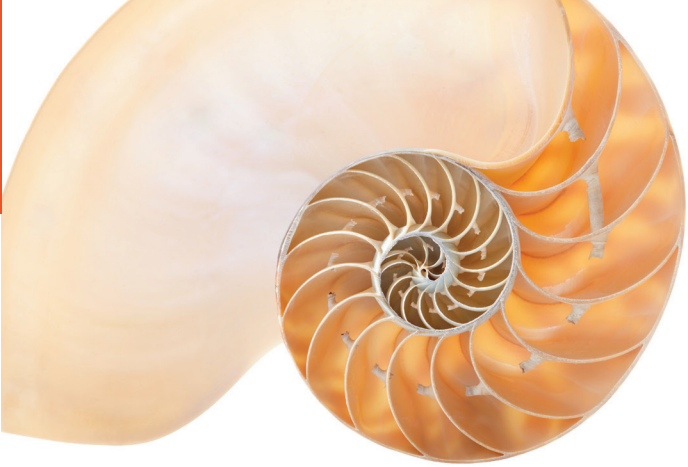
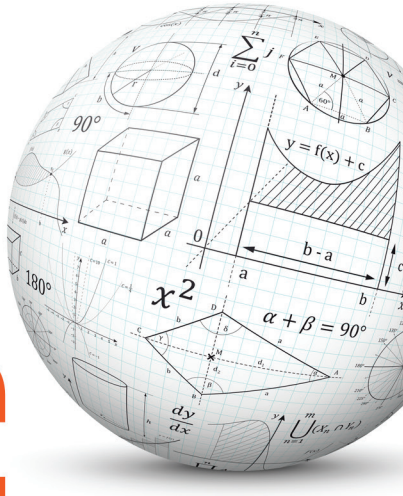
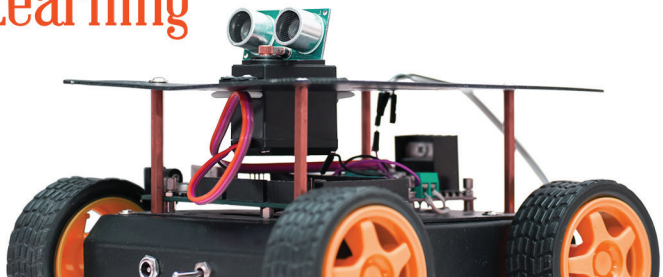


Michelle Stephan
David Pugalee
Julie Cline
Chris Cline



LESSON IMAGING in MATH + SCIENCE

Anticipating Student Ideas and Questions for Deeper STEM Learning



Introduction

To me, lesson imaging is a visualization process. You often hear about athletes visualizing their game. Imaging is a process in which teachers visualize what will take place in their classroom when they present a task.

—George McManus, middle school mathematics teacher, Florida

Imagine that your parents or grandparents are celebrating their 50th wedding anniversary this year. You and your siblings want to plan a special event with lots of family and friends, so you decide to throw a party for them three months from now. With the date decided, you need to think through numerous details carefully. Where will the event take place: the city where they currently live? The city in which most of your family lives? Somewhere central to all? Also, what kind of venue will be needed—a formal setting or more of a "party" atmosphere? Whom will you invite? When do invitations need to be sent? Will it be a surprise? And so on.

As the day gets closer, you excitedly begin to imagine the event in your mind, playing it out activity by activity. You imagine where you will seat certain relatives; you know, for example, that Uncle Lee does not get along well with cousin Meagan, so you should place them far away from each other. As you let the image unfold, you realize that there aren't enough nonalcoholic beverages at the party for those who do not drink, such as cousin Christine. Then you remember that even though your parents love pastries, Auntie Donna is on a diet, so you must make sure there are healthy snacks,

too. Aunt Connie is allergic to fish, so you must provide an alternative to the salmon you'd planned to serve. And of course Aunt Melanie's family will be late, so folks should probably have about 30 minutes to mingle until the major festivities begin. You schedule the speakers, plan the approximate time frame, gather photos to display in the room, and make the final decisions on the food and drinks the caterers will serve.

You have a clear vision of what the program will look like. You can see your parents' best friend, Julie, speaking, and you imagine the joke you will tell as a nice way to get her off the microphone (she is a bit long-winded). You visualize Uncle Mike taking the microphone and telling that "fish story" again—but he often uses colorful language, so how will you manage what he says? And you can't forget the traditional toast that Todd always makes at family occasions! You visualize all the grandchildren and great-grandchildren running around and dancing to the music.

If only the celebration would unfold as your mind imagines it!

We have all had similar experiences when we plan a party, a bat mitzvah, a wedding, and so on. We plan meticulously for every situation that might occur, given the diversity of people attending the event and interacting with one another in both predictable and unpredictable ways. You know your family traditions, relationships, desires, and motivations, and you can more or less envision how the night will play out. Of course, the event *never* happens the way we imagine it will. Sometimes it goes much better than we thought, and sometimes we wish we had never decided to do it in the first place. Nevertheless, you had an image of how people might act, communicate, and relate to one another. You anticipated a potential time line for events to occur and even imagined a bit of a contingency plan in case it didn't go exactly as you expected.

A very similar thought process goes on in what we call *lesson imaging*. When planning for the next day's class, a teacher might imagine what is going to happen when the bell rings to welcome students into first period science. She will have a warm-up activity on the board, and she imagines students taking the first two minutes to get settled and then getting on with the routine they established during the first two weeks of class. Around five

minutes after the tardy bell rings, the teacher anticipates that students will have finished the warm-up activity, and she will have a student explain his or her solution. That shouldn't take more than one minute, and then she can launch into the main exercise for the day. She is really excited about her science lesson because she expects students to be hooked when she shows a short video about the melting polar ice caps. She imagines students getting uncomfortable and a bit worried about the effect of climate change on their environment. The video will take about 15 minutes; she then envisions students writing two reactions to the video and one question in their science journal. After a few students share their reactions, she will state that their work for the next week will center on understanding the effect of human activities on the environment—that one generation's behavior affects the next. The teacher will then launch the major activity for the day. She anticipates how students will engage in a short exploration that simulates the effects of pollution on a small ecosystem. What questions will she ask to help students notice the cause of the dying ecosystem and the effect that pollution has on each part of the whole? What questions might the simulation evoke from students about pollution control? The teacher imagines a prolonged discussion where students raise concerns for the ecosystem and generate ideas about how to become better stewards of the environment. The lesson will end with students writing their ideas about improving pollution control and other actions they can take to preserve ecosystems.

Will the lesson happen as the science teacher imagines? What steps can she take to ensure that the science standards and lesson objectives are met in the student-motivated way she envisions? You might believe that her image will come to fruition if she is passionate enough about science to motivate students. Or you could argue that the catalyst for her image relies solely on the activity she has designed; if it is engaging enough, the lesson will happen just like she imagines. Some teachers might suggest that the right questions will steer the students in this direction. And others will say that a really neat technology program or video will inspire kids to have the deep conversations the teacher imagines.

In this book, we argue that fostering the inspiring, student-driven discussions that support students' deep inquiry into science, technology, engineering, and mathematics (STEM) ideas takes mindful planning and imaging of all the characteristics of a given lesson. A successful STEM unit requires not only displaying passion, choosing engaging activities, asking the right questions, and making effective use of technology; it also necessitates a carefully detailed image of how a chosen activity will play out in the classroom.

Lesson imaging is a term that comes from Alan Schoenfeld's (1998) work on the relationship between teachers' beliefs and goals and the way that teachers expect their plans to unfold in the classroom. In our view, lesson imaging is a pedagogical act during which teachers anticipate the ways in which their planned activities will unfold in interaction with students during real classroom time. It involves a number of practices that go beyond lesson planning. Much like the thought that went into 50th anniversary celebration discussed at the outset, *lesson planning* involves choosing the activities and structuring the time. Lesson imaging goes further by anticipating how students will engage in those activities, the questions they may have, and the questions teachers might ask to promote deeper reasoning about the central goal of the task. In the chapters that follow, we elaborate on our definition of lesson imaging and delve deeply into each component of a lesson image.

Who Is This Book For?

Although teachers can benefit from lesson imaging with any teaching approach, we find it most useful for those teachers interested in learning how to prepare for a more student-centered, inquiry STEM unit.

With direct instruction, the teacher has typically planned a lecture through a PowerPoint presentation or some other text- or lecture-based format. Teachers might ask questions as they provide the facts and explanations, but usually there is little need to anticipate how students are going to engage in the lesson, other than to predict the misconceptions they might have about the information the teacher provides.

With an inquiry approach, however, the teacher presents a problem or laboratory exercise that can provoke students to devise their own ways of

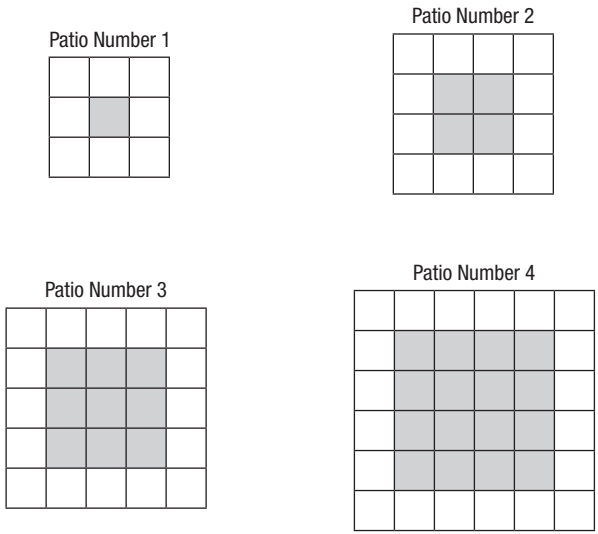
solving the task. Hence, the outcome of the lesson is less controllable than if lecture were the main vehicle for learning. With the more open-ended inquiry approach, lesson imaging gives teachers more insight into and control over the intended direction of the lesson, without heavy-handedly pushing the agenda forward with or without the students' understanding.

An example may help here. Mr. Clark, a 7th grade mathematics teacher, poses a problem to his students (Figure 0.1).

FIGURE 0.1

A Task from *Mathematics in Context*

Terry is designing a tile patio. Her design has an orange square in the middle and a white border around it. These patios can be different sizes. Four sizes are shown.



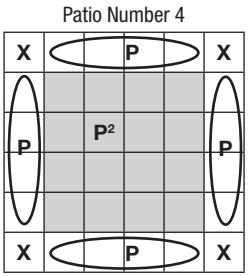
Write a direct formula to express the relationship between the total number of tiles (*T*) in any pattern number (*P*).

Source: From *Mathematics in Context* (p. 11), by T. A. Romberg and J. de Lange, 1998, Chicago: Encyclopaedia Britannica. Copyright 1998 by Encyclopaedia Britannica. Reprinted with permission.

Students discuss the problem and share their formulas. Mr. Clark then calls on Tai, who says he came up with $T = P^2 + 4P + 4$.

Mr. Clark writes Tai's solution on the board. He writes P^2 on the orange part of Patio Number 4; circles each of the four white tiles on the top, sides, and bottom of the figure and writes P inside each circle; and then puts an X on the four corners to show the class how Tai created his formula (Figure 0.2).

FIGURE 0.2
Mr. Clark's Symbolization of Tai's Thinking



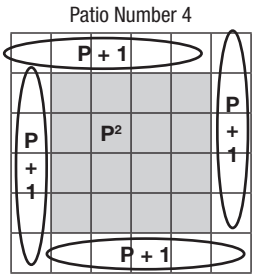
Another student, Tripp, suggests $T = P \times P + 4P + 4$, for very similar reasons.

Mr. Clark is very satisfied with these results and is ready to move on to another problem, when Mary-Riley raises her hand. She suggests another solution: $T = P^2 + (P + 1) \times 4$.

Mr. Clark considers Mary-Riley's solution. Because he had not thought about the problem this way, he has a difficult time, on the spot, determining whether her answer is correct. He tells Mary-Riley that he wants to think about her solution overnight, and then moves on to the next problem.

A teacher who has lesson imaged with colleagues prior to posing this problem might have engaged Mary-Riley and the class differently at this point. Our first question is to you, the reader: is Mary-Riley's solution valid? What does the $P + 1$ stand for in the picture? Try to figure that out before looking at the diagram (Figure 0.3).

FIGURE 0.3
A Symbolization of Mary-Riley's Thinking: $T = P^2 + (P + 1) \times 4$



The diagram shows that Mary-Riley was structuring the picture into four sets of $P + 1$ tiles plus the P^2 tiles on the inside. Indeed, if one simplifies the expression $P^2 + (P + 1) \times 4$, it is equivalent to both Tai's $P^2 + 4P + 4$ and Tripp's $P \times P + 4P + 4$. Really creative students might even write $T = (P + 2) \times (P + 2)$.

But the question remains: so what?

From a social point of view, capitalizing on Mary-Riley's contribution in the moment might instill a positive mathematical disposition in her and show the rest of the class that there is more than one way to solve the problem.

However, there is another powerful reason to discuss her solution. While one goal of the lesson is to write equations from spatial figures, another mathematical idea that can be explored here is equivalent expressions and equations. Without having to teach simplifying equations in a traditional

lecture format, the teacher can ask the class if Mary-Riley's equation is correct or not. Answering that question could be a mini-exploration by students, with the arguments centering on equivalence and simplification.

Lesson imaging includes anticipating as many different solutions as possible. It can help teachers not to be surprised by new solutions, where they must decide in the moment whether a proposed solution would contribute to the mathematical ideas for the lesson.

We argue throughout this book that when teachers engage in the act of lesson imaging prior to instruction, the lesson objectives will be attained more naturally and powerfully from the students than if the lesson were not imaged. Particularly when using an inquiry form of instruction, lesson imaging is crucial so that discussions don't stall and students' ideas are used most powerfully to drive instruction toward important content objectives.

What Are the Components of Lesson Imaging?

Once a worthwhile task has been selected, teachers should imagine how the lesson will unfold by considering the following components:

- Unpacking the lesson objective
- Talking through how to launch the task
- Anticipating how students will engage with the task and what their misconceptions might be
- Deciding which strategies will be presented and in what order
- Deciding what questions to ask to provoke reflection
- Determining what counts as evidence that students have understood the ideas

Almost 10 years ago, we decided to create a lesson imaging template in order to facilitate teachers' discussions that occur as an inquiry activity or scientific exploration is planned. Our template was inspired by the lesson planning of Japanese mathematics teachers (Stevenson & Stigler, 1992), who anticipated both how students will solve the problem the teacher poses and some questions the teacher will use to respond to students' misconceptions. Our template combines both ideas (Figure 0.4).

FIGURE 0.4

Lesson Imaging Template

Science, Technology, Engineering, or Mathematics Goal(s): **State Standard(s):**
Cycle 1
Launch (Task presentation)
Exploration (Anticipated student thinking—include class structure [in small groups, with partners, individually] and potential correct and incorrect strategies or solutions)
Whole-Class Discussion (Include tools, symbolizing, technologies, and questions you might pose)
Cycle 2
Launch (Task presentation)
Exploration (Anticipated student thinking—include class structure [in small groups, with partners, individually] and potential correct and incorrect strategies or solutions)
Whole-Class Discussion (Include tools, symbolizing, technologies, and questions you might pose)
Assessment (Evidence of student learning)

This template includes two cycles of exploration, in case teachers are imaging for a block day in which two or more activities can be accomplished. If there is time for a third activity, the teacher can modify the template by adding a Cycle 3. If the class period allows for only one exploration, teachers can skip the second cycle.

The lesson imaging template encourages teachers to begin by unpacking the meaning of the goals they are targeting in the lesson for the day. Are the goals merely procedural skills and practice, or are they more conceptual in nature? For example,

- What does it mean to *understand* photosynthesis?
- What concepts underlie engineering the most stable bridge?

When teachers unpack what it takes for students to understand the content, the activity, exploration, and student discussion will all be more fruitful.

The second major component of the template involves imaging how to launch an exploration that forms the crux of the lesson. The launch is the part of the lesson where teachers pose the problem or experimentation, *not* where they teach students everything they need to know in order to solve the task. Sometimes teachers miss the point of the launch by telling students how to do the exploration rather than letting students explore themselves.

The third and fourth components of lesson imaging entail anticipating students' solutions and then deciding which ones to capitalize on in whole-class discussion. How does the teacher decide which questions to ask to promote powerful ideas in class? What role does symbolizing play in supporting rich discussion? If students actually construct the solution strategies the teacher anticipated, how does the teacher then structure the whole-class discussion so that students share their ideas in a way that builds in an organized fashion and results in the mathematical or science ideas coming to the forefront? The answers to these questions are quite complex and will be explored more deeply to enhance inquiry instruction.

The template ends with an assessment block in order to encourage teachers to write down how they will document student learning each day. Whether through student observation or some type of formal document

(e.g., exit slip, homework, quiz), teachers should ensure that some type of assessment is done after each lesson, which will form the basis for lesson imaging for the following class period.

The Catalyst for This Book

Together, we have more than 75 years of experience teaching mathematics and science and working with teachers to help them shift their practice toward an inquiry approach in the STEM fields. Whether as mathematics and science coaches or professional development leaders, we have found that preparing for inquiry-based explorations is best accomplished when teachers work together to lesson image their instruction.

Both Julie Cline and Christopher Cline have worked as science and mathematics teachers for 22 and 21 years, respectively. Because of their success in the classroom, they were asked to coach other teachers in their school regarding lesson imaging in STEM classes. Additionally, they have each presented numerous times in their district about how to support learning communities of teachers who lesson image on a regular basis. They have practiced and promoted lesson imaging firsthand in their own and other teachers' classrooms.

Michelle Stephan was a tenured university professor who left academia to teach middle school mathematics for seven years. During that time, she taught using an inquiry approach and coached teachers in her own school and in schools throughout a large district in Florida. (It was here in 2007 that the idea of lesson imaging began to grow and the lesson image template was formed for use by other teachers throughout the United States.) Stephan is now a tenured faculty member in the College of Education at the University of North Carolina at Charlotte.

David Pugalee is the current director of the Center for STEM Education at the University of North Carolina at Charlotte. He entered higher education after more than a decade teaching middle and high school mathematics and science. His experiences in the classroom raised many questions for him about the role of language and communication in promoting student

learning, and he has since worked to improve STEM teaching and learning by focusing on rich experiences that promote students' development of STEM literacy, which is described in more detail in Chapter 1. Lesson imaging is a natural fit, as it provides a tool for exploring instructional planning as a critical component in promoting this vision of student learning.

About This Book

Chapter 1 addresses the meaning of *STEM literacy* and how teachers can effectively incorporate technology and other STEM areas into instruction.

Chapter 2 explores ways to unpack the goals and objectives of a lesson, the resources that teachers can draw on to accomplish this, and how to choose worthwhile problems and explorations that support the lesson objective.

Chapter 3 discusses how to launch an exploration that forms the crux of the lesson.

Chapter 4 looks at how to anticipate students' solutions and then decide which ones to capitalize on in whole-class discussion. How does the teacher decide which questions will promote powerful ideas in class? What role does symbolizing play in supporting rich discussion?

Chapter 5 explores the process of imaging a productive whole-class discussion, following student exploration time.

Chapter 6 brings together all the chapters by "walking through" a full lesson image, with snippets from the actual classroom in which the lesson was taught.

The final chapter examines how teachers can start this process, how STEM mentors and coaches can help teachers engage in lesson imaging, the role that administrators can play in supporting their teachers, and what resources are needed from administrators.

Before Reading Chapter 1 . . .

Consider these questions before moving on to the next chapter:

- How do *you* define STEM literacy?

- What are the important components to consider in a STEM lesson?
- What dispositions do you believe are important for your students to develop in STEM classes?

References

Akyuz, D., Stephan, M., & Dixon, J. K. (2013). Improving the quality of mathematics teaching with effective planning practices. *Teacher Development*, *17*(1), 92–106.

Battista, M. (2004). Applying cognition-based assessment to elementary school students' development of understanding of area and volume measurement. *Mathematical Thinking and Learning*, *6*(2), 185–204. doi:10.1207/s15327833mtl0602_6

Battista, M. T., & Clements, D. H. (1996). Students' understanding of three-dimensional rectangular arrays of cubes. *Journal for Research in Mathematics Education*, *27*(3), 258–292.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. In P. Griffin, B. McGaw, & E. Care (Eds.), *Assessment and teaching of 21st century skills* (pp. 17–66). Dordrecht, the Netherlands: Springer.

Bloom, B. S. (Ed.). (1972). *Taxonomy of educational objectives book 1—Cognitive domain*. New York: David McKay Company.

Campbell, P. F., & Malkus, N. N. (2010, May). *The impact of elementary mathematics coaches on teachers' beliefs and professional activity*. Paper presented at the annual meeting of the American Educational Research Association, Denver, CO.

Campbell, P. F., & Malkus, N. N. (2011). The impact of elementary mathematics coaches on student achievement. *The Elementary School Journal*, *111*(3), 430–454.

Cheuk, T. (2012). *Relationships and convergences among the mathematics, science, and ELA practices.* Palo Alto, CA: Stanford University. Retrieved from http://ell.stanford.edu/content/science

Clarke, D. (2014). *Disciplinary inclusivity in educational research design: Permeability and affordances in STEM education.* Retrieved from http://stem2014.sites.olt.ubc.ca/files/2014/07/Permeability-and-Affordances-inSTEM.pdf

Cobb, P., & McClain, K. (2006). The collective mediation of a high-stakes accountability program: Communities of networks and practices. *Mind, Culture and Activity*, *13*(2), 80–100.

Cobb, P., Yackel, E., & Wood, T. (1989). Young children's emotional acts while engaged in mathematical problem solving. In D. B. McLeod & V. M. Adams (Eds.), *Affect and mathematical problem solving* (pp. 117–148). New York: Springer Verlag New York.

Collins, J. C. (2001). *Good to great: Why some companies make the leap… and others don't.* New York: HarperBusiness.

Committee on Standards for K–12 Engineering Education & National Research Council. (2010). *Standards for K–12 Engineering Education.* Washington, DC: The National Academies Press.

Costa, A. L., & Garmston, R. J. (1994). *Cognitive coaching: A foundation for renaissance schools.* Norwood, MA: Christopher-Gordon.

Davis, B. (1997). Listening for differences: An evolving conception of mathematics teaching. *Journal for Research in Mathematics Education, 28*(3), 355–376.

Delors, J. (2013). The treasure within: Learning to know, learning to do, learning to live together and learning to be. What is the value of that treasure 15 years after its publication? *International Review of Education*, *59*(3), 319–330.

Dieker, L. (2001). What are the characteristics of "effective" middle and high school co-taught teams for students with disabilities? *Preventing School Failure*, *46*(1), 14–23.

DuFour, R. (2004). What is a professional learning community? *Educational Leadership*, *61*(8), 6–11.

English, L. (2015). STEM: Challenges and opportunities for mathematics learning. In K. Beswick, T. Muir, & J. Wells (Eds.), *Proceedings of the 39th Conference of the International Group for the Psychology of Mathematics Education* (Vol. 1, pp. 3–18). Hobart, Australia: International Group for the Psychology of Mathematics Education.

Evagorou, M., Erduran, S., & Mäntylä, T. (2015). The role of visual representations in scientific practices: From conceptual understanding and knowledge generation to "seeing" how science works. *International Journal of STEM Education*, *2*(1), 1–13.

Feger, S., Woleck, K., & Hickman, P. (2004). How to develop a coaching eye. *JSD: The Learning Forward Journal*, *25*(2), 14–18.

Fuchs, D., Fuchs, L., & Burish, P. (2000). Peer-assisted learning strategies: An evidence-based practice to promote reading achievement. *Learning Disabilities Research and Practice, 15*(2), 85–91.

Harrison, R., Higgins, C., Zollinger, S., Brosnan, P., & Erchick, D. (2011). Mathematics Coaching Program fidelity and its impact on student achievement. Brief research report. In L. R. Weist & T. Lamberg (Eds.), *Proceedings of the 33rd Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 1545–1553). Reno, NV: University of Nevada, Reno.

Herbel-Eisenmann, B., & Breyfogle, M. (2005). Questioning our patterns of questioning. *Mathematics Teaching in the Middle School*, *10*(9), 484–489.

Hurd, P. D. (1958). Science literacy: Its meaning for American schools. *Educational Leadership*, *16*, 13–16, 52.

Inoue, N., & Buczynski, S. (2011). You asked open-ended questions, now what? Understanding the nature of stumbling blocks in teaching inquiry lessons. *The Mathematics Educator*, *20*(2), 10–23.

International Technology Education Association. (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed.). Reston, VA: Author. Retrieved from https://www.iteea.org/File.aspx?id=67767&v=691d2353

Jackson, K., Shahan, E., Gibbons, L., & Cobb, P. (2012). Launching complex tasks. *Mathematics Teaching in the Middle School, 18*(1), 24–29.

Kamii, C. (1982). *Number in preschool and kindergarten*. Washington, DC: National Association for the Education of Young Children.

Karahan, E., Guzey, S., & Moore, T. (2014). Saving pelicans: A STEM integration unit. *Science Scope*, *38*(3), 28–34.

Killion, J., & Harrison, C. (2006). *Taking the lead: New roles for teachers and school-based coaches*. Oxford, OH: National Staff Development Council.

Kowal, J., & Steiner, L. (2007, September). *Instructional coaching*. The Center for Comprehensive School Reform and Improvement. Issue Brief (1–8).

Lappan, G., Phillips, E. D., Fey, J. T., & Friel, S. N. (2013). *Connected Mathematics 3. Thinking with mathematical models: Linear and inverse variation.* Boston: Pearson.

Mack, N. (2001). Building on informal knowledge through instruction in a complex content domain: Partitioning, unit, and understanding multiplication of fractions. *Journal for Research in Mathematics Education*, *32*(3), 267–295.

Mathematics Learning Study Committee. (2001). *Adding it up: Helping children learn mathematics*. Washington, DC: The National Academies Press.

Mehan, H. (1979). "What time is it, Denise?" Asking known information questions in classroom discourse. *Theory into Practice*, *18*(4), 285–294.

Murray, S., Ma, X., & Mazur, J. (2009). Effects of peer coaching on teachers' collaborative interactions and students' mathematics achievement. *Journal of Educational Research*, *102*(3), 203–212.

Nan-Zhao, Z. (2008). *Four "pillars of learning" for the reorientation and reorganization of curriculum: Reflections and discussions.* Paris: UNESCO. Retrieved from https://www.ibe.unesco.org/cops/Competencies/PillarsLearningZhou.pdf

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common Core State Standards.* Washington, DC: Authors.

Neufeld, B. (2002). *Using what we know: Implications for scaling up implementation of the CCL model.* Cambridge, MA: Education Matters, Inc.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by state*s. Washington, DC: The National Academies Press.

Organisation for Economic Co-operation and Development. (2007). *PISA 2006: Science competencies for tomorrow's world: Volume 1: Analysis*. Paris: Author. doi: 10.1787/9789264040014-en

Perkins, S. J. (1998). On becoming a peer coach: Practices, identities, and beliefs of inexperienced coaches. *Journal of Curriculum and Supervision*, *13*(3), 235–254.

Piaget, J. (1948/1973). *To understand is to invent*. New York: Grossman.

Polya, G. (1957). *How to solve it: A new aspect of mathematical method* (2nd ed.). Princeton, NJ: Princeton University Press.

Prud'homme-Généreux, A. (2011). *The evolution of human skin color*. Buffalo, NY: National Center for Case Study Teaching in Science, University at Buffalo, State University of New York. Retrieved from http://sciencecases.lib.buffalo.edu/cs/files/skin_pigmentation.pdf

Puttnam, D. (2015). Learning to be—Do our education systems do enough to enable learners to flourish as independent, autonomous and well-balanced individuals? *European Journal of Education*, *50*(2), 120–122.

Quarteroni, A. (2009). Mathematical models in science and engineering. *Notices of the American Mathematics Society, 56*(1), 10–19.

Romberg, T. A., & de Lange, J. (1998). *Mathematics in context.* Chicago: Encyclopaedia Britannica.

Schoenfeld, A. H. (1998.) Toward a theory of teaching-in-context. *Issues in Education, 4*(1), 1–94.

Smith, M., & Stein, M. (2011). *Five practices for orchestrating productive mathematics discussions*. Reston, VA: National Council of Teachers of Mathematics.

Stage, E. K., Asturias, H., Cheuk, T., Daro, P. A., & Hampton, S. B. (2013). Opportunities and challenges in Next Generation Standards. *Science*, *340*(6130), 276–277.

Steen, L. A. (2003). Data, shapes, symbols: Achieving balance in school mathematics. In B. L. Madison & L. A. Steen (Eds.), *Quantitative literacy: Why numeracy matters for schools and colleges* (pp. 53–74). Princeton, NJ: National Council on Education and the Disciplines.

Stephan, M., Akyuz, D., McManus, G., & Smith, J. (2012). Conditions that support the creation of mathematical communities of teacher learners. *NCSM Journal of Mathematics Education Leadership*, *14*(1), 19–27.

Stephan, M., & McManus, G. (2013). *Pre-interviewing as formative assessment*. Paper presented at the Bi-annual International Symposium in Elementary Mathematics Teaching, Prague, Czech Republic.

Stephan, M., McManus, G., & Dehlinger, R. (2014). Using research to inform formative assessment techniques. In K. Karp (Ed.), *NCTM annual perspectives in mathematics education: Using research to improve instruction* (pp. 229–238). Reston, VA: NCTM.

Stephan, M., McManus, G., Smith, J., & Dickey, A. (n.d.). *Ratio and rates.* Retrieved from http://cstem.uncc.edu/sites/cstem.uncc.edu/files/media/Ratio T Manual.pdf

Stephan, M., Underwood-Gregg, D., & Yackel, E. (2014). Guided reinvention: What is it and how do teachers learn this teaching approach? In Y. Li (Ed.), *Transforming mathematics instruction: Multiple approaches and practices*, *Advances in Mathematics Education* (pp. 37–57). Cham, Switzerland: Springer International Publishing.

Stephan, M., & Whitenack, J. (2003). Establishing classroom social and sociomathematical norms for problem solving. In F. Lester (Ed.), *Teaching mathematics through problem solving: Prekindergarten–grade 6* (pp. 149–162). Reston, VA: National Council of Teachers of Mathematics.

Stevenson, H. W., & Stigler, J. W. (1992). *The learning gap: Why our schools are failing, and what we can learn from Japanese and Chinese education*. New York: Summit Books.

Thompson, A., Philipp, R., Thompson, P., & Boyd, B. (1994). Calculational and conceptual orientations in teaching mathematics. In *1994 yearbook of the National Council of Teachers of Mathematics* (pp. 79–92). Reston, VA: National Council of Teachers of Mathematics.

Travers, K. J. (1993). Overview of the longitudinal version of the Second International Mathematics Study. In L. Burstein (Ed.), *The IEA study of mathematics III: Student growth and classroom processes* (pp. 1–27). New York: Pergamon.

Underwood, D. (2002). Building students' sense of linear relationships by stacking cubes. *Mathematics Teacher*, *95*(5), 330–333.

Underwood, D., & Yackel, E. (2002). Helping students make sense of algebraic expressions: The candy shop. *Mathematics Teaching in the Middle School, 7*(9), 492–497.

Voigt, J. (1995). Thematic patterns of interaction and sociomathematical norms. In P. Cobb & H. Bauersfeld (Eds.), *The emergence of mathematical meaning: Interaction in classroom cultures* (pp. 163–201). Hillsdale, NJ: Lawrence Erlbaum.

Warshauer, H. K. (2015). Strategies to support productive struggle. *Mathematics Teaching in the Middle School*, *20*(7), 390–393.

Welborn, J. (2013). 99.99%: Antibacterial products and natural selection. *Science Scope*, *37*(4), 58–68.

West, L., & Staub, F. C. (2003). *Content-focused coaching: Transforming mathematics lessons.* Portsmouth, NH: Heinemann; and Pittsburgh, PA: University of Pittsburgh.

Wiggins, G., & McTighe, J. (2005). *Understanding by design* (2nd ed.). Alexandria, VA: ASCD.

Yackel, E., & Cobb, P. (1996, July). Sociomathematical norms, argumentation, and autonomy in mathematics. *Journal for Research in Mathematics Education*, *27*(4), 458–477.

Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics*, *112*(1), 12–19.

About the Authors

Michelle Stephan, EdD, is an associate professor of mathematics education with a joint appointment in the College of Education and Department of Mathematics and Statistics at the University of North Carolina at Charlotte. She earned bachelor's and master's degrees in pure mathematics and in 1998 earned an EdD in mathematics education from Peabody College of Education at Vanderbilt University. After working as an associate professor at Purdue University Calumet, she left academia for the classroom, where she taught middle school mathematics for seven years in Florida. It was there that she began to explore the ideas of lesson imaging with her middle school teaching colleagues George McManus, Jennifer Smith, and Ashley Dickey. In 2012, Stephan became faculty at the University of North Carolina at Charlotte and began a collaboration with coauthors David Pugalee, Julie Cline, and Chris Cline. Together they have presented on lesson imaging at numerous conferences and provided professional development for several North Carolina school districts. Stephan has published a dozen book chapters and more than 25 journal articles, and she has made more than 50 presentations both nationally and internationally.

David Pugalee, PhD, is a professor of education at the University of North Carolina at Charlotte, where he serves as director of the Center for Science, Technology, Engineering, and Mathematics Education. He earned his PhD in mathematics education from the University of North Carolina at Chapel

Hill and has also taught at the elementary, middle, and secondary levels. With more than a decade of experience teaching mathematics and science, he has published research articles in *American Educational Research Journal, Educational Studies in Mathematics,* and *School Science and Mathematics*. His works include several books and book chapters published by the National Council of Teachers of Mathematics. In addition, Pugalee has published two books on communication and mathematical and scientific literacy: *Writing to Develop Mathematical Understanding* and *Effective Content Reading Strategies to Develop Mathematical and Scientific Literacy*. His research interest is the relationship between language and mathematics teaching and learning.

Julie Cline earned a bachelor's degree in education from Wingate University in North Carolina. She has taught middle school mathematics for 22 years and recently earned National Board Certification in Mathematics/Early Adolescence. After being introduced to Michelle Stephan, Cline began exploring lesson imaging in her practice. As the leader of her professional learning community, Cline encouraged other teachers to join her in using lesson imaging. She has provided professional development in her district as well as presented at several conferences. Cline continues to support teachers at her school in her current role as math facilitator.

Chris Cline is a graduate of the University of North Carolina at Charlotte, and holds a Bachelor of Arts degree in mathematics and a master's degree in mathematics education. He is also a National Board–Certified Teacher in Mathematics/Early Adolescence. Cline has taught 7th and 8th grade mathematics for 21 years. Three years ago, he incorporated lesson imaging into his practice and since has provided professional development in his district and has presented at several conferences. Cline has served as math facilitator at his school and has supported and coached colleagues.