IT IS ART: TEACHER SCAFFOLDING AND STUDENT PROBLEM POSING DURING MATH WALKS AT AN ART MUSEUM

Jennifer Sayed
Southern Methodist University
jsayed@smu.edu

Saki Milton
Southern Methodist University
slmilton@smu.edu

Marc Sager
Southern Methodist University
msager@smu.edu

Candace Walkington, Ph.D.
Southern Methodist University
cwalkington@smu.edu

This study investigates the interactions between informal educators and adolescents during math walk activities at an art museum. "Math walks" are activities where students notice and wonder about mathematics in the world around them, often creating their own "math walk stops" where they ask and answer mathematical questions. Drawing upon theories of informal math learning, scaffolding, and problem-posing, our research aims to enhance understanding of math walk implementation. Through video content, interaction analysis and artifact analysis of participants' iPad photos, we explore students' mathematical learning processes and the role of adult facilitators in guiding these activities. Results from a three-day summer camp are given, and findings offer implications for designing effective informal math education programs and fostering meaningful student engagement with mathematics in real-world contexts.

Keywords: Informal Education, Integrated STEM / STEAM, Middle School Education

Research Purpose and Question

Investigating interactions between informal educators and adolescents in informal learning settings provides valuable insights into students' perceptions of mathematics. "Math walks," or "math trails," a method linking mathematics to real-world occurrences, can foster meaningful dialogues in community-based settings (English et al., 2010; Fesakis et al., 2018; Wang & Walkington., 2023). During math walks, learners critically assess their surroundings with their "math lenses," observing both mathematical and non-mathematical elements, generating and addressing their own questions (Wang & Walkington, 2023). However, the role of informal educators in guiding learners through this process remains underexplored (Sager et al., 2023).

This study explores how informal educators facilitate connections between school math and real-world math during math walk activities at a downtown art museum. Focusing on scaffolding techniques and student-created math walk stops, we aim to address gaps in the literature on informal math learning, where research has documented the challenges that learners have while making connections between school math and real-world math (e.g., Inoue, 2005; Lave & Wenger, 1991; Masingila et al., 1996). Insights from our case study of six students shed light on student-educator interactions and problem-posing processes, with implications for informal math education. Our research questions are: (1) How do student and facilitator interactions unfold during math walk activities as educators employ scaffolding techniques? (2) What are the characteristics of, and problem-posing processes leading to, student-created math walk stops? Next, we present our theoretical framework, methodology, findings, and conclude with a discussion on future research implications.

Theoretical Framework

Students' ability to describe mathematics can be explicit or implicit (Kaur et al., 2013). Explicit forms often involve the use of standard mathematical terminology. Whereas implicit forms involve understanding and using mathematics without explicitly describing it as such, often embedded within real-world contexts, like those found in informal settings, and are influenced by factors such as prior knowledge and cultural background (Kaur et al., 2013). To this end, we draw upon *informal math learning*, *scaffolding*, and *problem-posing* in our study.

Firstly, *informal math learning* research has examined how people use math in their everyday lives and in careers (e.g., Nunes et al., 1993; Walkington et al., 2014). More recent empirical studies on learning math within informal settings has helped to understand program effects on achievement outcomes (e.g., grades, GPA, test scores) in school mathematics (Lauer, et al., 2006; Lynch et al., 2023). Although place-based mathematics education in informal learning environments is gaining increasing interest (Mokros, 2006), research on this topic remains limited (Pattison et al., 2017). They go on to explain that visitors in place-based settings are often unaware of their engagement with mathematics, and that promising mathematical thinking and social interactions around mathematics can emerge in informal spaces (Pattison et al., 2017).

Secondly, *scaffolding* describes the guidance and support a teacher (or knowledgeable adult) provides a student during problem solving activity in a particular learning context (Dingman et al., 2019), namely in the context of adult-child interactions (Stone, 1998). This is to center the students' learning and reasoning through a process of "the adult 'controlling' those elements of the task that are initially beyond the learner's capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of competence" (Wood et al., 1976, p. 90). From their work, we employ four of the six primary scaffolding strategies in our methodology and in our findings: (1) *Recruitment:* the instructor elicits the student's interest in the problem and highlights the requirements of the task. (2) *Direction maintenance:* the instructor keeps the student in pursuit of a specific objective. (3) *Marking critical features:* the instructor highlights or emphasizes the relevancy of certain features of the task. (4) *Frustration control:* the instructor reduces stress from working the problem (Wood et al., 1976, p. 98).

Thirdly*, problem posing* in mathematics education involves teachers and students (re)formulating or expressing new mathematics problems within a specific context, as described by Cai et al. (2023). These tasks require students to generate or shape new problems based on real-life mathematical situations, which include both contextual situations and prompts (Cai, 2022; Cai & Hwang, 2023). Contextual situations provide problem posers with necessary data to craft their problems, while prompts guide students in problem posing tasks (Cai et al., 2023). Creating math walk stops is a problem-posing task with the potential to enhance students' interest in and understanding of mathematics. Studies by Walkington and Bernacki (2014) and Wang and Walkington (2023) highlight the challenges students face in problem posing due to the need for prior math knowledge and familiarity with "school math" norms. Problem posing research offers opportunities to enrich the informal math literature by transcending the constraints of formal "school math." Next, we present methods for data collection and analysis.

Methods

Background Context

This study highlights findings from the second year of the MathExplorer project, a research practice partnership (RPP) connecting a university in the southwestern United States, a STEMoriented nonprofit, and nine informal learning sites. We partnered with informal educators at a local art museum ("Art Museum") to conduct a three-day summer camp. Students from the local community participated, alongside five researchers and supervising professor from the university and the director of the STEM-based nonprofit. The Museum Teacher who led the camp was trained on the app, scaffolding strategies, and problem-posing techniques by the research team.

Student participants used the app to explore real-world objects that they encountered during their math walks at the Art Museum. Accompanied by a facilitator, they gained an understanding of and proficiency in applying mathematical concepts while engaging with objects. During the camp, participants explored selected art pieces each day with the facilitators. They watched previously recorded videos embedded in the App, discussing math concepts related to the informal learning space. Afterward, they freely explored the museum to create their own math walk stops about things they noticed and wondered about in their environment (Sager et al., 2023). At the end of the day, they convened for whole group discussions, sharing their photos and math question(s). On the final day, students presented their math walk stops to the group.

Research Participants

The student participant group was diverse, and relevant demographic information including anonymized pseudonyms is summarized in Table 1.

Table 1: Camp Participants

Name (Pseudonym)	Grade	Race/Ethnicity	Gender
Astrophel Seven (505)	8th	Hispanic/African American	Male
Hamal Slope (201)	3rd	White/African American	Male
Apollo Osmium (202)	4th	White	Male
Zania Copper (203)	6th	African American	Female
Zenith Bit (204)	5th	African American	Female
Daniah Roentgenium (506)	5th	African American and Other (not specified)	Female

Data Collection

We collected video and artifact data while observing students and teachers during the Art Museum's three-day summer camp. Students were divided into partner groups, each paired with at least one adult from either the research team or the Art Museum. Each group was provided with a tablet containing the MathExplorer app. Researchers recorded video footage of each small group using handheld recording devices, resulting in twelve videos totaling 340 minutes of footage. Additionally, we retrieved photos of various artifacts from each participant's iPad, some of which were annotated with markings and included posed questions and answers. All collected data was stored in a shared Box folder, organized by data source type (video, image), group number, and date to facilitate the subsequent analysis.

Data Analysis

This study focuses on three main forms of collected data: demographic surveys, small group video recordings, and walk stop screenshots taken from students' iPads. Transcripts and content logs of videos were manually created by the researchers (Jordan & Henderson, 1995). Eighteen math walk stops were created and shared by camp participants over the three days. Following an iterative process informed by the data analysis spiral (Creswell & Poth, 2018), the authors engaged in systematic reading, viewing, and memoing of data, followed by collaborative meetings to categorize and recategorize codes (Saldana, 2021). Further, the authors rewatched videos, read content logs, and revisited transcripts. We used an inductive process to identify various types of interactions between the adults and students. After two rounds of inductive coding, we categorized interactions by the four scaffolding strategies (Wood et al., 1976). Codes were labeled with a schema (theme-interaction category-type), seen in Table 2 under Findings.

Artifact analysis involved a comprehensive review of student-created walk stops from iPad photos to address the second research question. Authors employed an inductive process to identify walk stop types, categorizing them into explicit and implicit mathematics themes using a "problem-posing-type" schema. Subcodes were generated where necessary to denote specific aspects of the walk stops. A decision was made collectively to classify codes as "explicit school mathematics," "implicit mathematics," or "unrelated" discussed later in detail.

Triangulation involved comparing student-selected walk stops with facilitator-student interactions to understand engagement leading up to each walk stop creation. The process included systematic comparison and integration of data sources to ensure coherence and reliability in the analysis. By using triangulation strategies, our data analysis methods offer a transparent framework for analyzing collected data and generating meaningful insights.

Findings

We present our findings for the qualitative case study by looking at each research question separately. The number of instances we observed for each code is provided in Table 2.

Table 2: Codebook from Interaction Analysis and Artifact Analysis

Code	Definition	Coded As	Example	Count
Scaffolding: Recruitment	Instructor elicits student's interest in problem and highlights requirements of task	Probing (prior knowledge)	"You mean Zeus?"	24
		Probing (connection)	"You think it's interesting? What makes it interesting?"	52

Scaffolding: Direction Maintenance	Instructor keeps student in pursuit of a specific objective	Probing (directive)	"So, remember…at each stop there's gonna be a little video for you to watch…and then there'll be some questions that they ask…"	32
Scaffolding: Marking Critical Features	Instructor highlights or emphasizes relevancy of certain features of the task	Probing (mathematical)	"How can we find the diameter of the eye?	48
Scaffolding: Frustration Control	Instructor reduces stress from working the problem	Probing (redirect)	"It's art."	2
Problem Posing: Explicit School Mathematics	Student explicitly uses school mathematical terms	Measurement, Count, Patterns, and Shapes	"…it was about finding a symmetrical ah a little symmetrical with the white and black arrows."	31
Problem Posing: Implicit Mathematics	Student poses questions about aesthetic elements without using explicit school math terms	Design, Functionality, Artist Motivation	"Q: My question is why is it so colorful and how was it made??"	9
Problem Posing: Unrelated	Student poses questions of situational interest, but not of mathematical interest	Unrelated	"Q: If she sad."	1

RQ1. How do student and facilitator interactions unfold during math walk activities in informal learning settings as educators employ scaffolding techniques?

In addressing Research Question 1, we observed facilitators employing four of the six traditional scaffolding methods (Wood et al., 1976).

Recruitment. Facilitators elicited students' interests as learners observed artworks, sometimes probing students by accessing their *prior knowledge* or making *personal connections*. For instance, Figure 1 illustrates a facilitator-student exchange employing both recruitment strategies. Green highlights indicate scaffolding coded as "probing-prior knowledge" and yellow highlights indicate scaffolding coded as "probing-connection." In this example, and others, the facilitator is eliciting student's interest in the art (situational context) to foster the prompting portion of the problem posing task, as summarized next.

11:37	202	"Can I take more than one picture?"
11:39	Researcher A	"Mmm, hmm."
11:41	202	"Just in the orange?"
11:43	Researcher A	"Would you like to walk around just a little bit more? (pauses for 8 sec) Oh, that's a good picture!"
11:55	202	"What's this?" (taking picture with iPad)
12:10	Researcher A	"202, what do you like about this?"
12:12	202	"It looks like a magician's hat."
12:15	Researcher A	"Okay. What else does it remind you of?"
12:17	202	"Umm, a magician's hat!"
12:22	Researcher A	"What do you notice about it?"
12:25	202	"It looks like a mouth and two eyes."
12:27	Researcher A	"Yeah, okay. (pauses for 3 sec) Do you think it's beautiful?"
12:34	202	"I think it's interesting."
12:36	Researcher A	"You think it's interesting. What makes it interesting?"
12:38	202	"Umm, the thing-a-ma-bob at the top and the thing-a-ma-bob at the bottom. (points to different parts of the object)

Figure 1: Photo-transcription of Museum Teacher Scaffolding by Recruitment

Direction Maintenance. Our analysis also shows facilitators employing direction maintenance techniques (coded as "probing-directive"), to keep students focused on the task of posing mathematical questions. This involved providing explicit directives related to the task, ranging from simple reminders to more descriptive instructions, as exemplified in a transcript excerpt where facilitators guide students through the task step-by-step beginning with the Museum Teacher:

> We can also spread out so we're not like all clustered together to make listening to it a little more easily…Please don't leave the orange area over here…So, you're gonna watch the video, and then you're going to formulate questions and answer the questions. Okay?...

Researcher A, then builds with further instructions to assist a nearby student with using the App's embedded voice recorder:

> You're gonna click on 'record answer' to answer the question that it asks you in the box. (student listens to question) So, what are some math questions you could ask here? (student records herself but has trouble hearing her recording) Can you hear yourself?...Do you want to try again? (student tries again)…Do you have any other questions that you need to answer? Think about another question. You can go look at it if you need to so that you can notice some things. They can be any math questions that you're thinking.

Researcher C, overhearing the adult-student exchange, interjects, "Or any…It doesn't have to be math, just any question you have about this place." This dialogue example is rich with scaffolding techniques that moved students along in the problem posing task including self and group management, technical support, and clarifying the task.

Marking Critical Features. At times, facilitators marked critical features of the artwork, highlighting or emphasizing emphasized the relevancy of certain features of the task. For example, Student 202 is drawn to a large indigenous artifact (shown in Figure 2) stating, “The eyes are really big (30:43).”

Figure 2: Photo Example of Marking Critical Features Taken from Video

Researcher A acknowledges, and then draws attention to the eyes to highlight and emphasize their relevance to the problem posing task, “Okay. Do you see anything on the eyes?” This scaffolding made way for Student 202 to formulate and then pose his question, “I've got a question…What is the diameter of the eye?” It is important to note that scaffolding is also used to mitigate student frustration when seeking mathematical connections with diverse artforms.

Frustration Control. Additionally, facilitators employed frustration control techniques to mitigate student frustrations and maintain focus on mathematical learning. During one session, Student 202 deemed a particular exhibit as inappropriate for kids because it contained nudity. Then, Student 201 agreed how he hoped “nobody makes a walk stop about the naked people”. Researcher A replied, “It’s art,” and Researcher H reinforced, “It is art.” However, the students carried on about “it’d be creepy,” and if there was one it wouldn’t be “for kids.” Researcher A steered the conversation back to mathematical inquiry with a definitive, “All right.”

In addition to facilitator strategies, students described specific characteristics of and the problem-posing process that led to their math walk stops, further enriching our understanding of student-facilitator interactions during math walk activities.

RQ2. What are the characteristics of, and problem-posing processes that lead to, student-created math walk stops?

Students described mathematics in both explicit (coded as “problem-posing-explicit school mathematics-type”) and in implicit ways (coded as “problem-posing-implicit mathematics-type”); “type” refers to more specific characteristics or problem posing processes observed in our analysis. Figures 3a-d illustrate select mathematical examples captured during artifact analysis, categorized by subcodes – *measurement*, *count*, *patterns,* or *shapes*.

Explicit School Mathematics. These codes corresponded closely with the questions students posed during the camp and with their accompanying iPad photos. Firstly, *measurement* questions often pertained to length, such as “how long” (see Figure 3a). Secondly, students inquired about quantities, or *count,* exemplified by questions like, “How many carvings in this photo?” (see Figure 3b). Next, *patterns* revealed students’ describing identified patterns within artworks, posing questions like “How many patterns are there?” (see Figure 3c). Lastly, s*hapes* refer to named or drawn geometric shapes, mostly circles and triangles, as seen in Figure 3d. These explicit school mathematics connections were pronounced during our analysis; however, we also found some implicit mathematical connections as well.

Implicit Mathematics. In contrast, some students described mathematics implicitly, focusing on artistic aspects, namely the object's *design* or *functionality* and the *artist's motivation*. Such descriptions reflect students' ability to see applied mathematical principles in art (Figures 3e-g). For instance, Student 505 questioned the materials used to *design* a clock (Figure 3e), while Student 203 expressed curiosity about an object's usage (Figure 3f), exemplifying *functionality*. Also, Student 204 inquired about an *artist's motivation* for color choices and sewing techniques (Figure 3g). Nine photos fell under this theme, illustrating students' intriguing observations of mathematical applications in art through aesthetic.

Unrelated. Lastly, a student's inquiry about a painting's emotional content (Figure 5d), without any explicit or implicit mathematical connections, highlights the diversity of student responses and interests during the math walk activities.

Our findings present a plethora of observations that underscore the multifaceted nature of student problem posing during math walks. Next, we discuss their significance related to the literature and implications for informal math education.

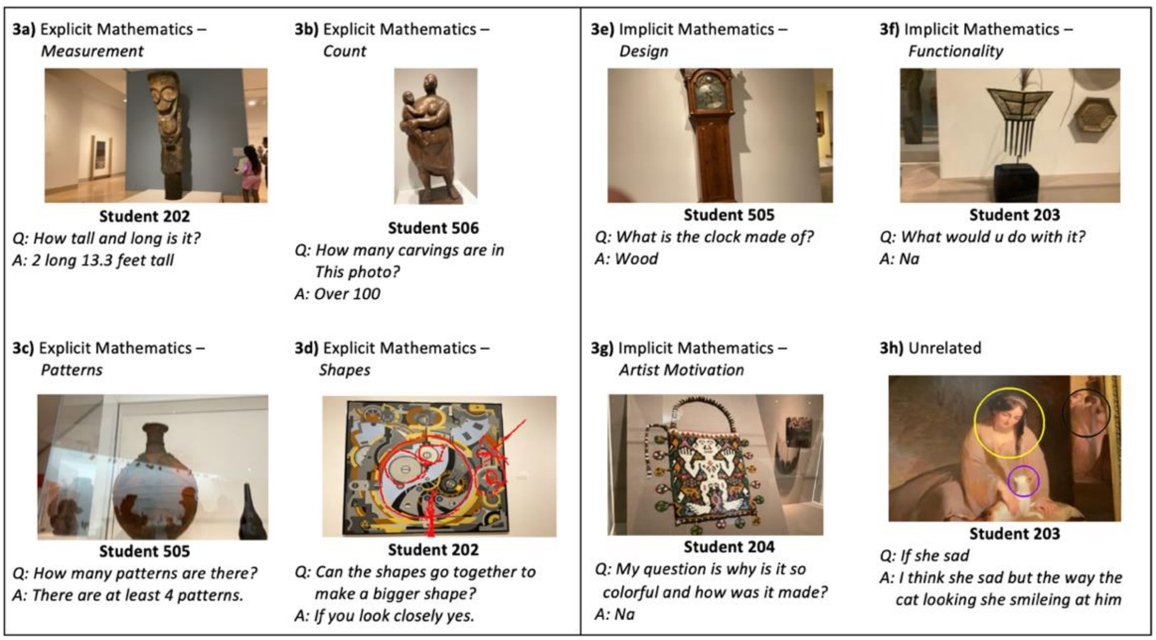

Figure 3: Problem Posing Student Examples (by Codes)

Discussion and Conclusion

While math walks have been identified as an important informal mathematics learning activity, little research has examined how student-facilitator interactions unfold during math walks. Having students generate their own noticings and wonderings from their surroundings is a challenging process, as it involves creativity and the ability to see mathematics as an expansive and situated domain for looking at the world. Here, we show how facilitators can use scaffolding processes like recruitment, direction maintenance, marking critical features, and applying frustration control to make these activities more feasible and rewarding for students, while still allowing students to maintain their independent voice. This offers important guidance for how informal educators can be best trained or prepared to implement math walks – by rehearsing, watching videos of, and discussing these scaffolding strategies.

We also show the kinds of math walk stops students created at an art museum, highlighting the explicit and implicit mathematics they noticed. One striking finding from this study was that the students' walk stops in Figure 3 was quite simple and un-nuanced compared to the rich conversations students had ***while creating*** these math walk stops. Thus, the math walk stops themselves are not the most important demonstration of or product of students' learning from math walks – instead, it is the mathematical discussions that students and facilitators have leading up to the submission of the formal walk stop that best show students' transformations.

Acknowledgments

This work was supported by the National Science Foundation under DRL 2115393. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

Cai, J. (2022). What research says about teaching mathematics through problem posing. *Éducation & Didactique*, *16*, 31–50. https://doi.org/10.4000/educationdidactique.10642

Cai, J., Hwang, S. (2023). Making Mathematics Challenging Through Problem Posing in the Classroom. In: Leikin, R. (Ed.) *Mathematical Challenges For All . Research in Mathematics Education* (pp.115-145). Springer. https://doi.org/10.1007/978-3-031-18868-8_7

Cai. J., Ran, H., Hwang, S., Ma, Y., Han, J., & Muirhead, J. (2023) Impact of prompts on students' mathematical problem posing. *The Journal of Mathematical Behavior, 72(*101087). https://doi.org/10.1016/j.jmathb.2023.101087

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. SAGE Publications.

Dingman, S. W., Kent, L. B., McComas, K. K., & Orona, C. C. (2019). *The language of mathematics education: An expanded glossary of key terms and concepts in mathematics teaching and learning*. BRILL.

English, L. D., Humble, S., & Barnes, V. E. (2010). Trailblazers. *Teaching Children Mathematics*, 16, 402–409. doi: 10.5951/TCM.16.7.0402

Fesakis, G., Karta, P., & Kozas, K. (2018). Designing math trails for enhanced by mobile learning realistic mathematics education in primary education. *International Journal of Engineering Pedagogy*. *8*, 49–63. https://doi.org/10.3991/ijep.v8i2.8131

Inoue, N. (2005). The realistic reasons behind unrealistic solutions: The role of interpretive activity in word problem solving. *Learning and Instruction*, *15*(1), 69–83. https://doi.org/10.1016/j.learninstruc.2004.12.004

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences, 4*(1), 39–103. https://doi.org/10.1207/s15327809jls0401_2

Kaur, B., Anthony, G., Ohtani, M., & Clarke, D. (2013). *Student Voice in Mathematics Classrooms Around the World*. Springer.

Lauer, P. A., Akiba, M., Wilkerson, S. B., Apthorp, H., Snow, D., & Martin-Glenn, M. L. (2006). Out-of-school-time programs: A meta-analysis of effects for at-risk students. *Review of Educational Research*, *76*(2), 275–313. https://doi.org/10.3102/00346543076002275

Lave, J., & Wenger, E. (1991). *Situated learning: legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lynch, K. E., An, L., & Mancenido, Z. (2023). The impact of summer programs on student mathematics achievement: A meta-analysis. *Review of Educational Research*, *93*(2), 275–315. https://doi.org/10.3102/00346543221105543

Masingila, J. O., Davidenko, S., & Prus-Wisniowska, E. (1996). Mathematics learning and practice in and out of school: A framework for connecting these experiences. *Educational Studies in Mathematics*, *31*(1–2), 175–200. https://doi.org/10.1007/bf00143931
Mokros, J. (Ed.). (2006). *Math momentum in science centers*. Cambridge, MA: TERC.
Nuñes, T., Schliemann, A. D., & Carraher, D. W. (1993). *Street mathematics and school mathematics*. https://ci.nii.ac.jp/ncid/BA21077958
Pattison, S., Randol, S., Benne, M., Rubin, A., Gontan, I., Andanen, E., Bromley, C., Ramos-Montañez, S., & Dierking, L. D. (2017). A design-based research study of staff-facilitated family learning at interactive math exhibits. *Visitor Studies*, *20*(2), 138–164. https://doi.org/10.1080/10645578.2017.1404348
Sager M.T., Sherard, M.K., Milton S., Walkington C., & Petrosino, A.J. (2023) Rising in the ranks!: Learning math or playing games? *Frontiers in Education, 8*:1302693. doi: 10.3389/feduc.2023.1302693
Saldaña, J. (2021). *The Coding Manual for Qualitative Researchers*. SAGE.
Stone, A. (1998) The metaphor of scaffolding: Its utility for the field of learning disabilities. *Journal of Learning Disabilities, 31*(4), 344-364. https://doi.org/10.1177/002221949803100404
Walkington, C., & Bernacki, M. L. (2014). Motivating students by “personalizing” learning around individual interests: A consideration of theory, design, and implementation issues. In S. Karabenick and T. Urdan (Eds.), *Advances in motivation and achievement* (pp. 139–176). https://doi.org/10.1108/s0749-742320140000018004
Walkington, C., Nathan, M., Wolfgram, M., Alibali, M., & Srisurichan, R. (2014). Bridges and barriers to constructing conceptual cohesion across modalities and temporalities: Challenges of STEM integration in the pre-college engineering classroom. In S. Purzer, J. Strobel, & M. Cardella (Eds.) *Engineering in pre-college Settings: Research into Practice* (pp.183-210). University Press.
Wang, M. & Walkington, C. (2023). Investigating problem-posing during math walks in informal learning spaces. *Frontiers of Psychology, 14*, 1106676. https://doi.org/10.3389/fpsyg.2023.1106676
Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Child Psychology & Psychiatry & Allied Disciplines*, *17*(2), 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x