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Article

Building Learning Trajectories for Intentional, Inclusive, and Individualized Instructional Experiences in STEM

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Abstract: Early science, technology, engineering, and math (STEM) learning experiences often exclude children with disabilities and intersecting identities. To promote learning in STEM for all children, the Curriculum Research Framework (CRF) was applied to build learning trajectories of STEM for children from birth to age 5. The CRF was extended and enhanced to generate explicitly inclusive learning trajectories for children with and without disabilities. The process of generating a priori foundations, building learning trajectories, and testing the results in inclusive settings led to new resources for early childhood education (ECE) and early childhood special education (ECSE) practitioners and generated implications for creating and evaluating learning trajectories in ways that affirm that all children belong in STEM. Challenges faced and lessons learned in this process are presented to guide future research and development using the revised and enhanced CRF.

Keywords: STEM education; curriculum research; equity; inclusion; early childhood education; early childhood special education

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1. Introduction

Children with disabilities (CWD) and intersecting identities are frequently left out of STEM practices due to low expectations and ableism [1,2]. Ableism is "a system of assigning value to people's bodies and minds based on societally constructed ideas of normalcy, productivity, desirability, intelligence, excellence, and fitness" [3]. In this paper, we describe the revision and application of a framework for creating research-based curricular material enhanced with high-quality inclusive strategies in the STEM domains for children birth to age 5 years. At the core of the framework are research-based learning trajectories, paths of learning, and teaching based on children's natural ways of thinking. The project supporting this work is complex and extensive; this article provides only an overview of our processes and citations for printed and online resources the project has produced. We hope the enhanced framework and our processes will engender discussions and support similar work.

1.1. Making Inclusive Practices Explicit in Learning Trajectories of STEM

A learning trajectory (LT) is an asset-based construct that integrates three components: (1) educational goals, (2) a developmental progression of levels of thinking through which most children advance, and (3) teaching activities and strategies connected to each level. To attain a certain competence in a given topic or domain (the goal), students learn each successive level (the developmental progression), aided by tasks (educational activities) designed to build the mental actions-on-objects that enable thinking at each higher level.

The LT approach stands out as consistently empirically validated and developmentally appropriate. Before describing this approach, we present three principles of high-quality STEM education.

1. Content that focuses on big ideas of STEM that are central and coherent.
2. Focusing on children's natural ways of thinking and learning is the core of planning and implementing educational experiences.
3. Teaching practices are inclusive of and honor STEM disciplines and the children's cultures, families, individual characteristics, and patterns of thinking and learning.

The learning trajectories (LT) approach combines these principles [4–7]. To attain a specific competence in a given topic or domain (the goal), students learn each successive level (the developmental progression), aided by experiences (educational activities) designed to build the mental actions-on-objects that enable thinking at each higher level. Consistent with high-quality STEM education, the first component, the LT's goal, goes beyond behavioral objectives to include clusters of concepts, skills, practices, and affect. Consistent with high-quality ECE, the approach puts the second component, children's development, at the core, describing levels of this natural development. The third component of learning trajectories, educational activities, includes a broad definition of teaching practices—educational environments, interactions, and activities—matched to each level in a progression to help children develop ever-higher levels of thinking. Because inclusion and learning trajectories are built on the idea that all effective teaching is individualized to the child, the learning goal is the same for all children.

To make inclusive practices more explicit in the learning trajectories approach, the developmental progression guides the educational content while access to the learning content is addressed with universal design and individualization as needed. Universal design is a concept that architects and product designers originally used to ensure that the environment and products could be used to the broadest extent by people of all ages and abilities [8]. By providing multiple means of engagement, representation, and expression within learning environments [9], UDL principles and practices can ensure that children's access to the learning environment, materials, and instructional strategies is maximized. Additionally, two types of adjustments support individualization—(1) adaptations that target accessibility for children with specific needs and (2) adjustments to instruction that scaffold learning along a developmental progression. UDL practices complement these more individualized adaptations that some children need to fully participate in STEM learning.

1.2. The Curriculum Research Framework

The Curriculum Research Framework (CRF) [10–15] is an empirically validated framework successfully used in many research and development projects. The CRF includes ten phases structured in three categories: (1) building a research foundation (a priori), (2) building learning trajectories based on children's thinking and learning, and (3) evaluating these formatively and eventually summatively. Importantly, each phase in the last two categories must yield positive results for all children, including CWD, before proceeding to the next. Therefore, this process can address limitations, iteratively re-evaluating and refining the curriculum. This approach has higher validity than others because evaluations are more frequent and trustworthy. Suppose research on children's thinking and learning in the goal domain is not carefully reviewed or conducted. In that case, it is considerably less likely that later phases of development (curricula, professional development, implementation, etc.) will be successful. The process of implementation and implications of the inclusive enhancements for each phase are described.

1.3. Past Practices and Aspirations for the Future

As discussed by Grisham-Brown and Hemmeter [16], the blended practice draws from two traditions—integrating early childhood education (ECE), which often focuses on the quality of environments, and early childhood special education (ECSE), which often focuses on individualized intervention and multi-tiered systems of support. This separation is evident in the research dissemination of STEM, with 76% of research articles about math teaching and learning that included children with disabilities published in special education or psychology journals [17]. This segregation of STEM teaching and learning strategies between those that are deemed "for" children with disabilities and those "for" children without disabilities weakens the effectiveness of education research [17]. This separation is harmful as it perpetuates the notion of who STEM is for. It is also important to note that the research base in our field is primarily based on the experiences of White, middle-class children and families. In ECE, general education, and educational research and practice in STEM, the need to integrate ECE and ECSE research and practices is unambiguous, as is the need to affirm every child's social, cultural, and historical experiences. The most recent edition of the Developmentally Appropriate Practice [18] calls for a shift toward more equitable and inclusive practices. The position statement challenges all practitioners to consider commonalities in child development and learning and individual children's intersecting identities, including disability, interests, strengths, and the social, cultural, and historical contexts of their development when designing teaching and learning environments and instruction. Using intentional STEM teaching and inclusion practices can remove systemic barriers that exclude children with disabilities from high-quality STEM teaching and learning experiences.

The STEMIE project described herein seeks to dismantle the systems that exclude children from STEM by integrating explicitly inclusive practices into the creation and refinement of new learning trajectories for STEM. We now turn to the methods we used to do so.

2. Methods

To fully realize the goals of making STEM accessible and inclusive for CWD and other marginalized populations, this multi-year study sought to use multiple methods and sources of information to generate and test learning trajectories of STEM in inclusive settings. The CRF was chosen as a framework due to its iterative nature that allows for efficient and systematic updates to knowledge gained through ongoing research. The CRF was refined and expanded to build knowledge and test practices within diverse settings and thus provide practical resources while contributing to the scant existing literature. The following section describes 7 of the 10 phases implemented thus far, developing and testing learning trajectories through small-scale qualitative research. Participants and settings are described within their relevant phase. Phases 8–10 are discussed in future research, in which the approach and resources will be scaled up, and effectiveness will be tested.

2.1. Phases 1–3: A Priori Foundations

The first three phases of the CRF can be conducted simultaneously or in any order. They entail establishing procedures for reviews and content analyses. Phase 1 identifies developmentally appropriate concepts, generative of present and future learning, and interesting to children in the target population. Phase 2 reviews theories and empirical research on students' thinking and learning to establish the general theoretical and philosophical approach to the curriculum. Phase 3 reviews empirical work on specific pedagogical issues, including the effectiveness of particular teaching strategies and activities. This process follows a research-to-practice model by translating research findings to observable learning of children and actionable strategies for practitioners. In anticipation of developing the learning trajectories, the extant research is reviewed for implications to goals or broad topics of content, a developmental progression based on research implications about children's thinking, and instructional strategies that research suggests are effective.

The review process differs from traditional reviews in several ways. The outcome may not be a highly structured, coded compilation of research (although, of course, that could be conducted simultaneously if resources allowed), but rather a nascent understanding of children's thinking and learning in a particular topic, culled and qualitatively synthesized from resources with disparate theoretical and empirical characteristics. A list of journals consulted is provided in the online supplement. Up to eight staff members were involved in various reviews, gathering information on how children from birth to age 5 years thought or learned about a topic or phenomenon at hand. This information was synthesized to be a starting point for the learning trajectory's developmental progression, but other empirical methodologies were more impactful in creating, refining, and evaluating that progression. Reviews were also identified if they used an instructional activity that was empirically evaluated as successful for a given level of a learning trajectory; these were considered in designing the instructional component.

Process

The literature in early childhood STEM is somewhat scant, except for early math, for which learning trajectories were well developed [4], and the STEMIE goal was to make them more inclusive. STEMIE conducted a literature review of 516 references. Of these references, 33.3% focused on lesson plans, 30% on classroom environments or resources, and 27.3% on evidence-based practices [19]. However, very few articles focused on evidence of children's development and learning in science, technology, and engineering, and there were no articles addressing specific learning trajectories or topics. The STEM and CWD research base is also small, with very few articles incorporating STEM and CWD (5.8%) and few that included children who were non-White [19]. Thus, the initial developmental progressions (iteration 1) for this project were hypothesized in part based on an understanding of young children's development in broader areas, such as cognition and executive function, as well as through input from experts in early science, technology, and engineering. Multiple sources contributed to the revision of the first iteration, including a review of early learning guidelines and additional rounds of input from advisors such as educational researchers, teacher educators, early childhood practitioners, and experts in each subject domain. The Delphi method was used to solicit input from 15 advisors that included inclusion and STEM experts, staff of children's museums, technical assistance centers, and early childhood education organizations. Through the process, input from participants converged at agreement on a nascent but usable set of developmental progressions across science, technology, and engineering content, as well as cross-cutting knowledge and child-level processes. This led to updates (iteration 2) of the developmental progressions used in phase 4.

2.2. Phase 4: Building the Learning Trajectories

The fourth phase of the CRF builds the learning trajectories around the hypothesized learning progression to develop a full learning trajectory that includes a goal, the developmental progression, and instruction. Activities are structured in accordance with models of students' thinking and learning in targeted domains. Children's thinking is posited to have specific characteristics that can be identified through observation and organized into levels. These levels are also posited to be malleable to specific instructional approaches and activities.

Process

Building the learning trajectories (phase 4) and testing them (phases 5–7) are iterative phases. Because the creation of content often generated conversations about the progressions themselves, the content of the curricula then adapted to the evolving definitions of the progressions. Likewise, and as intended, testing the content with small groups of children (phase 6) led to changes in the hypothesized developmental progression, which in turn led to revisions in content. These alternating and iterative processes are described in two phases, primarily for clarity and reproducibility.

Content creation of STEM investigations took several forms as the research team experimented with templates of various lengths and with various components. All the investigations included adaptations to ensure accessibility to and children's participation in the activity, a task intended to prompt children's thinking at a given level, and suggestions for extending the opportunities for children's learning. Adaptations to the investigations followed the framework of considering the environment, materials, and instruction [20,21]. Most investigations included an introduction to a scenario or critical questions, resource lists for additional learning, extensions of the main activity, scripts for practitioners to follow, and formative assessment. Formative assessment included observing a child's response followed by a counter-response from the practitioner that built more foundational knowledge or challenged children beyond the intended levels.

More extended activities with all the components were developed at the beginning of the phase in consultation with STEM subject matter experts. Team members then reviewed these with expertise in ECE or inclusion. Shorter activities were also developed for more rapid testing and revision cycles. Elicitation activities and simple observation of children's natural learning were also part of content development—as observation of what children were interested in and doing revealed examples and non-examples of specific levels of thinking or inspired structures for extending and enriching children's natural play. Across all types of content development, the goal was to align inclusive and developmentally appropriate instruction to the hypothesized learning progression.

2.3. Phase 5–7: Testing the Learning Trajectories

Phase 5 pursues an understanding of what works for ECE and ECSE practitioners (and, traditionally, expectations of "the market"). Traditional market research is commercially oriented research conducted to understand what customers want and will buy. The CRF does not ignore these expectations but keeps them documented for public use as part of the research, contrary to the usual commercial procedures. This phase is collaborative rather than targeting consumers for marketing purposes. The goal is to support later uptake. Methods can include focus groups, surveys, or interviews.

Phase 6 evaluates the usability and effectiveness of the LT by implementing instructional activities with one child or a small group of children. Methods can include a mix of model testing and model generation strategies, including teaching experiments, clinical interviews, and participant observation. Phase 7 expands the work to larger groups of children and asks highly motivated adults to implement the instruction. Methods include classroom-based teaching experiments and ethnographic participant observation. The LT is altered based on empirical results, with a focus on the usability of the curricula and satisfaction for teachers, including sensitivity to cultures, disabilities, and professional support [22]. These phases emphasize iterative refinement of all aspects of the LTs. The methods aim to test (a) what students can do, (b) what they are not yet able to do but should be able to learn, and (c) why—that is, how they think at each level and how they learned these levels of thinking.

2.3.1. Setting and Participants

After creating hypothetical learning trajectories, testing began in inclusive early childhood classrooms in North Carolina and Colorado and home-visiting settings in Pennsylvania called "incubator" sites. The center-based settings included 19 classrooms across 13 centers. The home-based settings included 10 practitioners working with 1–3 families each. Eligibility criteria for center-based settings included having children with diagnosed disabilities enrolled and receiving services. Home-based practitioners were eligible if they were providing services specific to meeting the needs of children with IEPs or IFSPs. Additionally, the project sought practitioners with a high level of enthusiasm for the project for this early phase of pilot testing.

2.3.2. Process

In phase 5, we used survey methods to ask practitioners about the perceived usability of the learning trajectory components, emphasizing their view of the instructional activities' feasibility in these inclusive settings. In phases 6 and 7, the learning trajectories' investigations were used primarily by research staff in center-based incubator sites and, to some extent, by ECE and ECSE practitioners in center-based and home-visiting incubator sites. Children with and without disabilities engaged in activities designed to elicit responses at specific developmental progression levels.

Because instructional activities were developed for each learning trajectory, both instructional activities and the progression steps were evaluated through their implementation. Field notes and data collection forms documented children's observable actions that indicated evidence or non-evidence of a level of thinking. Because most interactions with children were video recorded, a group of 2–3 researchers viewed the same videos and then compared observed examples of evidence or non-evidence of a child's level of thinking. Consensus conversation generated more reliably interpretable definitions of the progression steps.

Analysis of video review data allowed researchers to examine whether the progression steps proceeded in the hypothesized order, whether steps not originally in the hypothesized progression should be added, and whether hypothesized steps should be removed. A step was added when the observation of children's responses indicated a level of thinking not previously articulated in the developmental progression. When no examples or only counterexamples of a level of thinking were observed, a step was removed or re-ordered. The analysis also indicated when more parsimonious levels could be created from progression steps initially thought to represent separate levels of thinking. Video documentation also provided rich examples for later use in training early childhood professionals to implement inclusive STEM teaching strategies.

Adaptations that worked well or needed to be added and teaching strategies that seemed particularly effective or ineffective were documented in field notes and through video review. Adaptations included communication supports, preparation of the environment, and preparation of materials. Communication supports included using augmentative and adaptive communication (AAC) devices, sign language, and visual response cards. Adaptations to the environment included creating a visual workspace and seating space, propping visuals for easier viewing, and adjusting block-building areas for easier reach. Material adaptations to provide physical support included interlocking blocks rather than smooth-sided blocks, adding Velcro to materials to support manipulation of instructional materials, and adding grasping supports.

3. Results for the CRF Categories and Phases

3.1. Phases 1–3 Challenges and Lessons Learned: A Priori Foundations

Although the learning trajectories approach has always emphasized a developmental focus that begins with children's assets, previous research and development did not explicitly center on children with disabilities and inclusion. To disrupt this previous paradigm, the research team's experts in inclusion ensured that literature, early learning guidelines, and practice-based suggestions were reviewed with an anti-ableist lens. For example, one state-level early learning guideline suggested that children should learn to use a joystick. Although this skill may help some children navigate technology, a joystick or computer mouse is not accessible for all children who may be more able to navigate technology using keyboard shortcuts or assistive technology. A priori foundations were, therefore, more inclusive because of the anti-ableist lens researchers brought to the CRF.

The blending of ECE and ECSE also required the addition of new frameworks within the overall CRF. These included a universal design for learning and considerations for adapting to children's specific needs. A framework considering environment, materials, and instruction [20] organized plans for the next phase in the project–developing the learning trajectories. The CRF was therefore enhanced by seeking out research and practitioner articles that included children with disabilities, as well as including experts on the inclusion of children with disabilities in the development of the first iterations of the hypothesized developmental progressions.

3.2. Phase 4 Challenges and Lessons Learned: Building the Learning Trajectories

The developmental progressions were clarified and elaborated upon as part of the creative process—documented within protocols developed for this purpose and involving multiple perspectives. The development and critique of these investigations generated important questions, proposed changes, new elicitation strategies, and learning activity ideas. When generating new activity ideas, inclusion experts would challenge the team to consider how it would be done for a child who was non-speaking or had visual impairments. Similarly, it was often the ECE experts who would bring perspectives on the feasibility of conducting a certain activity within a group setting or with typical classroom materials. When descriptions of developmental progressions were difficult to translate into instructional activities, the group was challenged to reduce the academic tone. These perspectives were brought about in both group meetings and through documents developed for this purpose. Thus, an important extension of the CRF is the importance of including and facilitating the inclusion of multiple viewpoints to iterate the learning trajectories.

A challenge in this phase was the matter of how many adaptations to include in each activity. Many inclusive practices across the environment, materials, and instruction fell into one of two categories—(1) adaptations that made the STEM content more accessible for children with disabilities to participate fully and (2) teaching strategies that represented good teaching practices for all children. Additionally, many adaptation considerations about ensuring access, such as positioning children so they could reach materials, were repeated across all activities. The inclusion specialists then recommended the creation of a general guide to adaptations that could be linked across the activities rather than written into each one. Content revisions only included adaptations that were specific to the activity and had been successfully tested in incubators. This challenge led the research team to consider needed supplements to the instructional activities—enhancing this component with resources for common adaptations and incorporating universally beneficial teaching strategies into the activities themselves.

Another challenge of content development was whether and how to incorporate Individual Education Program (IEP) goals and Individual Family Service Plan (IFSP) goals in addition to the STEM learning goals. Research has documented that teachers rarely incorporate individual IEP goals into plans for teaching science [23]. This was also reflected in observations of ECE and ECSE practitioners. The research team intended to support practitioners in aligning STEM learning goals with IEP and IFSP outcomes and goals. To this aim, the team developed resources through discussion with a community of practice composed of ECSE practitioners. These resources provided a strategy for practitioners to make decisions about their practice and adaptations when working with families to incorporate STEM learning. They challenged practitioners to use the three core considerations of DAP by considering commonality in development (i.e., the goals and developmental progressions within the LTs), the individuality of the child (i.e., IFSP goals, interests, strengths, and level of thinking), and the contexts where learning and development are taking place for the child (i.e., family priorities, routines and activities, and materials available at home). This extended the CRF beyond the classroom and into settings and activities that are a regular part of young children's learning environments.

This phase generated expansions to the CRF, such as protocols for collecting multiple perspectives about inclusion at each level of a developmental progression, systems for incorporating both general and specific adaptations, and resources for practitioners to consider (a) learning trajectories of STEM, (b) IEP and IFSP goals, and (c) contexts of learning and development in planning. These protocols and resources explicitly built inclusion into learning trajectories.

3.3. Phase 5–7 Challenges and Lessons Learned: Testing the Learning Trajectories

The intention of phases 5 through 7 was to involve ECE and ECSE practitioners, families, and children in testing the learning trajectories' components. The COVID-19 pandemic, however, created delayed access to the center-based and EI programs and ECE workforce shortages. Although we were able to work with practitioners who served as reviewers to determine the social validity of the prototype activities and work with EI practitioners who coached families to try out activities within the EI incubators, researchers participated in most of the instruction within the center-based incubator sites, leading many of the instructional activities developed for the learning trajectories.

Efforts to enhance CRF phases 5 through 7 with inclusive practices generated several insights important for the future development of inclusive learning trajectories. First, testing the learning trajectories in inclusive settings with practitioners invested in inclusion provided many opportunities to use and observe inclusive practices that complemented the intended STEM learning. Second, inclusive settings provided opportunities for practitioners to share their thoughts about STEM and reflect on their practice with us. These bidirectional benefits are an important contribution to the existing CRF.

Testing in inclusive settings provided unique opportunities to try STEM investigations in an environment where inclusion was already valued and incorporated into daily practices. An example of this occurred when a researcher entered a classroom where the researcher had been testing investigations for several months. These investigations often began with "I have a problem".—that is, "I have a problem. I am trying to see if this ball can knock down this block". Or "I have a problem. I am trying to figure out how to make a shadow. Can you help me?" A child used his communication board to communicate the word "problem" and pointed to the researcher. The classroom practitioner asked, "Does she have a problem?" The child pressed "Yes". The practitioner asked, "Would you like to help her with her problem?" and the child pressed "Yes" again. This example of a child with a disability not only engaging in, but initiating inquiry is one example of the potential for inclusive practices to create belonging in STEM.

Testing learning trajectories in inclusive settings also provides examples of the overlap of ECE and ECE practices. Wait time, or naturalistic time delay [24], is recommended in ECSE settings to encourage communication skills. Wait time is also a common ECE practice to allow young children time to process information. It served both purposes in the context of testing learning trajectories. One activity asked children to find the error in a debugging activity to develop computational thinking skills. Providing wait time after asking, "Did Ms. Mix-Up make a mistake?" gave children opportunities to show their understanding in a variety of ways, including with spoken language, sign language, or AAC devices. Most young children need wait time to process questions or prompts from adults. This can be particularly true with new or complex STEM concepts.

To further enhance instructional activities with inclusive adaptations, video review protocols were developed for researchers to report observations of effective adaptations and recommend refinements or additional adaptations. Researchers viewed video recordings of the use of both universal supports and targeted adaptations, then documented which strategies seemed effective and noted additional strategies to incorporate into final content revisions.

In communities of practices (COP), shared review of the video provided opportunities for researchers and practitioners to reflect on practice. In one COP meeting, the group discussed a practitioner's efforts to support an infant with cerebral visual impairment (CVI) to learn about force and motion. The practitioner and family worked together to engage the child in noticing the motion of a rolling ball by considering a color she could attend to and providing her with adaptations that included additional sensory experiences (i.e., auditory and tactile) to notice and recognize. The research team also worked with the practitioner to ensure better positioning so the child could have an even more optimal learning experience. These examples illustrate the power of synthesizing the learning trajectories approach with explicitly inclusive practices.

4. Discussion

These lessons and challenges highlight ways in which the CRF was applied in new ways to further the development of inclusive STEM learning trajectories for children ages birth to 5. These enhancements can be replicated in other work by including multiple voices. In this work, the gathering of anti-ableist perspectives facilitated the identification of exclusionary standards, practices, and research. Without this identification, the project would be more at risk of incorporating language or practices that failed to provide access to learning opportunities. Incorporating new frameworks, such as intentional considerations of the inclusiveness of environment, materials, and instructional practices, further removed this risk. Thus, a priori foundations of the development of learning trajectories are stronger when embracing and protecting perspectives that have previously been segregated or excluded from educational research.

Another key takeaway is the bidirectional benefits of conducting educational research in inclusive settings. This project benefited from the incubator sites by observing what teachers were already doing to meet the needs of their students. These observations inspired the incorporation of high-quality ECE and high-quality ECSE. They additionally shared reflections with practitioners and provided insight into ways to create practical resources that would enhance their work while minimizing the additional effort.

A somewhat unexpected result of the project was the variety of resources and tools created. The partnership and collaboration within the research team and across the research participants resulted in resources for common adaptations, adaptations that were specific to an instructional activity, printable materials, digital materials, training materials, planning resources, and family resources. New research tools were generated to collect questions, new ideas, proposed changes, and additions to the hypothesized learning trajectories. Forms created for viewing and documenting observations of videos became relevant tools for the rapid iteration of developmental progressions and instructional activities. Thus, while the CRF outlines clear and seemingly linear processes and phases, each step in the process requires enhancements to improve the usability of products for specific contexts.

STEMIE has focused on building new STEM learning trajectories that eschew ableist language and content, allowing children to demonstrate their learning and understanding in multiple ways. These efforts have yielded progressions for seven topics within science (weather, living things, force and motion, light and shadow, sounds, states of matter, and structure and properties of materials), three topics within technology (repetition and looping, sequencing, and debugging), and three topics within engineering (investigation, design, and evaluation). These topics or goals each have a set of inclusive instructional activities aligned to the progression, generating complete learning trajectories to support ECE and ECSE practitioners to provide intentional and inclusive instructional STEM experiences to young children. In mathematics, multiple resources and modifications were made to the existing learning trajectories to ensure they were inclusive for CWD (see https://www.learningtrajectories.org/); a contribution to the field is the recognition of the necessity of including an anti-ableist lens, experts in inclusive education, and adaptations throughout the creation of learning trajectories in any field.

UDL undergirds all the activities and experiences within the learning trajectories, providing educators with ways to include children. On top of this, incubator testing has yielded promising modifications and adaptations to the environment, materials, and instructional practices that allow any child to participate in the provided learning experiences. Although some are useful across many activities, others are tailored for specific activities, giving educators the confidence to implement them. All of these are blended seamlessly into a single framework, focused on the individual child and their needs and interests, integrating the best of ECE and ECSE into a cohesive pedagogy across the STEM domains. This was embedded in the learning trajectories but, to avoid overwhelming activities with adaptations, complemented with a general guide to adaptations that could be linked across the activities.

Creation of the learning trajectories required considerable ground-breaking work in the domains of science, technology, and engineering (STE), applying the CRF's phases over the last five years. The scant extant literature required a heavier reliance than used in previous projects on interviews with experts and practitioners and rapid cycle testing.

Including cross-cutting concepts and child-level processes that support learning in those domains was also a new demand in the work. These challenges ensured that the resulting STEM curriculum accurately portrays how children from the earliest ages learn about and apply concepts and skills from these domains, how those early skills are built upon to create more complex, accurate understandings of the world, and how educators, parents, and home visitors effectively move children forward in their STEM journeys. Moreover, the testing of UDL principles and tiered supports, built around modifying the environment, materials, and instruction for the activities and learning experiences, promotes usability for educators and caregivers in all settings and ensures that the needs of every single child can be met within the STEMIE framework. The STEMIE websites (https://stemie.fpg.unc.edu and https://www.learningtrajectories.org/) present the results of this work, including information on complementary publications and direct online access to the learning trajectories.

Limitations and Future Research

Although the STEMIE project made substantial progress in the creation and field testing of inclusive learning trajectories for STEM, the study is limited in scope and size. The scope of these phases of the project included knowledge and content development. The number of participants was, therefore, small and specific to the purpose of studying and iterating products rather than measuring the quantitative impact of those products on people. Future work is needed to further evaluate and refine the learning trajectories, especially in the STE domains, extend the work to other topics in STE, and produce support materials for teachers, faculty, professional development providers, and families.

To complete the phases of the CRF, the remaining phases (8–10) will extend this work. Phase 8 scales the work to larger groups of ECE and ECSE practitioners who serve children with disabilities, including those who are multilingual and racially, ethnically, and culturally diverse across different geographical and cultural contexts, using the set of learning goals, progressions, and instructional activities and resources to provide professional development (PD). Evidence suggests that practitioners both attempt to use inclusive practices and desire more PD on the topic [25]. These PD opportunities will also allow the team to develop further and ensure that the approach is culturally appropriate and individualized across contexts. This and data gathered from multiple sources (e.g., a diverse interdisciplinary advisory board including partners from minority-serving institutions and new incubator sites) will support the revision and improvements to the learning trajectories' accuracy, effectiveness, and usability. Additional content analysis of video codes will also improve their clarity and usability.

Summative phases 9 and 10 can use randomized field trials and single-case designs to test efficacy and effectiveness. The two phases differ most markedly depending on the characteristic of scale. That is, phase 10 examines the fidelity, enactment, and sustainability of the curriculum when implemented on a large scale and the critical contextual and implementation variables that influence its effectiveness. Phase 9 does this on a smaller scale. Experimental or carefully planned quasi-experimental designs, incorporating observational measures and surveys, are helpful in generating political and public support and their research advantages. In addition, qualitative methods continue to help provide a deeper understanding of the complexity and indeterminateness of educational activity.

5. Conclusions

Best practices in the ECE and ECSE literature have remained siloed for far too long. This separation is but a reflection of systemic ableism in our society about who belongs and who is 'able'. However, inclusion is not a new concept. The separation of this literature has driven the separation of children, with ECE practitioners remaining uncomfortable about working with CWD and ECSE practitioners not knowing how to collaborate with ECE teachers and ensure CWD can fully participate in the ECE environments.

To disrupt this paradigm, educational researchers must enhance existing knowledge development frameworks with an anti-ableist and inclusive intent. The anti-ableist lens seeks out exclusionary language, practices, and standards. These must then be replaced by inclusive practices that increase engagement by removing barriers and providing opportunities for all children to reach STEM learning goals. Furthermore, this may include bringing new frameworks into EC and ECSE settings to produce a common language for engaging young children in STEM learning.

Integrating best practices from ECE and ECSE also calls researchers to learn from and with practitioners. This approach enhanced the CRF by elevating the bidirectional and iterative nature of the framework, infusing each phase with voices that challenged the team to consider a variety of individualized and inclusive teaching and learning strategies.

There is great urgency to move beyond the status quo where children with disabilities, particularly those who are multilingual and racially, ethnically, and culturally diverse, continue to be denied opportunities to participate in STEM learning across their environments [26]. Systematically, including and lifting up the voices of multiple perspectives can bring about this crucial change.

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