

Transformative Professional Development Through Integrated STEM



INTRODUCTION

Having taught math for nine years, I (Percy) needed to find more in-depth and individualized professional development and decided to embark on a full-time master's degree in mathematics education program. I wanted to know everything there was to know about student mathematical thinking, and it was eye-opening to realize that there was such a huge world of mathematics education research that I had never heard about that was helpful for my practice.

Upon graduating, I hoped to build bridges between my math teacher colleagues and math research in order to continually refine our knowledge of student thinking. I wanted teachers to consider what it is that we do as math teachers, why we do it, why the students need it, and how to make our teaching better. However, I soon recognized that, because they were so busy with daily responsibilities, encouraging my colleagues to bring research into their practice was a challenge.

In my 13th year of math teaching in 2016, I joined a new kind of team of teachers, one that I'd never been on before but had heard about for years: an integrated science, technology, engineering and math (STEM) teaching team. We were

responsible for teaching students through three years of a brand new three-block integrated STEM course, and we were supported by external collaborators from the Knowles Teacher Initiative. I was suddenly immersed in developing and teaching the Global STEM Challenges Program in Fairfax, Virginia.

Integrated (or sometimes “integrative”) STEM learning is “problem-based learning that purposefully situates scientific inquiry and the application of mathematics in the context of technological designing/problem solving” (Sanders, 2009, p. 21). The integrated portion means we are not just math teachers but science, engineering, and technology teachers too. We came to the conclusion that, in order to make this program work, we couldn’t be driven by our own disciplines. Instead, we needed to be driven by student thinking: striving to find out what it is and how to improve it.

Through teaching integrated math in the program and in close collaboration with my team and Knowles collaborators, including my co-author Katey Shirey, my understanding of student thinking improved tremendously, both in and out of the integrated STEM course itself. In particular, I learned how exploring mathematics through its many applications and using multiple modalities for learning helps to unveil misconceptions and contributes to teachers’ understanding of student thinking.

Together, Katey and I have unpacked my reflections over the years in informal conversations as well as in formal meetings, classroom visits, and planning sessions. As collaborators, we’ve discussed the many ways that teaching integrated math has shifted my thinking about how students learn. I’ve come to recognize that teaching integrated math has had a more positive influence on my understanding of student thinking than traditional, non-integrated professional development (PD). Realizing this is an important outcome, Katey and I are excited to share in this article what we’ve uncovered and how it might encourage other teachers to try integrated math teaching.

THE PITFALLS OF TRADITIONAL PD FOR TEACHER DEVELOPMENT AND INSTRUCTIONAL CHANGE

Learning how to teach integrated math in our school’s STEM program has not involved PD as teachers usually define it. While there is coaching and reflective support, we’re not experiencing an external intervention of the kind that’s usually impressed upon teachers in a typical PD. Instead, we’re collaborating as a team to

design and to teach the integrated math, science, design and technology course material in a novel environment that is rich for learning about student thinking.

Typical in-service PD and higher education coursework are designed to help teachers acquire knowledge about how students learn and adapt it to their contexts (Darling-Hammond & McLaughlin, 2011). We know that teachers hope to expand their teaching skills, defeat stagnation in teaching, improve student learning, and learn new pragmatic and usable ideas for their classrooms during PD. However, it doesn't take a research base to tell us that PD often receives lukewarm reception from teachers. Teachers' negative reactions to PD is due to inconsistencies between the needs of teachers and the design and outcomes of the PD, which results in low implementation (Guskey, 2002).

PD sometimes ignores research on adult learners, lacks actual classroom-related content, or discounts best teaching practices in its delivery (Borko, 2004; Guskey, 2002). For instance, say you go to a professional development training on student learning through multiple modalities. You might spend an entire hour listening to someone read a Powerpoint presentation on multiple modalities with lots of examples and ideas, and yet you recognize that this instruction is being conveyed through only one modality—oral.

In my experience, three things might happen after training like the one I've described. One, as a "seasoned" teacher, you feel you rarely get anything out of PD, so you tune out the training and your teaching doesn't change. Two, because the presentation was overloaded with information on several current trends in multiple modalities instruction, you leave the training feeling so overwhelmed that you end up trying none. Three, you leave the PD determined to use one new approach for leveraging multiple modalities in your instruction. However, since you used it to repackage old unit material, the application of what you learned is merely superficial. Teachers who fall into the third category believe that the training included good ideas but become frustrated and overwhelmed because it took a lot to come up with a brand new approach for just one unit. They realize they can't keep the effort up all year, so they revert back to their old packaging and begin to doubt the utility of the material presented at PD training in general.

In PD sessions like the one I described above, we teachers are expected to learn "new knowledge" and incorporate it into our work. PD in this sense is a form of filling in the gaps or adding new practices, so-called "additive PD." Additive PD

leads to an emotional response: an overwhelming feeling of needing to do more and profound insecurity about what to actually do. Eventually, we might also experience feelings of defeat because our learning was so superficial that our implementation lacked staying power.

INTEGRATED STEM INSTRUCTION AS A TRANSFORMATIVE PD EXPERIENCE

In contrast to additive PD, “transformative PD” (Thompson & Zuili, 1999) seeks to make holistic transformations in practice that are more sustainable and useful (Barlow, et al., 2014). Teaching integrated math has been a transformative professional learning experience for me. In our school’s integrated STEM courses, we introduce math through the contexts of solving real-world engineering challenges that require a combination of math, science, technology, designing, and problem solving. The contextual nature of integrated STEM instruction provides opportunities for me to learn about and use meaningful applications of math in my instruction, to gain experience with multiple student modalities, and to reveal student misconceptions. Below, Katey and I discuss three of my teaching practices that were transformed by teaching integrated STEM.

Creating meaningful applications for math through connections

Connections is a National Council of Teachers of Mathematics (NCTM) process standard (National Council of Teachers of Mathematics, 2000). Yet, in my single-content math classes, it is rare to see how the students take the content and apply it elsewhere. Furthermore, it can be challenging as a content expert in math to invent opportunities which lead to deep and meaningful connections from math to other subjects or phenomena.

In our integrated STEM program, however, my students are presented with wildly open-ended problem spaces that require them to work from all STEM perspectives—science, math, technology, and engineering—on one problem. The choices that the students make create connected contexts for math applications as they work without me having to contrive the connections.

For instance, in one project, students are asked to create a chemical heating or cooling device for an application of their own choice. (Readers might recognize the idea at the center of this unit as a common chemistry endothermic/exothermic lab where students optimize a hand warmer.) Student projects have included coffee heaters, reusable self-heating gloves, an avalanche-melting helmet, self-warming baby blankets, and self-cooling t-shirts for the gym. Students’ focus as

they find rates and functions to describe their experimentally-derived heating curves is much more intense than when I teach math content areas out of context. Because the students are able to choose the application they will explore, they pick something with meaning to them. I've also noticed that students interrogate their data for mathematical patterns more intently when they are invested in a context that they control.

I'm learning that student choice in modalities and application allows the students to tailor the math learning for themselves!

Overall, I've found that when the mathematical application has more personal meaning, students forge stronger connections back to the concepts embedded in the challenge and their new math content knowledge. I always knew this type of teaching would work, especially after reading about the link between context and learning from authors like Jo Boaler (1998), but I never really saw it work until I experienced the integrated context. I used to say "plug in a number" to help my students connect abstract expressions to more relatable numbers, but integrated STEM brings the connection into physical reality. Logarithms are much more concrete when used to describe hydrogen ions present on the pH scale; trig functions more relatable when used to describe the tides, the orbit of the moon, or the rotation of a windmill. Since teaching integrated STEM, I've even started to ask my non-STEM International Baccalaureate® math classes, "Who's taken physics?" because I know that it will be more valuable to connect calculus to physical motion and vectors when possible.

Accessing multiple modalities

My integrated STEM teaching team quickly realized that accessing multiple modalities when we teach has a profound impact on student learning in our program. Building on multiple intelligences (Gardner, 1999), individualized learning (Dunn & Dunn, 1972), and cognitive science, the term multiple

modalities refers to the various techniques that teachers can use in the classroom to address their students' needs as learners. Examples include lecture-based teaching, skills-based teaching, technology-enhanced teaching, individual teaching, group teaching, and inquiry-based teaching (Bransford, et al., 2000). It was clear to the team that we could understand more about students' thinking if we restructured both instruction and assessment using multiple modalities as a lens.

By providing lots of student agency, we found we created a wide variety of teacher-led and student-led learning opportunities. The choices our students get to make mean that their thinking is explored and expressed within their favored modality as they work— which allows me to better understand their thinking. Among our integrated STEM teaching team, “multiple modalities” has become shorthand for the variety of ways that students choose to interact throughout each day and with each unit. By observing their choices and the artifacts we produce, we are able to learn more about how students are processing and learning.

One method we use consistently to provide space for multiple modalities is under-defining our design challenges and problem-solving procedures; this way, students have to proceed within their own modes of working and learning. For instance, our 10th-grade students are asked to design a digital tool for communicating information from a large Chesapeake Bay dataset to local stakeholders. First, they must select information to analyze based on stakeholders' concerns and decide what kind of communication platform they'll design (i.e., programming phone apps, storyboarding websites, or illustrating a children's book and teachers' guide). I can take advantage of their comfort and interest in the platform they select to discuss with them how they will share the data most efficiently in that mode and for that audience. As a result, students develop a nuanced fluency about the dataset and make decisions while justifying their choices, all while using and communicating appropriate data analysis.

Our STEM classes also capitalize on multiple modalities by using common science representations in math and technology applications across the program. We strive to express quantities and relationships with graphs and algebraic expressions in addition to numbers. We also ask students to write sentences to describe mathematical relationships; reviewing the writing provides insight into students' understanding of the phenomena at hand. These modalities are

automatic in STEM and flatten the notion that graphs or equations only belong to one discipline.

I was surprised by how naturally this all developed out of integrated math instruction. I'd learned from Nicholson-Nelson (1998) in her celebrated book, *Developing Student's Multiple Intelligences*, that "by knowing our students' strengths and weaknesses, we can tailor individual projects and activities to help students learn in their own way" (p. 71). I've found that integrated STEM goes well beyond the expectation that I should differentiate the learning experience for my students. Instead, I'm learning that student choice in modalities and application allows the students to tailor the math learning for themselves! I just try to keep up by providing more, different, or contrasting skills and perspectives to keep nudging them along toward mathematical mastery.

Unveiling student misconceptions

In my master's program, I learned about Piaget's theory of cognitive development and the enormous body of research dedicated to student misconceptions in math and science (Confrey, 1990). I had been under the impression that "once the student misconceptions are identified, teachers can work to remedy the faulty conceptions with appropriate instructional approaches" (Gurel, et al., 2015, p. 993). I was taught to look for common misconceptions in student work or assessments so that I could highlight, interrogate, and correct the misconception. But by teaching integrated STEM, I've had more access to student thinking, including identifying misconceptions, than traditional math instruction allows.

By listening and responding to student mathematical needs, the math I'm teaching is immediately relevant.

Since the STEM program's design challenges are open-ended, students are less inhibited to share what is truly in their minds. They are more inclined to share

their thoughts through their perspectives, in their own chosen modality, and using their own terminology. Instead of looking for a particular, known misconception, I can pick up on ways that students might be misinterpreting a relationship, a concept, or inappropriate tools based on their own words. In my math-only classes, students are frequently tuned into the math that they should be using because it is the topic of the lesson or unit. In integrated STEM, the bounds for what math is appropriate to use are loosened, and students are asked to bring forward whatever math that they need for a given problem or situation. If I notice a misconception, or a lack of skills that might be helpful, I can adjust my instruction to deliver a useful lesson or reminder. For instance, when students discuss data and designs, I often hear them pose questions that might be better answered with different mathematical tools, which I can then teach them in a responsive way. By listening and responding to student mathematical needs, the math I'm teaching is immediately relevant.

I can use the context of the challenge to learn more about student confusions regarding the underlying math. For example, we teach a unit that involves defining the motion of space debris falling from low Earth orbit to teach kinematics, which incorporates both physics and calculus to describe the relationships between position, velocity, and acceleration. Often, we think our students understand the rules that connect accelerated motion through calculus when they can recite "velocity is the derivative of position" and "acceleration is the derivative of velocity"—so we move on.

During a recent kinematics lesson in the space debris unit, I heard students discussing acceleration due to gravity with some misunderstandings laced throughout. One student said, "When you throw an object in the air it goes fast then slow and then fast again so acceleration must not be constant." Whoa, I thought, let's see where this goes! Other students agreed and disagreed explaining their reasoning. Okay, I thought, the students are confusing acceleration with velocity, and speed, which I can address. But to me, even more exciting than identifying their confusion was finding it through their conversation! I didn't have to wait until a difficult question on a quiz or test prompted a long conversation to reveal that my students really did not understand how acceleration affects velocity. Instead, their confusion was raised during a group's discussions while the students were expressing a need and desire to want to find the answer.

POTENTIAL CONCERNS

Katey and I wrote this article with the hopes that other teachers will try integrated STEM for the reasons articulated above, but we also recognize that teachers might have some concerns. For one, teachers might be afraid that they don't have enough knowledge in the other STEM fields to pull this off. Rest assured, your primary content knowledge is adequate to get started, and you'll learn a lot about the other subjects as you go. I have personally learned so much about science and technology from collaborating with my colleagues and listening to what students bring to the challenges, that I consider this a learning opportunity for me!

Teachers might be concerned that they'll never be able to tackle all of the needed STEM content in a math classroom. Fear not, your students have additional assets that they will draw upon: other teachers, other student teams, and other hours of the day. I feel much more secure knowing that I am not solely responsible for resolving all of the students' concerns in an integrated unit. In fact, it might be an asset that I can't resolve all of them—it makes the students take more agency for their learning.

But to me, even more exciting than identifying their confusion was finding it through their conversation!

Finally, teachers might worry that if they're not doing the math curriculum in some known order, optimized for maximum efficiency, then their instruction won't maintain rigor or pacing. This is a false dichotomy. Revisiting content throughout the year as an actual project when needs arise gives credence to the usefulness of mathematics; it's not simply a unit that once tested can be forgotten. I've not seen any lack of rigor when the instruction is responsive instead of following a traditional sequence. As math teachers have always known, there is math

everywhere and connected to everything, so there is no shortage of appropriate mathematical content to teach. By planning with my colleagues, I can ensure that we will have time to do what I hope to do while staying in sync with the team.

CONCLUSION

Teachers of integrated STEM can learn so much about how students learn and how to support them from teaching this way. Learning math in a STEM classroom context feels genuine to students and creates opportunities to work within multiple modalities, increase their ownership of the learning process, and feel empowered to make decisions. Students are required to express the mathematical reasoning for their decisions and how math is used in various contexts. As a result, I have been able to access a more authentic representation of students' productive reasoning along with their misconceptions.

Through my experience of teaching integrated STEM, I have come to appreciate it as an opportunity for transformative PD; it is relevant to my teaching context, addresses my students and my own learning needs, aligned with math standards, grounded in reflection, and experienced within a community of teachers. For my colleagues and me, this experience has been more beneficial for our professional growth than traditional PD.

For more information on Percy's integrated STEM course, visit

<https://edisonhs.fcps.edu/academics/stem>.

To learn more about how this integrated STEM course was planned, visit

<https://www.sciencedirect.com/science/article/pii/S2095809917307403>.

Download Article

***Percy Canales**, a math teacher in Fairfax County (Virginia), has 15 years of math education experience ranging from junior high to college settings. In addition to teaching STEM, he currently teaches the IB Higher Level Math classes at Edison High School. Reach Percy at pcanales@fcps.edu.*

***Katey Shirey**, a Knowles Senior Fellow, is a STEAM education consultant for eduKatey, LLC., and a member of the Knowles Engineering Leadership Team, through which she brings her experience as a high school physics teacher and*

sculptor to her work with teachers and students. Reach Katey at katey.shirey@knowlesteachers.org.