve as senior personnel, leveraging her extensive experience in developing and customizing GenAI chatbots for math education (e.g., math assistant chatbot developed by Dr. Park) (see ***Resumes*** and ***Supportingdoc6***).

Partner Libraries: A strong co-design team will be formed in Phase 1. Two public librarians in IN and NY have already shared their interest in being co-design partners (see ***Supportingdoc4–5***).

Advisory Board (AB): The team will convene an Advisory Board (AB) twice every year, comprised of a library storytime expert, an AI expert, a math education expert, an early literacy specialist, a co-design expert, and a researcher of public library storytime and math learning. The AB will evaluate MPLS program materials and also provide diverse perspectives and synergistic input on the development of project activities and data collection instruments, and evaluate the program design, data analysis, findings, and provide mid-course corrections. AB members will also assist with recruiting library sites and provide input on the overall recruitment process. They will also be individually reached out according to their expertise. **(1)** ***Alissa Lange****, PhD*, an associate professor in early childhood education at East Tennessee State University, director of the EC STEM Lab, and PI of IMLS-funded Libraries Count project, will support our project team to build on the cutting-edge research from Libraries Count project and extend the best practices in the field to develop MPLS curriculum that focuses on children's algebraic reasoning. **(2)** ***Beck Trench***, a senior researcher at the Center for Digital Thriving at Harvard University, is currently leading the IMAGINE AI portfolio project that provides frameworks and co-designed tools to establish human-centered digital agency with AI. She will inform the effective use of GenAI tools during the co-design process and provide evaluation on the AI chatbot. **(3)** ***Kary Henry****,* the School Outreach Coordinator at Deerfield Public Library with passion and extensive experience of integrating mathematics into storytimes for preschool-aged children and their caregivers. Her previous experience of developing in-services for early childhood educators and collaborating with ALSC will provide advice for developing the webinars and support dissemination. **(4)** ***Jason Yip****, PhD*, an associate professor at the University of Washington with expertise in co-design and participatory design, will advise on the co-design structure, approach, and process. Dr. Yip has extensive experience in community-based research and design and will contribute to the evaluation of the community-based research program design. **(5)** ***Rebecca Borowski****, PhD*, an associate professor at Western Washington University, is a mathematics teacher educator and researcher and a former kindergarten and first-grade classroom teacher. Dr. Borowski will advise on effectively integrating mathematics learning for young children and share best practices for supporting caregivers and adult educators as supporters of children's math engagement. **(6)** ***Tracy Lyman***, a Pyramid Model Policy coordinator at NYS Council on Children and Families, has extensive experience in implementing statewide initiatives in early childhood education. Ms. Tracey will advise on integrating developmentally appropriate early literacy and math learning into storytimes and share best practices for supporting the dissemination of MPLS to a wide audience (see ***Supportingdoc7–12***).

ALSC: ALSC will support the recruitment of librarians for the co-design team and dissemination of the project outcomes and webinars via ALSC's digital resources and create space for a preconference workshop (see ***Supportingdoc3***).

Evaluation Plan: The AB members will examine the projects' process, timeline, and outcomes. They will also provide formative evaluation on each phase and the final MPLS program resources prior to the implementation. AB members and the research team will conduct performance measures evaluation per year to assess the effectiveness, efficiency, quality, and timeliness of the project (see ***Perfmeasurement***). The project website and ALSC website/blog will collect analytics about site visits and usage as another means of evaluating impact.

PROJECT RESULTS

Implementation of MPLS to support a minimum of 110 families across 22 libraries will contribute to and directly address the need to develop an evidence-based, math-integrated storytime that supports children's early algebraic reasoning and strengthens the role of caregivers and librarians as educators of children's learning in the area of math engagement. Expected project outcomes are: (1) development of children's early algebraic reasoning skills and adults' self-efficacy in math literacy skills through engaging in algebraic reasoning talk at MPLS; (2) a nationally scalable Gen-AI integrated MPLS program and resources (e.g., stories, play-based math activities, at-home math resources, facilitation guide, webinar, project website), which includes an AI chatbot designed to help caregivers and librarians navigate algebraic misconceptions and learn scaffolding strategies they can use for children; and (3) a working co-design model, including design principles, for GenAI–librarian collaboration around early algebraic storytimes.

The intellectual merit from the Mathematizing Public Library Storytimes (MPLS) project—involving public library staff to co-design and provide input in every phase of the project—will include a novel understanding of effective mechanisms for mathematizing storytime programs for young children and caregivers and its impact on increasing children's algebraic reasoning and enhancing adults' self-efficacy in math literacy skills. The proposed project is unique in integrating algebraic reasoning into library storytime through using GenAI tools as a co-design partner with librarians and leveraging an AI chatbot to provide coaching and facilitation support for adults. This project also empowers librarians and caregivers as mathematics educators through their engagement within MPLS in collaboration with young children. Additionally, this project attends to a prevalent need within mathematics education, preparing children with the algebraic reasoning for future mathematical success. Moreover, this project considers the possibility for utilizing GenAI as a personalized learning tool within immersive, in situ educational environments.

Communication and Dissemination Plan: To ensure project deliverables are readily adaptable, generalizable, and usable, we take multiple approaches in communication and dissemination. Our communication and dissemination will be ongoing and throughout all phases to reach practitioner and scholarly communities at the local, state, and national levels. The project website will share project progress and findings, which will be shared also via ALSC website/blog. We will present findings in practitioner-oriented journals (e.g., Public Libraries Magazine) and local/ state librarian e-newsletters. We will also communicate research findings through conferences, educational research, and library professional journals (e.g., *Information and Learning Sciences, Public Library Quarterly, Library and Information Science Research, Journal for Research in Mathematics Education*). In addition to sharing the research findings and case studies at academic conferences (e.g., ASIST, ALISE, AERA, ICLS), we will provide a pre-conference workshop at either ALA or ALSC National Institute event (see ***Supportingdoc3***). Finally, we will encourage librarians from our research to co-present findings at practitioner-focused conferences (we have included a budget to support this: see ***Budgetjustification***).

Sustainability Plan: MPLS program resources, case studies, and the evaluation report will be published on our website, where they will continue to be available for free, shared under a Creative Commons non-commercial license. Additionally, ALSC and the Advisory Board will support strengthening the dissemination by providing feedback on developing a training webinar for children's services library staff. The online webinars and dissemination efforts across multiple avenues will help increase public library staff's awareness of the MPLS and support them to implement them at their libraries.

Schedule of Completion: Year 1

Phase	Activities	Year 1												
		2026					2027							
		J/A	S	O	N	D	J	F	M	A	M	J	J	A
1. Co-design	*IRB application (before grant begins) and approval	■												
	*Hire student researchers	■												
	A national call distributed through ALSC listserv		■											
	Recruitment of 6 librarians for co-design team		■	■										
	Prepare co-design meetings/ receive AB feedback		■	■	■									
	Co-design meetings (bi-weekly for six months)				■	■	■	■	■	■				
	Data collection: Co-design meetings (i.e., AI logs, recorded meetings) (Aim 1)				■	■	■	■	■	■				
	Data collection: Focus group and artifact collection from librarians (Aim 1)									■	■			
	Customization of AI chatbots							■	■	■				
	Evaluation of 10 MPLS curriculum & 4 home activities									■				
	Full advisory board virtual meeting			■						■				
	Co-revise 10 MPLS curriculum & 4 home activities based on feedback									■	■	■		
2. Implement the MPLS program (four local libraries)	Recruitment of two additional local libraries										■	■		
	Caregiver and child recruitment												■	■
Ongoing	Analysis							■	■	■	■	■	■	■
	Dissemination (including website development)							■	■	■	■	■	■	■

*Please note that we plan to submit the IRB application two months before the project start date. The hiring of student researchers will be one month prior to the project start date.

Schedule of Completion: Year 2

Phase	Activities	Year 2											
		2027				2028							
		S	O	N	D	J	F	M	A	M	J	J	A
2. Implement the MPLS program (four local libraries)	MPLS implementation (10 weekly sessions)	■	■	■	■	■							
	Data collection: Caregiver and Librarian self-efficacy survey (pre-post) (Aim 2)	■	■			■	■						
	Data collection: Caregiver and Librarian exit focus group interview (Aim 2)						■						
	Data collection: AI logs (Aim 3)	■	■	■	■	■	■						
	Data collection: Video data of adult-child interactions (Aim 3)	■	■	■	■	■	■						
	Data collection: Children's play-based algebraic reasoning questionnaire (pre-post) (Aim 4)	■	■			■	■						
	Full advisory board virtual meeting		■					■					
3. Scale up the MPLS program (two local and six remote libraries)	Recruitment of libraries					■	■	■					
	Preparation of implementation								■				
	Refine AI chatbots based on data collection from Phase 2						■	■	■				
	MPLS implementation (10 weekly sessions)									■	■	■	■
	Data collection: Caregiver (Control & Intervention) and Librarian self-efficacy survey (pre-post) (Aim 2)									■	■		
	Data collection: Caregiver and Librarian exit focus group interview (Aim 2)									■	■		
	Data collection: AI logs (Aim 3)									■	■	■	■
	Data collection: Video data of adult-child interactions (Aim 3)									■	■	■	■
	Data collection: Children's play-based algebraic reasoning questionnaire (pre-post) (Aim 4)									■	■		
Ongoing	Analysis	■	■	■	■	■	■	■	■	■	■	■	■
	Dissemination (including website development)						■	■	■	■	■	■	■

Schedule of Completion: Year 3

Phase	Activities	Year 3											
		2028					2029						
		A	S	O	N	D	J	F	M	A	M	J	J
3. Scale up the MPLS program (two local and six remote libraries)	MPLS implementation (10 weekly sessions)	■	■	■									
	Data collection: Caregiver (Control and Intervention) and Librarian self-efficacy survey (pre-post) (Aim 2)		■	■									
	Data collection: Caregiver and Librarian exit focus group interview (Aim 2)		■	■									
	Data collection: AI logs (Aim 3)	■	■	■									
	Data collection: Video data of adult-child interactions (Aim 3)	■	■	■									
	Data collection: Children's play-based algebraic reasoning questionnaire (pre-post) (Aim 4)		■	■									
	Full advisory board virtual meeting				■								
4. Disseminate (10 remote libraries)	Recruitment of a minimum of 10 libraries				■								
	MPLS implementation of at least 4 MPLS sessions					■	■	■					
	Data collection: Caregiver and Librarian self-efficacy survey (pre-post) (Aim 5)					■		■					
	Data collection: Librarians exit focus group interview (Aim 5)							■					
	Evaluation and finalization of MPLS								■	■			
	Development of training webinars							■	■	■			
	Distribute MPLS program resources and training webinars									■	■	■	■
	Full advisory board virtual meeting									■			
Ongoing	Analysis	■	■	■	■	■	■	■	■	■	■	■	■
	Dissemination	■	■	■	■	■	■	■	■	■	■	■	■