STEM AND MODEL-ELICITING ACTIVITIES: RESPONSIVE PROFESSIONAL DEVELOPMENT FOR K-8 MATHEMATICS COACHES

Courtney Baker	Terrie Galanti	Sara Birkhead
George Mason University	George Mason University	George Mason University
cbaker@gmu.edu	tgalanti@gmu.edu	sbirkhea@gmu.edu

This research highlights a university-school division collaboration to pilot a professional development framework for integrating STEM in K-8 mathematics classrooms. The university researchers worked with mathematics coaches to construct a realistic and reasonable vision of STEM integration built upon the design principles of model-eliciting activities (MEAs). Analysis of participant reflections after they experienced two MEAs as learners in mixed grade-level teams suggests an evolving conceptualization of STEM integration with an explicit connectedness to mathematics content. Mathematics coaches valued the potential for MEAs to provide multiple entry points to open-ended problem solving, but they articulated a sense of vulnerability as they contemplated the challenges of time and teacher buy-in within the contextual realities of curriculum pacing and standardized test preparation.

Keywords: Teacher Education-In-service/Professional Development, Modeling, Instructional Activities and Practices, Problem Solving

Introduction

School divisions across the United States have "embraced" the slogan of STEM (Bybee, 2010), but there is limited evidence of theoretical frameworks for the design and development of sustainable STEM integration in K-12 education [National Academy of Engineering (NAE) & National Research Council Committee (NRC), 2014]. Mathematics may be relegated to a supporting role in STEM integration (Fitzallen, 2015) when it is characterized as the calculations or the data representations in science classrooms, technology labs, or outside-of-school programs. To bring mathematics content to the forefront in STEM integration, designers must attend to "learning goals and learning progressions" within mathematics (NAE & NRC, 2014, p. 148) and avoid a dilution of mathematics content (Shaughnessy, 2013). Without specific connections to mathematics content, teachers may perceive STEM integration as an additional instructional requirement that is placed on top of the existing curriculum (Wang, Moore, Roehrig, & Park, 2011).

The university researchers reflected upon these challenges as they collaborated with a school division to develop a STEM integration professional development (PD) framework for mathematics coaches. They hypothesized that model-eliciting activities (MEAs) offer a vehicle for *reasonable and realistic* STEM integration in K-8 mathematics classrooms by providing open-ended problems within a client-driven, real-life context. With mathematics coaching support and explicit connectedness to content, teachers can use MEAs to engage students in both collaborative mathematical thinking and productive engineering design processes.

In this paper, we describe preliminary findings from our exploratory study during a STEM integration PD initiative in a mid-Atlantic school division. The mathematics coaches experienced two MEAs as learners and collaborated to envision MEAs as an instructional vehicle for integrating STEM within the bounds of their coaching contexts.

Conceptual Framework

STEM integration should offer students and teachers the opportunity to engage in "real-world, rigorous, and relevant learning experiences" (Vasquez, Sneider, & Comer, 2013). For many mathematics teachers, this conceptualization of STEM integration is so distant from their daily

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understandings of content, curriculum, and pacing that implementation becomes unrealistic. STEM may be perceived as a project or activity that is ancillary to content-specific instruction and may become an unintended barrier to richer opportunities to learn. Although reform curricula have emphasized the need for problem-solving opportunities in mathematics, many teachers still perceive problem solving as an elite activity, accessible only to students who have mastered essential mathematical skills and formulas (Crespo, 2003). This perception impedes conceptualization of mathematics content instruction through STEM activities. In addition, mathematics students in underperforming populations are often denied access to opportunities to practice 21st century skills as they are instead provided with remediation and extra support to gain computational fluency in preparation for standardized assessments.

Drawing from Stohlmann's (2013) definition of STEM integration as "an effort for mathematics teachers to use the engineering design process as the structure for students to learn mathematical content along with science concepts through technology-infused activities," the researchers designed a PD structure that would support teachers in incorporating MEAs within existing mathematics curriculum. The research team's goals were to: 1) explore participant understanding of mathematics within STEM integration; 2) use hands-on MEA experiences to elicit a more accessible classroom implementation of STEM aligned with coach and teacher beliefs; and 3) build coaching capacity to use MEA design principles to develop STEM tasks with a specific focus on keeping the mathematics content explicit.

MEAs were originally conceptualized as a device to help mathematics education researchers elicit student modeling and to develop expertise about cognition and problem-solving behavior. They have since become a tool that can also be used to help teachers and students develop their own competencies (Hamilton, Lesh, Lester, & Brilleslyper, 2008). MEAs support the learning of mathematics within STEM by integrating other content areas found inside and outside of mathematics, by encouraging learning through discovery, and by promoting problem-solving dispositions (Magiera, 2013) with a specific focus on accessibility to varied learning styles and experiences (Stohlmann, 2013). MEAs offer teachers a contextual and content-focused lens on student mathematical thinking (Chamberlin & Moon, 2008; Stohlmann, 2013) that yields explicit evidence of student learning that is needed to ensure the mathematical rigor in STEM integration.

Because educator expertise may be the "key factor" in STEM integration (NAE & NRC, 2014, p. 115), PD is needed to support teachers who did not learn mathematics in STEM contexts to build a working knowledge of what STEM integration can look like (Stinson, Harkness, Meyer, and Stallworth., 2009). PD that is both "site-based" and "curriculum-linked" (Penuel, Fishman, Yamaguchi, & Gallagher, 2007, p. 928) is theorized to improve teacher enactment of reform-oriented instruction, and prior research has shown that ongoing mentoring and support (p. 124) and teacher collaboration (p. 125) increase the likelihood of successful STEM integration (NAE & NRC, 2014). The university researcher-school division partnership offered a bridge between research with MEAs and the practical demands of existing curriculum and standards. As the division mathematics coaches experienced MEAs as learners, they could begin to conceptualize STEM integration built upon engineering design and real-world contexts with an explicit connectedness to mathematics content. The research question which guided this study was as follows: How do iterative experiences with MEAs during a university-facilitated PD help mathematics coaches to envision STEM integration in K-8 classrooms?

Methodology

Design-based implementation research (DBIR) is an emerging methodology in which stakeholders are committed to iteratively developing an educational innovation with a goal of broader and sustainable impact (Penuel, Fishman, Cheng, & Sabelli, 2011). This collaborative PD connected research on MEAs which “engage learners in productive mathematical thinking” (Hamilton, et al., 2008, p. 5) to STEM integration efforts within one school division. The university-school division partnership drew upon studies of specific enactments of MEAs as tools in mathematics and engineering education and theorized a STEM PD structure to explicitly focus on instructional coaching and mathematics content. The team worked to construct coaching expertise that schools would need to broadly implement MEAs as a vehicle for STEM integration.

Setting and Participants

The university researchers and the division mathematics supervisor collaborated to create a longitudinal PD structure in response to a district directive to integrate quarterly STEM tasks at each grade level. Within this school division, 73% of students were traditionally underserved and 53% were economically disadvantaged students (State Department of Education, 2015). The division had five elementary schools, each with Title I designation, one intermediate school, one middle school, and one high school. The supervisor sought to leverage the university’s mathematics education and instructional coaching expertise to bring mathematics to the forefront of STEM integration. She allocated time for mathematics coaches from the seven K-8 schools to explore and design MEAs with university facilitator support during their monthly academic year coaching meetings.

The Professional Development Context

The university researchers developed resources aligned with the partnership’s PD goals and piloted a four-day summer institute for eight aspiring STEM teacher leaders to engage with MEAs and plan for use within their classrooms. Two of the participants were mathematics coaches. The summer institute participants explored their perspectives on STEM, engaged with MEAs as learners, evaluated the affordances and challenges of implementing MEAs in their classrooms, and adapted existing curricular materials and online resources to design MEA instructional materials for their schools. The university researchers drew upon participant reflections and questions from the summer institute as they designed ongoing PD for the mathematics coaches during monthly academic year meetings. The evolving PD structure was purposefully adapted to support coaches in seeing the possibilities of MEAs, first through the eyes of students, then as teachers, and finally as coaches.

Month 1. The university researchers asked the coaches to reflect on the meaning of STEM in order to situate their existing understandings before introducing MEAs. The definition of MEAs offered by Maiorca and Stohlmann (2014) provided an accessible set of four design features (open-ended, client-driven, mathematics similar to real-life, and engineering design process) to help coaches as they began to build a working knowledge of model eliciting. These practitioner-friendly constructs were a crucial bridge from the researcher language of MEA design principles (Hamilton et al., 2008) to coach envisioning of MEAs in classrooms.

Teams of coaches engaged with the Survivor MEA (Maiorca & Stohlmann, 2014) to explore the affordances and challenges of MEAs from a student perspective. Although the Survivor MEA offered an engaging, relatable context for the participants as they experienced their first mathematics-focused STEM integration task, the research team observed that the physical construction of the weather-resistant shelter model became the primary focus of iterating and refining. The coaches required additional hands-on experiences to see the potential for explicit mathematics content instruction within this type of engineering activity.

Month 2. Before the coaches engaged in a second hands-on MEA experience, they needed time to make sense of MEAs and connect them to their own K-8 educational contexts. The university researchers offered a task adaptation template based upon the four MEA design features to support coaches in thinking critically about MEAs and in exploring online resources. This space for exploration allowed the coaches to purposefully think about not only the teachers they would support and the classrooms in which they would pilot MEAs, but also to build important contextual knowledge that would prepare them for their second hands-on experience.

Month 3. The university researchers selected the Pelican Colonies MEA (see Figure 1) as a second hands-on experience because the mathematics content could be more flexibly connected to K-8 standards and there were more varied opportunities for use of manipulatives. The coaches were purposefully grouped to offer mixed levels of content expertise and grade-level experience. The goal of this second exploration was to allow the coaches an opportunity to not only analyze their own collaborative engagement with the MEA as learners but also to reflect on transferring these ideas to their coaching practice.

Data Collection

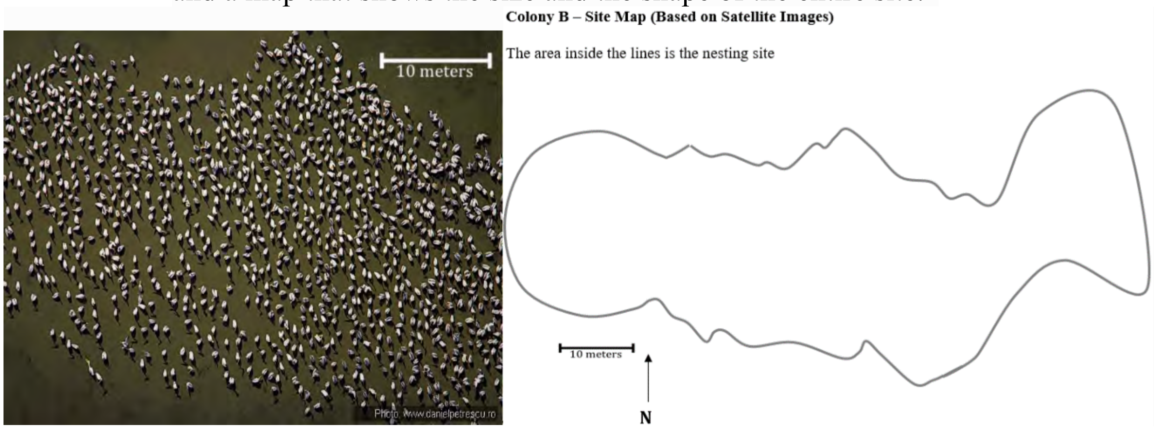
Multiple qualitative data sources were used to characterize the envisioning and enactment of MEAs as vehicles for STEM integration. Written reflections were centered on the participants' perceptions and understandings of STEM integration and the affordances and challenges of using MEAs in mathematics teaching and coaching. Additionally, discussions during and after MEA problem-solving experiences were audio recorded to capture the dynamic nature of conversations and preserve the integrity of the participants' experiences and perceptions. Finally, PD artifacts, mathematics task adaptation charts, and modified curriculum materials provided evidence of the evolution of participant thinking on specific strengths of MEAs and the contextual challenges of implementing MEAs.

Data Analysis

Data gathered was qualitatively analyzed to inform real-time changes in the PD structure and to support longitudinal evaluations of changing conceptualizations of STEM integration. The university researchers examined participant writing prompts at the end of each session as they modified each iteration of the PD to maximize stakeholder involvement and negotiation in design decisions (Fishman, Penuel, Cheng & Sabelli, 2013; Penuel et al., 2011). Group discussions and written reflections provided evidence of beliefs about the potential role of MEAs in mathematics instruction and the emerging challenges of using MEAs to integrate STEM in their classroom contexts. Sample codes that emerged from the analysis of audio recordings and reflection prompts included: reasonable, realistic, teacher buy-in, appreciation of PD design, need for collaboration, student readiness, and time. The reduction of all codes into categories led to the emergence of themes which illuminated the role of PD design decisions in both evoking and alleviating coaches' concerns about introducing and supporting MEA enactments.

Pelican Colonies MEA - Excerpts from Client Memorandum

"The U.S. Fish and Wildlife Service needs a procedure to estimate the number of nests at each pelican colony...We are enlisting your team's help to create a procedure that will allow us to estimate the number of nests in a pelican colony, based on the photograph that shows a sample of the colony, and a map that shows the size and the shape of the entire site."



MEA Design Features	Affordances of Pelican MEA for PD for Mathematics Coaches
Client-Driven	Request from U.S. Fish and Wildlife Service; Context activated by one-page newspaper article; connection to scientific research
Open-Ended	Variety of relevant manipulatives: ruler, tape measure, small beans, transparencies, and markers
Mathematics Similar to Real Life	Multiple K-8 entry points: Multiplication; decomposing area of a polygon into rectangles; measurement; estimation; ratios and proportions; unit rate; random sampling and inferential statistics
Engineering Design Process	Iterative refining and testing

Figure 1. Pelican Colonies MEA Summary and Design Features (Adapted from http://wordpress.unlvcoe.net/wordpress/wp-content/uploads/2013/01/Pelican-Colonies-MEA-Teacher-Materials.pdf.

Findings

Because mathematics coaches have varying school contexts and administrator expectations, the university researchers needed to be responsive to the changing needs of the participants as they engaged in a collaborative journey toward envisioning MEAs as a vehicle for STEM integration with a specific place for K-8 mathematics content. The PD design decisions to provide time and space for peer exploration of MEA resources and to offer a second hands-on experience with an MEA were critical moments in the collaborative journey toward STEM integration in mathematics classrooms. While coaches expressed enthusiasm about the problem-solving potential of MEAs, they also became more fully aware of the pedagogical and leadership challenges they would face in bringing MEAs to classrooms.

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Affordances of a Second Hands-On Experience

As the coaches discussed their experiences with the Survivor MEA during Month 1, they initially focused on the relatability of the context to their lives. They also adopted a teacher lens as they discussed the possibilities of tailoring the context, introducing mathematical language, and completing the written component of the task outside of mathematics instructional time. However, there was no organic discussion of possible application of grade-level content. One of the university researchers needed to prompt the coaches to specifically think about the mathematics content within this MEA.

In contrast, the coaches' second hands-on experience with the Pelican Colonies MEA during Month 3 elicited deeper mathematical thinking that aligned with familiar standards. The centrality and potential flexibility of mathematics application elicited by the Pelican Colonies MEA encouraged the coaches to draw on their content knowledge and past teaching experiences. Mathematics coaches looked at engagement with the MEA through a different lens than Month 1 as they initiated discussions on the multiple mathematical entry points and their grade-level expectations. In Group 1, the district math supervisor acknowledged that her problem-solving approach was consistent with her secondary math experiences. "I thought unit rate, others on the team thought ratio." The other two K-6 mathematics coaches in her group connected to content by drawing on their most recent classroom teaching responsibilities. "Amy said 60 x 19 because that's what we would do in 3rd grade, while I was still thinking ratio because the last grade I taught was middle school." (Jill, K-6 mathematics coach)

Because the previous monthly PD sessions built working knowledge of MEA design features and task design, coaches were able to reflect on the MEA from a teaching perspective centering on mathematical implementation. Yet they also maintained an important attentiveness to client-driven, open-ended, real-world aspects of the MEA. Although the coaches in Group 2 did not progress as far into the task as Group 1, they engaged in an engineering design process. "We did not finish because we took time to think, which the kids need to do" (Mia, 6-8 mathematics coach). Mia also wondered if middle school students would question the purpose of the MEA. "Why are we trying to save the pelicans?" Anticipating potential student responses to the MEA context was essential for the mathematics coaches to think about the future enactments in K-8 classrooms. "Real world to kids is something they can activate - something they can be interested in doing. In middle school it's hard to get them engaged to think something is important."

The university researchers had selected the Pelican Colonies MEA because of its broad potential for K-8 mathematical thinking and for use of manipulatives. The mathematics was more accessible to the coaches than it had been with the Survivor MEA, and the coaches responded by discussing the explicit use of mathematics content without specific prompting by the university researchers.

Coaching Challenges

During Month 3, the coaches transitioned from acting as students to anticipating the unique demands of implementing MEAs in their own schools. Their critical thinking about the potential of MEAs to improve student opportunities to learn was accompanied by a vulnerability they would feel as they introduced MEAs to K-8 mathematics teachers and students. They shared their anxieties about advocating for the use of a resource that they were still exploring.

> Because I am new to MEAs, I feel like I will be entering uncharted territory where I will no longer be the 'knowledgeable other' or expert... It's hard to walk into someone else's classroom. If [the experience] is perceived as a waste, what is the fall out for that? (Jill, K-6 mathematics coach)

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The concern about consequences of failure extended beyond elementary contexts. Mia, the middle school mathematics coach, worried that an unsuccessful MEA could harm her ongoing efforts "to get kids to do more than the teachers." She further wondered how teachers would see MEAs connecting to math, specifically standardized tests and other accountability measures.

> The math piece of it is where I think the teachers will struggle as much as the kids do when we talk about there not being [one] answer. They are at that level where they think there should be [one] answer or [the task] needs to look like the [standardized test] questions. (Mia, 6-8 mathematics coach)

Finally, the coaches articulated concern that students would not be able to make the important "connection between what they are doing and the content that they know" (Jess, K-6 mathematics coach). They also speculated that teachers would assume that the MEA would be too hard for their students.

While the coaches expressed vulnerability with respect to student and teacher readiness, they believed that opportunities to collaborate with other coaches and teachers could build their confidence in addressing these challenges. In her written reflection at the end of the Month 3 PD, Jill described her planned collaboration with another mathematics coach, a STEM coach, and a 3rd grade teacher to "help build buy-in with other teachers, provide more adult support with students, and increase excitement/engagement of the students." Three of the coaches expressed a need for more time to collaborate to develop their MEAs. These needs were shared with district mathematics supervisor as the university-school division partnership planned future directions for the STEM integration PD.

Conclusions

The construction of a *reasonable* and *realistic* STEM orientation for teachers is critical as the education community looks toward connecting STEM integration and mathematics learning. At the beginning, the coaches were challenged to reevaluate their conceptualizations of STEM from prior PD experiences. The university facilitators engaged in real-time iterations of planning, reflecting, and revising as they gauged participant perceptions and responded to participant challenges to connect research to practice. As the coaches iteratively engaged with MEAs, they envisioned multiple entry points within these problem-solving structures with respect to grade-level content and student readiness.

School contexts, administrator expectations, and assessment-driven cultures must inform the ongoing negotiation of STEM implementation. The challenges that the coaches articulated in bringing their MEA designs to the classroom is consistent with prior research on the need for ongoing school-based support. Coaches, teachers, and researchers will continue to engage in this STEM integration design and development process as they reflect upon prototype MEA enactments and redesign resources for wider implementation. Their shared investment in realizing classroom and school STEM integration capacity with a specific focus on mathematics outcomes and coaching contributions will offer a model for STEM integration that challenges "one-size-fits-all" PD, defines a new role for mathematics coaches and teachers as STEM instructional leaders, and promotes meaningful readiness for STEM citizenship and careers for their students. The district supervisor articulated the student-centered possibilities of MEAs that continue to motivate the work of the team. "The kids are acting as mathematicians instead of learning about math."

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