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Article

"Everybody Was Included in the Conversation": Teachers' Perceptions of Student Engagement in Transdisciplinary STEM Learning in Diverse Elementary Schools

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Abstract: This qualitative interview study examines STEM integration in three diverse elementary schools through the eyes of the teachers and instructional coaches (n = 9) who facilitated the transdisciplinary Box Turtle Model-eliciting Activity (MEA). Prior to implementation, participants attended a full-day professional development workshop in which they experienced the MEA in school-based triads of principals, coaches, and teachers. The educators then implemented the MEA with elementary students from across multiple grade levels. We used the guiding principles of productive disciplinary engagement in our analysis of educator interviews to interpret participants' perceptions of how an MEA encourages elementary students to (a) problematize real-world scenarios, (b) direct their own learning, and (c) collaborate through meaningful academic discourse. Educators also identified challenges to integrating STEM in elementary classrooms. The Box Turtle MEA offered more equitable access to STEM by positioning students as authorities and providing space for them to be accountable to themselves and others in solving an authentic, real-world problem.

Keywords: elementary; integrated STEM; model-eliciting activities (MEAs); disciplinary engagement; academic discourse; real-world problem-solving

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1. Introduction

Integrating science, technology, engineering, and mathematics (STEM) within K-12 education is the focus of researchers and policymakers who strive to increase creativity, innovation, and initiative across the disciplines [1]. Elementary school is an ideal time to integrate the STEM disciplines, yet K-12 STEM is still largely taught within its separate disciplines with little overlap or integration [2].

Integrated STEM in elementary classrooms is far more than worksheets and memorization of facts and procedures without context; it provides space for students to use skills and knowledge developed across multiple disciplines to ask scientific questions or to solve problems [3,4]. Young learners gain the opportunity to see how science and mathematics content is applied in practice in relevant, real-world contexts [5]. Integrated STEM positions students as problem solvers who employ the engineering design process, scientific inquiry, mathematical reasoning, and computational thinking as they model real-world situations [6].

Vasquez proposed a spectrum of STEM integration [7] to support teachers in moving from a disciplinary approach to learning mathematics and science as separate disciplines to a transdisciplinary approach of applying STEM subject knowledge in real-world problem solving [8]. Hjalmarson and colleagues described how teachers can learn to assess the products of integrated STEM tasks as representations of iterative thinking aligned with existing mathematics and science curricula [9]. Teachers can also use STEM integration to empower students to develop their identities as critical thinkers and problem solvers [10].

There has been limited research on teachers' conceptualizations of integrated STEM education and its potential to deepen disciplinary learning, develop 21st-century skills, and encourage students to pursue STEM careers [11]. Prior studies have shown that teachers who observe increased student engagement in an integrated STEM lesson see the value of STEM, are more motivated to teach STEM, and seek to elicit student ideas about STEM [12,13]. Teachers who allow their students time to collaboratively develop creative solutions begin to appreciate the open-ended complexities of integrated STEM [3].

Further research on teachers' beliefs and understandings about effective classroom implementation is necessary to advance these STEM educational reforms [14]. This study analyzes interview data from nine elementary educators who implemented a transdisciplinary STEM activity in their classrooms and schools. The purpose of this study was to explore their overall experiences and perceptions of engagement as a path to student learning in elementary classrooms.

2. Literature Review

2.1. Model-Eliciting Activities as an Approach to STEM Integration

Model-eliciting activities (MEAs) were initially conceptualized as problems to help mathematics education researchers study student modeling and gain insight into cognition and solving behaviors [15]. Modeling is the process by which learners use STEM knowledge to describe, explain, represent, and predict real phenomena [6]. MEAs have more recently been used as a transdisciplinary curricular approach to STEM integration with an emphasis on problem solving and the engineering design process [16,17]. Creating and applying models within MEAs engages learners in inquiry around a meaningful STEM problem and provides teachers a window into student thinking. While problem-based learning and MEAs share many characteristics (e.g., authentic problems, open-ended tasks, and collaborative higher-order thinking), MEAs are designed to be completed in one to two class periods and produce mathematical models to externalize student thinking [18].

Teachers facilitate collaborative problem solving in MEAs as students evaluate a challenge posed by a real-world client, explore possible solutions, iteratively assess their thinking, and produce a reusable prototype. MEAs support the goals of teaching and learning in elementary math and science curricula by (1) engaging students in authentic design challenges beyond traditional word problems, (2) encouraging learning through discovery [19] to reveal misconceptions and develop understanding of STEM concepts [20], and (3) promoting intrinsic motivation and self-regulation [21].

MEAs are well-suited for integrating STEM within elementary mathematics and science instruction because they require one to two class periods and produce models that offer teachers a contextual and content-focused lens on student thinking [20,22]. Teaching through MEAs can help students see the relevance of mathematics and science in their lives and society, build critical thinking skills, engage in meaningful mathematics and scientific discourse, and present their solutions to others [23–25]. Researchers have explored students' experiences with MEAs in elementary classrooms [25–27] and pre-service teachers' experiences with MEAs [17,20,28,29], yet there is limited research on how elementary teachers perceive student engagement and student learning within MEAs.

2.2. Teachers' Perceptions of STEM Integration in Elementary Schools

Most of the STEM education research on teachers' perceptions of STEM has focused on secondary settings [30]. Teachers at the secondary level consider STEM to be inherently motivating [31,32] and value STEM as offering authentic and challenging learning opportunities for their students [33]. Studies in elementary settings offer evidence that teachers generally have positive perceptions of integrating STEM within their classrooms and believe it can enhance student learning outcomes [34,35]. In particular, early childhood teachers value STEM experiences as developmentally appropriate ways to build foundational knowledge in the STEM disciplines [36]. K-12 teachers' perceptions of STEM can change over time when they have opportunities to write and implement integrated STEM curricula [14].

STEM-focused professional development plays a key role in supporting teachers' positive perceptions of STEM. Effective teacher learning through graduate coursework and within school district structures can increase K-12 teachers' self-efficacy for teaching STEM [37–39]. Teachers who believe they have the knowledge and skill sets needed to teach STEM are more willing to do so [30]. Self-efficacy for teaching STEM can be developed in elementary teachers by offering opportunities to experience STEM as learners before considering the pedagogical approaches and instructional strategies to employ in the classroom [3,12].

Teachers are aware of the potential barriers to teaching STEM, particularly logistical and contextual barriers. Time constraints are frequently cited by teachers [30,37,40–43]. Teachers have expressed concerns about student readiness to integrate STEM [40,44], alignment of STEM to current standards [42], lack of content knowledge [30], and a lack of integrated STEM resources [36,41]. Teachers have also noted that they were not certain that they had the required support of their administrators to implement integrated STEM activities [36,37].

2.3. Conceptual Framework: Teachers' Perceptions of Student Engagement

Transdisciplinary STEM learning environments, characterized by scientific inquiry and mathematical reasoning, create opportunities for students to engage in real-world problem solving as a path to learning. Engle and Conant offered a model of productive disciplinary engagement (PDE) to characterize the learning environments in which students genuinely participate in productive disciplinary work [45]. Engagement in classroom activities can be described as disciplinary when "there is some contact between what students are doing and the issues and practices of a discipline's discourse" [45] (p. 402). The four guiding principles of PDE [46] constitute a conceptual framework for analyzing teachers' perceptions of how students interact with transdisciplinary STEM curricula and instruction.

1. Students should have opportunities to problematize STEM subject matter beyond recall of facts and procedures. Problematizing gives students the space to make intellectual progress, and it is evidenced in questioning about disciplinary context and constraints, reasoning about potential solutions, and productive struggle [47]. Students work with the teacher and with peers to resolve disciplinary uncertainties [48].
2. Students should have authority to develop and share ideas as they play an active role in identifying, formulating, and resolving problems [49,50]. Students are positioned as authors of their own ideas [51], local authorities on disciplinary topics, and contributors in collaborative problem solving.
3. Students should have accountability to themselves, to other students, and to disciplinary and school-based norms [52] as they explain, reflect upon, and revise their ideas.
4. Students should have access to necessary resources, including time, materials, locations, scaffolded instruction, and technology. These resources promote problematizing, authority, and accountability.

Agarwal and Sengupta [53] responded to Engle's [46] call for greater attention to how students from varying backgrounds have differential opportunities for participation in disciplinary learning in their conceptualization of disciplinary engagement as not only productive but also connective. They elaborated on the PDE framework with attention to students' diverse cultural histories, identities, and ways of knowing to further define problematizing, authority, and accountability in science and mathematics. They also expanded on the ideas of resources to include teachers' positioning of students and their ideas in classroom discourse [54,55]. Both of these models inform our approach to understanding how students engage in productive problem solving beyond what curriculum designers or teachers may have envisioned prior to implementation [45]. We, therefore, used the guiding principles of PDE to analyze teachers' perceptions of student engagement as a path to learning during their facilitation of a transdisciplinary STEM MEA with elementary students.

3. Method

This qualitative interview study focuses on the experiences of nine elementary educators as they implemented a STEM MEA in their schools. This study is situated within a larger design-based implementation research (DBIR) project. Design-based implementation research (DBIR) is a methodology in which stakeholders are committed to iteratively developing an educational innovation with a goal of broader and sustainable impact [56]. This study describes the findings from one iteration of the Box Turtle MEA as an integrated STEM curriculum intervention in three elementary schools. Specifically, this qualitative research examined the perceptions of elementary educators, including classroom teachers, mathematics and literacy coaches, and a STEM specialist, as they implemented the Box Turtle MEA in their classrooms.

3.1. Setting and Participants

Central School District (CSD) is in the outer suburbs of a major city in the Mid-Atlantic region of the United States. CSD is an ethnically and racially diverse district with more than 7500 students. Approximately 60% are Hispanic, 20% are White, and 12% are Black. Across all of the schools in this district, 42% of students have limited English proficiency, and 53% of students are economically disadvantaged. The three elementary schools in this division are all designated as Title I schools, and all have subgroups with proficiency gaps in mathematics of 15% or higher in either the Black or Hispanic subgroups, as reported to the state.

The authors of this study collaborated with this district for several years to support mathematics coaches and elementary teachers with STEM professional development [9,16]. The participants in this study attended a full-day professional development workshop to learn about integrating STEM using MEAs. This workshop provided opportunities for participants to connect research on MEAs as an approach to "engaging learners in productive mathematical thinking" [57] (p. 5) to their ongoing STEM integration efforts. In two of our schools, the school-based teams who attended our professional development workshop later led an MEA workshop with other teachers at their school so that they could implement the MEA in multiple grade levels and classrooms within their school. Our research team was not involved in the individual school workshops. For this study, we focused on the nine educators who attended our professional development workshop, implemented the MEA in their classrooms and/or schools, and participated in an interview with our research team.

Educators from three elementary schools in CSD participated in this study. Delano Elementary is an economically diverse K-4 school with 600 students, approximately half of whom are English learners. As described in Table 1, four educators from Delano Elementary participated in this study. Newton Elementary and Nickel Elementary are similar to Delano Elementary in student population and demographics. Two educators from Newton and three educators from Nickel participated in the study. All participants in the study were women with 3–27 years of experience as educators. All names used in this paper are pseudonyms.

Table 1. Participating schools and educators.

School	Implementation	Participating Educators
Delano Elementary	All grades K-4 classrooms (~600 students)	Classroom Teacher, grade 4: Sophia Math Coach: Emma STEM Specialist: Chelsea Literacy Coach: Sammy
Newton Elementary	One grade 3 classroom (~25 students)	Math Coach: Bianca Classroom Teacher, grade 3: Leah
Nickel Elementary	All grades 5 and 6 classrooms (~250 students)	Math Coach: Denise Classroom Teacher, grade 5: Gemma Classroom Teacher grade 6: Carina

3.2. The Box Turtle MEA

The research team developed the Box Turtle MEA using data collected by scientists at the Smithsonian Conservation Biology Institute located in Front Royal, Virginia and shared with the team through our partnership with the institute. The MEA was aligned with state standards in mathematics, literacy, and science so that educators would have flexibility in emphasizing specific disciplinary skills and knowledge development with their own students. The Box Turtle MEA centers on the authentic problem of determining the age of a box turtle using photographs of turtles found in the wild. Students have the opportunity to engage with a problem that conservation biology researchers are still trying to solve. Following the structure of MEAs [15,58], teachers launch the Box Turtle MEA with a client letter explaining the context of the problem and the need for a model as a solution. The letter is written from the perspective of a county park ranger, who calls on students to create a generalizable procedure for determining the age of box turtles photographed in a local park.

Teachers initially use the client letter to engage students in a large-group discussion around the problem they are seeking to address. Teachers offer a series of questions to check for understanding of the problem and support students in identifying ambiguities that will drive the development of their models. Teachers then provide students with relevant mathematical information, including images of eight box turtle plastrons (bottoms), a map of where each turtle was found, and a description of the specific terrain. Finally, students engage in the engineering design process to iteratively design, develop, and construct their models [59] for determining the ages of the box turtles. Teachers deliberately position students as authorities within the lesson, with teachers serving as facilitators rather than leaders of classroom activities. Students manage discussions within their small groups, drawing on the mathematical and scientific resources provided by teachers. They are accountable to one another and to classroom norms as they work to identify strategies they would use to solve the problem. As shown in Table 2, the Box Turtle MEA is aligned with the guiding principles of PDE.

Table 2. Alignment of teacher actions in the Box Turtle MEA with principles of PDE.

Guiding Principles of PDE [46]	Box Turtle MEA Teacher Actions
1. Students have opportunities to problematize STEM subject matter beyond recall of facts.	Teachers read a client letter and engage students in discussion about the problem. Students create a model to determine the age of the box turtles.
2. Students are positioned as authors of their own ideas and contributors in collaborative problem solving have authority to develop and share ideas as they play an active role in problem solving.	Teachers empower students to collaborate as problem solvers as they work in small groups to iteratively develop their models for determining the ages of the box turtles. Teachers take the role of facilitator rather than knowledgeable expert.

3. Students have accountability to themselves, to other students, and to disciplinary norms as they explain, reflect upon, and revise their ideas.	Teachers position students as owners of the knowledge and managers of their group discussions and to work collaboratively to develop their models.
4. Students have access to necessary resources that promote problematizing, authority, and accountability.	Teachers provide students with STEM data (i.e., photos, map), and tools (e.g., paper, rulers, math manipulatives, string, sticky notes, markers).

3.3. Structure of Our Professional Development

To prepare to implement the Box Turtle MEA in elementary schools across the district, our Central School District partners sent school-based teams of classroom teachers, mathematics specialists, and administrators to a two-day professional development at the Smithsonian Conservation Biology Institute. Our university-school division partnership drew upon research on MEAs as tools for modeling in mathematics education [60] and explicitly focused on mathematics coaching as an in situ resource to advance mathematics content in K-6 classrooms [9].

Our goal in the Box Turtle MEA professional development was for participants to understand how teachers can use MEAs to engage students in STEM reasoning and sense-making about a tangible real-world phenomenon [16]. School-based teams collaboratively engaged in the MEA process and considered potential barriers to STEM integration, such as curriculum constraints, time, logistics, and student readiness [40,61]. Each team discussed what student learning would look like, evaluated how the MEA could meet their various instructional goals, and reflected on the specific needs of their school sites. Administrator participation in these school-based teams was especially critical for teachers to feel supported in implementing innovative STEM curricula with their students [30,62].

3.4. Research Context

Each school team decided when and how to implement the MEA, and our research team supported each of the schools in preparing to implement the MEA. Nickel Elementary was the first to implement the MEA and chose to do this with all fifth and sixth-grade students during a school-wide STEM Day on the final day before winter break. A fifth-grade teacher at Nickel who had attended the professional development launched the MEA in a large-group session with all students and teachers in the fifth and sixth grades. After hearing the client letter and engaging in initial question posting, students worked through the MEA within their classrooms in small groups. Students were then brought together into large grade-level groups to share their models and discuss their strategies using a gallery walk format.

The mathematics coach and third-grade teacher at Newton Elementary implemented the MEA in mid-March because the MEA content aligned with the science standards taught at that time. Delano Elementary implemented the MEA in the week before spring break during a whole school STEM Day. Prior to implementation, the mathematics coach at Delano Elementary worked with the literacy coach and STEM specialist to organize a pre-launch field trip to a regional park for students to meet with a park ranger. They also collaborated with the physical education teacher, art teacher, and librarian to design relevant activities related to box turtles to demonstrate cross-disciplinary thinking about STEM. All Delano teachers in grades K-4 implemented the MEA with the support of the mathematics and literacy coaches and the STEM specialist. To launch their STEM Day, the Delano Elementary principal read the client letter to students during the schoolwide morning announcements. His personal request for help from the students on behalf of the client, Ranger Tom, was intended to strengthen both student enthusiasm and student investment in solving an authentic problem.

3.5. Research Question

In this study we sought to understand teachers' experiences facilitating the MEAs and what they observed related to student learning. The following research question framed our inquiry:

What are educators' perceptions of engagement as a path to student learning during the implementation of a transdisciplinary STEM model-eliciting activity?

3.6. Data Collection

The data analyzed for the current study included semi-structured interviews with nine participants who participated in the Box Turtle MEA professional development workshop (classroom teachers, mathematics and literacy coaches, and a STEM specialist) from across the three elementary schools. Although many more educators participated in the MEA implementation at Delano and Nickel Elementary, we only interviewed professional development participants because our larger research study focused on educators participating in the university-school district DBIR process. Interviews were conducted in person by members of the research team immediately following the MEA implementation by members of the research team who had observed the participants' interactions with students. Interview questions focused on the teachers' experiences preparing for the MEA implementation, what they observed from their students during the MEA, and their perceptions of teaching STEM in the future.

3.7. Data Analysis

We conducted a thematic analysis of participant interviews. Three members of the research team analyzed the nine interviews using open coding [63] and collaboratively identified initial codes. Following the initial round of analysis, we engaged in interactive rounds of analysis to reduce codes and categorize the coded data into meaningful themes [64]. To develop validity, in the final round of coding, two researchers reviewed the interviews to ensure quotes were not taken out of context and to search for alternative explanations.

4. Findings

Our analysis of teacher interviews yielded four distinct themes, including three significant themes related to teachers' perceptions of engagement as a path to student learning during the implementation of the Box Turtle MEA and one related to the barriers they discussed to the future integration of STEM activities at the elementary level. During the implementation of the MEA, teachers noted that (a) students connected classroom problem-solving to real-world scenarios, (b) students had the authority to engage in self-directed learning, and (c) students were accountable to one another in meaningful academic discourse. The findings section is organized around the four main findings of this research study. Within each of the findings, the specific themes identified from coding participant interviews are presented. Specific quotations from data are included to illustrate the themes that contribute to each of the findings.

4.1. Problematizing Real-World Scenarios

While the Box Turtle MEA implementations varied in length and complexity, teachers across all implementations perceived that their students made meaningful connections between classroom content and the real world. Many teachers reflected that the authentic investigation and real-world applicability of the problem presented in the MEA enabled students to transfer their knowledge of STEM and their communities to a relatable design challenge.

Carina, a sixth-grade teacher, focused on the importance of helping students make meaningful connections between their personal experiences and their learning in her classroom. She described leveraging their enthusiasm for turtles as an opening to connect their experiences with exploring something new. She reported that when she asked her students who had ever seen a turtle, "every hand went up. I mean, this is directly relatable." Carina's math coach, Bianca, stated that students "felt that it was useful and important. That's what I really wanted to see and the love of learning something new." These teachers felt it was important that student learning extended beyond traditional in-classroom lessons and activities.

Chelsea, an elementary STEM specialist, found that her students made significant connections to the content due to the authenticity of the Box Turtle MEA. Her students connected back to the MEA content related to preserving box turtle habitats and what turtles need to survive.

> The kids are coming here saying, 'Oh my gosh, Mrs. D., I saw a turtle in my yard. And now I knew not to do this. I knew what this meant.' So, they're taking the knowledge they learned the science way and taking it out there. And I think that this is totally authentic. It's something that relates to them.

Teachers also noted that the authenticity of the investigation provided a hands-on opportunity for students to engage in mathematical problem-solving activities they may otherwise not have enjoyed. Engaging students in answering mathematics questions differs from engaging students in an activity where their opinions and solutions matter. Emma, a math coach, remarked how MEAs are real and meaningful and that students buy into them. She added that "their opinion is valued, so that's definitely a success because it's hard. It's hard to engage students in the way that you want with all your lessons." She perceived that students' sense of agency in problem solving differs when they are working with traditional mathematics word problems and those that are connected to real-world scenarios, noting:

> I think my biggest takeaway is just providing the students with more activities and more experiences with that type of problem-solving. Because it's a real-world problem, in going back to that real-world application, their opinion right now matters, and they love it.

Across the three implementations, teachers felt that the ways in which their students benefited from learning problem solving through MEAs differed from how they learned to problem solve through direct instruction. Furthermore, teachers stated that there were not enough opportunities like the Box Turtle MEA to engage students in the type of authentic problem-solving. Leah, a third-grade teacher, observed, "I think in this particular instance, especially with the MEA and these real-world problems, they're getting a lot more than they would if it were a lot more direct instruction."

4.2. Engaging in Self-Directed Learning

In their interviews, teachers reflected on classroom behaviors they observed in students during the MEA implementation. They described behaviors that empowered students to learn, including self-directed learning and multiple facets of student engagement.

4.2.1. Self-Directed Learning

Two teachers interviewed saw their students as self-directed learners who took the initiative and were comfortable with working independently during the MEA. Carina stated, "I was pleasantly surprised that I'd walk away from a group, and when I would come back, they seemed to have found a way to cycle around whatever they were working on." Gemma, a fifth-grade teacher, said, "I think me not explicitly telling them everything that they needed to know gave them a lot more thought and conversation while they were working together." These teachers valued the collaborative thinking students engaged in together, which allowed students to persist when facing challenges without constant direction from the teacher.

Many of our participants also discussed what they noticed about student engagement during the MEA in two distinct ways. Some educators focused on a lack of student misbehaviors as evidence of productive engagement, while others pointed to evidence of student engagement with content. These different descriptions of student engagement during the MEA suggest that school personnel had varying goals for student learning in STEM integration.

4.2.2. Engagement as Lack of Misbehavior

Several teachers and coaches observed that students who were normally off task were able to stay engaged and complete the classwork during the MEA. These teachers were less focused on what students learned as a result of their increased engagement and more focused on students' lack of misbehavior. Gemma noted,

> As far as challenges with the students, we didn't have any. One of the other teachers came up to me [and said about] one of our students who just really has a hard time focusing on school, always a behavior concern, she said, 'He's doing the best I've ever seen him do. He's so engaged.' So that was a very interesting point for me... He's working with a group; he's doing a really good job...what more could you ask for?

Similarly, Denise, a math coach at Gemma's school, stated, "I was really worried about specific kids in this activity, and I haven't had any issues with them. And they've actually…participated more in this activity than they normally do." These teachers valued the MEA for keeping students from going off task but did not make connections between student engagement and student learning.

4.2.3. Engagement with Science and Mathematics Content

Several teachers noted students' specific learning of content as evidence of engagement. One of these was Carina, who saw student perseverance as evidence of engagement.

> It was nice to see them do something with the information, and it was nice to see that they could do that. Sometimes, I think we worry that when we give them a task, they're just going to get stumped too quickly and not be able to stick with it. So, I was impressed with how long they were as deeply engaged as they were.

Sophia, a fourth-grade teacher, also noted, "It was my kids that would be in a self-contained [classroom] who were giving an opinion...it was nice to see them finally engaged." These teachers valued the Box Turtle MEA for making STEM problem solving and STEM content accessible to all of their students.

4.3. Authority and Accountability: Collaborating through Meaningful Academic Discourse

Teachers noticed a difference in how their students collaborated and engaged in meaningful academic discourse during the MEA implementation. They characterized meaningful academic discourse as students interacting in on-topic discussions, debates, and the ultimate justification of answers. One teacher commented that this level of communication and discourse was unusual for her group of students. Teachers perceived it was their students' interest in turtles and the authenticity of investigation that led to higher levels of authority and agency in collaborative STEM discourse.

Emma remarked that it was the first time she had experienced her first graders participating in group problem-solving discussions, reasoning, and defending their solutions. Sophia stated that her most significant takeaway from the implementation was how purposefully integrating content sparked more purposeful academic discourse. "It was a chance for them not to just sit in here, it was a chance for them to be interactive and really have those discussions, and they all seemed really engaged."

The Box Turtle MEA also provided equitable learning opportunities for students to experience collaboration in which they listened to and respected their peers' ideas and input. Our participants noted that this type of collaboration led to increased student authority. Students felt like their opinions mattered and that everyone felt like they had a say. Sammy, a literacy coach who supported the implementation of the STEM MEA, expressed surprise that group discussions were not dominated by the students who were normally high achievers in her class: "Everybody was included in the conversation…they were comfortable with each other, and they were talking with each other."

Because the open-ended nature of an MEA offers multiple entry points and approaches to finding the solutions, the conversations were robust as students discussed viable solutions and were accountable to one another for listening to all ideas. Sophia shared, "I felt like it was more that they were actually having a conversation and having the agreements and the talking back and forth." Educators credited the MEA's integration of disciplinary content and relevant real-world situations as the contributing factor in making the MEA a situation in which all were positioned to actively participate in the discussions.

4.4. Barriers to Sustaining Integrated STEM

Despite the enthusiasm that the educators in this study expressed about how students interacted with both content and with one another as they worked on the Box Turtle MEA, many educators made explicit statements that revealed potential barriers to the future use of integrated STEM in their classrooms.

4.4.1. Constraints of Conventional Approaches to Teaching

When asked about their plans to implement integrated STEM activities like the Box Turtle MEA in the future, teachers and math coaches indicated that they felt constrained by school structures, including available time in their daily schedules and siloed curriculum. Several teachers noted constraints put upon them by the school curriculum, like Gemma, who shared,

> I think that school would be so much different if we were just allowed to teach how we wanted and connect things, so that way the kids can see that things in life are really connected and just trust that we're doing our jobs and trust that the kids are learning things.

Although these teachers valued the productive engagement that occurred during the Box Turtle MEA, they struggled to imagine incorporating student-centered STEM activities on a regular basis because of existing school structures. Furthermore, Gemma's quote indicates that she does not feel trusted as an educator and that students miss out on real-world connections in education as a result.

4.4.2. Perceptions of STEM as a Fun Activity

Throughout our observations of implementations of the MEA in the three different schools in CSD, we noted that integrating STEM with the Box Turtle MEA was treated as a fun activity disconnected from standards-based instruction. Nickel Elementary implemented the activity across grades 5 and 6 during the last day of school before winter break, and Delano Elementary featured the MEA as the centerpiece of its whole-school STEM Day. Teachers and specialists, including physical education and art teachers and math and reading specialists, supported the Delano implementation across all K-4 classrooms within a single day, using the library and other large classrooms to implement the activity with students from multiple classes. Several participants emphasized that the Box Turtle MEA was a "fun" activity, including Gemma, a fifth-grade teacher at Nickel Elementary.

> I think today the amount of fun that they had and just the day before winter break, the engagement that they had and the background knowledge that they were talking about, the vocabulary—I heard them saying just theories and things like that—I mean, it was fantastic. It was amazing.

Carina, a sixth-grade teacher at Nickel, indicated that they chose to implement the MEA on the day before winter break because it was not connected to content, noting, "Today is a day in which the students are already pretty energized…it makes it easier for teachers to implement today thinking that maybe nobody is actively teaching brand new content deeply." When asked about how she saw the MEA connecting to her curriculum, Carina replied, "The biggest way for me in sixth-grade math is just general problem solving. Honestly, I've actually not stopped to think about specific standards." For Gemma and Carina, this STEM activity held value because it was a fun activity that kept students busy and did not require content instruction. These teachers did not see the MEA as connected to the standards, even though the research team mapped the MEA to multiple standards within their curriculum. This alignment was shared with the teachers during professional development.

5. Discussion

In this study, we analyzed interviews with educators who supported the implementation of the Box Turtle MEA, a transdisciplinary STEM activity, with students at three different diverse elementary schools. We focused on educators' perceptions of engagement as a path to student learning during this activity and found that educators saw their students making real-world connections as they problematized a real-world STEM issue. Educators also noted that students directed their own inquiry within their small groups. They had a general sense that students were more engaged than normal. For some of our educators, this meant that they saw fewer student misbehaviors, while others focused on the ways that students persisted within the problem-solving challenges presented by the MEA. Many educators were particularly excited about the level and depth of STEM discourse that was evident in student groups. Students had the authority to create, present, and revise their own ideas, and they were accountable to their peers as they iteratively developed and presented procedures for estimating the ages of the box turtles.

Although educators perceived PDE in their facilitation of the Box Turtle MEA, they also described barriers to implementing more transdisciplinary STEM activities in their schools in the future. These barriers included school structures that prevent teachers from choosing how and when to implement STEM activities and an overall perception that STEM activities are fun but not necessarily useful for helping students learn content. The teachers involved in this study did not make explicit connections to standards and did not describe specific grade-level learning goals for their students. As teachers are expected to prepare students for high-stakes standards-based assessments, failing to connect integrated STEM activities to those standards will relegate those activities to something teachers do not have time or school support to implement. Our findings support our prior work preparing teachers and mathematics coaches to facilitate integrated STEM, in which we noted that school context and assessment-driven culture must be part of how educators conceptualize STEM integration [9,62,65].

The barriers expressed by our teachers are consistent with prior literature, particularly as they relate to concerns about time [30,61] and support from their school administrators [36]. However, the teachers in our study were not concerned about student readiness to integrate STEM, which may indicate that the Box Turtle MEA is particularly accessible for the diverse learners in our teachers' classrooms.

MEAs were originally created to serve as assessment instruments for research on modeling in mathematics education [37] but have more recently been used in elementary contexts to teach STEM content within problem-solving contexts [16,24]. We aligned the Box Turtle MEA with a variety of K-6 science, mathematics, and literacy standards so that it could be implemented across the elementary grades. Yet, many of the educators in this study did not make explicit connections to the standards alignment in the Box Turtle MEA. This lack of connection may further explain educators' perceptions of time as a barrier to future integration and beliefs that integrated STEM is a fun activity that is separate from the district curriculum.

The interviews analyzed in this study were collected from nine educators who implemented the Box Turtle MEA in three elementary schools within a single small school district. This design may limit the transferability of our findings to other schools and districts [66]. Another limitation of this study is our exclusive focus on educators' perceptions rather than on elementary students' perceptions of engagement as a path to learning. As STEM teacher educators, our primary focus is teachers and mathematics coaches, but the literature would benefit from additional research that examines students' experiences with MEAs.

6. Conclusions and Implications

This study offers insight into how practicing teachers perceive both opportunities for student engagement and challenges to STEM integration within their classrooms and schools. The Box Turtle MEA served as a transdisciplinary STEM resource that offered authentic learning opportunities in which students had the authority to engage in self-directed learning and were accountable to one another in meaningful academic discourse. Facilitating this MEA with elementary students provided a tangible experience in which teachers could see and describe these affordances of PDE consistent with a transdisciplinary approach to STEM content integration [67]. Teachers understood how problematizing a relatable real-world scenario and providing students with a variety of resources created a productive learning environment in the classroom and content connections beyond the classroom. They appreciated how the Box Turtle MEA gave students the authority to propose potential solutions and accountability for collaborating to finalize and present shared solutions.

Our research team designed the Box Turtle MEA and created resources in collaboration with local Smithsonian Institute scientists to offer a novel professional development experience centered on triads of educators from multiple elementary schools within a district. Prior to implementing the MEA in their schools, teachers, coaches, and administrators attended the professional learning workshop at the Smithsonian Conservation Biology Institute and engaged in collaborative problem solving with the Box Turtle MEA. Few studies have examined professional development experience tailored to a triad of school leaders and educators, but it is likely that this experience serves to infuse STEM-focused school components within a traditional elementary school environment [68].

The triads of educators (teachers, coaches, and administrators) who participated in this study were beginning to consider how to productively engage elementary students in STEM disciplinary learning. At the same time, educators struggled to see how the PDE they observed with the Box Turtle MEA could translate to everyday science and mathematics teaching. Our findings emphasize the importance of supporting teachers in making explicit connections between integrated STEM activities and the STEM content standards in lesson planning. Coaches and administrators in schools and districts have a critical role to play in encouraging teachers to make these explicit connections to improve curriculum and instruction.

Movement toward all school staff seeing themselves as STEM educators can foster an environment of more equitable access to high-quality STEM instruction. Our research team developed the Box Turtle MEA, which limited teacher ownership of the curriculum. Ideally, teachers would be authors or at least curators [40] of the STEM curricula they implement in their classrooms. As educators begin to take greater ownership of STEM curricula and design their own professional development, they will make progress toward sustaining integrated STEM in elementary schools.

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