Designing Technology Activities that Teach Mathematics

By Eli M. Silk, Ross Higashi, Robin Shoop, and Christian D. Schunn

Teaching mathematics in a technology classroom requires more than simply using mathematics with technology. It requires designing the lesson to focus, motivate, and highlight the mathematics in a meaningful way.

Introduction

Some teachers believe that if mathematics is integrated into technology education lessons, then students will become mathematically competent. We agree that many activities commonly found in technology classrooms have the potential to develop students' mathematical literacy (Litowitz, 2009). We also believe there are a number of important benefits to targeting math within technology instruction. When students define a technological design problem mathematically they develop more sophisticated solutions and understandings of those solutions. Mathematics taught within well-designed technology education lessons provides students opportunities to learn math in contexts that they understand and that can lead to cross-discipline connections. Finally, in this era of high stakes accountability, contributing to math instruction helps convince school and district administration that technology education should continue to be supported.

On the other hand, research conducted by our team suggests that, just because the math is present in an activity, it doesn't mean that students will learn math. Over the past three years, our team has conducted research in middle and high school classrooms in an effort to improve the effectiveness of robotics to teach science, technology, engineering, and mathematics (STEM) education—our focus has been on math. We have found that subtle changes in the design and setup of the lesson make a substantive difference in what students learn. In this article, we share our experiences in redesigning a lesson that uses robotics technology to teach proportional reasoning in order to generate some general principles for effectively teaching math in the context of technological problem solving.

Designing and Redesigning a Robotics Unit to Teach Math

As curriculum developers and learning science researchers, we have had many experiences helping teams of students solve technological design problems in robotic competitions and in designing formal classroom curricula intended to teach STEM concepts through robotics. Building on those experiences, our goal in this project was to design a unit that would tightly connect formal mathematics concepts with technological design in an integrated way, instead of developing either in isolation. In other words, we wanted to make the students' design goal in the unit activities so tightly interwoven with an important math idea that the students couldn't help but learn about the math in order to solve the design problem.

With that goal in mind, we designed the *Robot Synchronized Dancing* (RSD) unit. RSD began as a redesign of an existing STEM unit from the Robotics Academy, which focused on learning the mathematics of basic robot movements (Photo 1). We modified the activities so that they were contextualized within a design problem and narrowed the mathematical focus to target proportional reasoning.

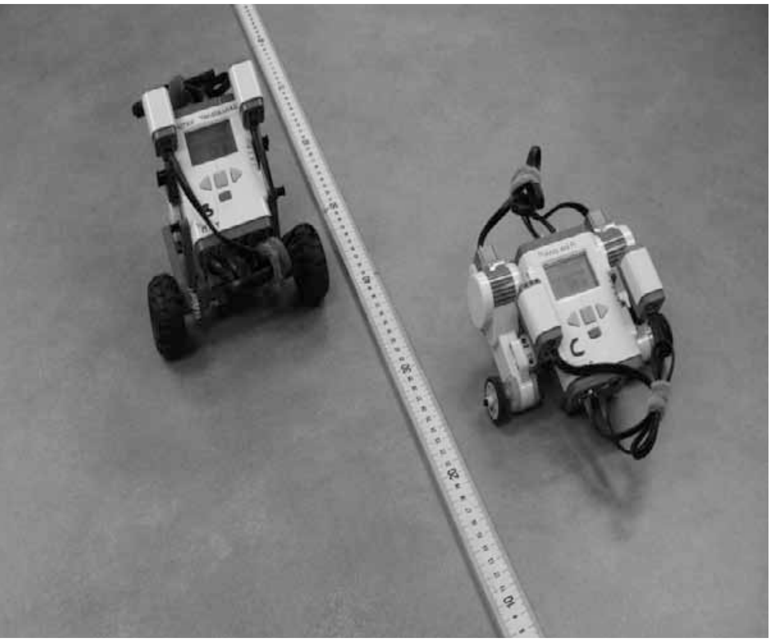

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Photo 1. When programming the number of wheel rotations, the distance a robot travels forward is a function of the size of its wheels.

Proportional reasoning is a foundational mathematics concept that relates to a wide range of situations in everyday life and in the workplace, such as those that involve unit rates, mixtures, or scaling (Cramer & Post, 1993; Langrall & Swafford, 2000). Proportional reasoning is also central in understanding how a robot's movements can be controlled, as the relationships between the physical construction of the robot, the values used to program the robot, and how the robot actually moves are often proportional in nature. This led us to our initial unit design that challenged students to program robots of different sizes so they danced in sync with each other. (See Photo 2 and Silk, Schunn, & Shoop, 2009.)

Over the past year, we tested and redesigned the RSD unit. We implemented the unit with middle school students in technology education classrooms, in after-school programs, and with teachers who came to the Robotics Academy to learn how to teach robotics. In this article, we explain some of the design principles that we found useful in redesigning RSD, using examples from that redesign experience to make the principles concrete. The principles, as summarized in Table 1, address sustaining student engagement, targeting key content, generalizing understanding, and explaining to others. These principles may be helpful for any teacher interested in redesigning his or her own technology activities to better target mathematics.

Principles for Designing Technology Activities to Teach Math

Principle 1 – Motivate Sustained Engagement Through Problem Design

Deep learning requires challenging students to revise deep-seated beliefs about a given subject, but initial interest alone is not sufficient to carry a student through a lengthy renovation of beliefs. The design of the activity must both promote student engagement at the beginning of a lesson and actively maintain it through the unit's end.

Robotics, like many high-tech fields, is inherently "cool." This is a great boost to student interest initially, and an invaluable attention-getter for kicking off a lesson. RSD and its precursors have long "played the robot card" to get students' attention for the critical first few minutes.

However, those first few minutes are all that initial coolness buys, especially once it becomes clear that real

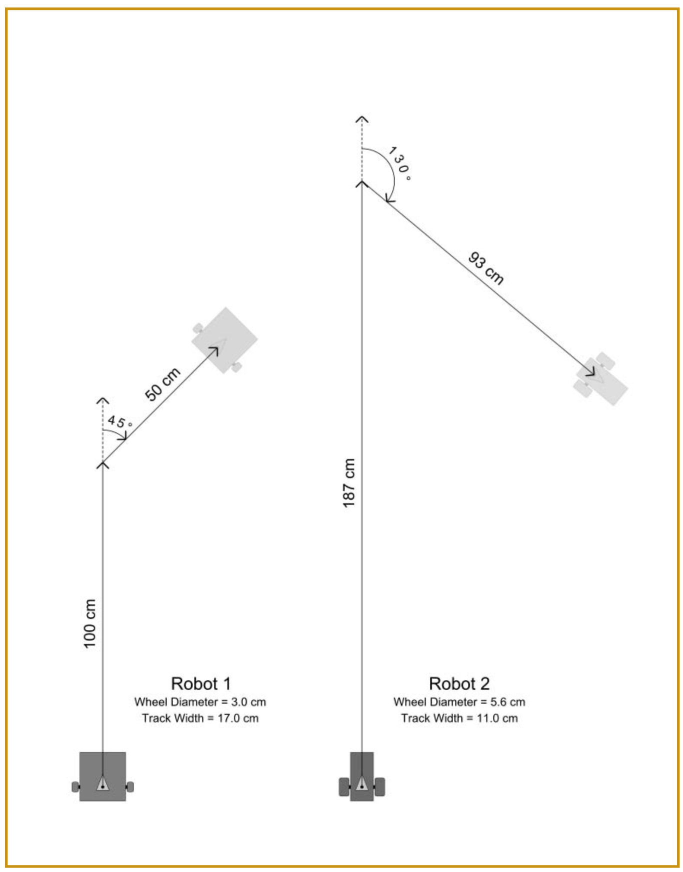

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Photo 2. Two robots of different sizes out of sync when putting the same program on both robots. The design problem in the RSD unit is to develop a toolkit for putting these two robots in sync with each other.

Task Design Goal	Solution	RSD Initial	RSD Revised
Engagement	**Principle 1** Contextualize in a design problem	Solve the design problem of getting different-size robots to dance in sync with each other	
Focused Content	**Principle 2** Foreground the target ideas	Create a dance routine, specify the routine, then synchronize across robots	Synchronize using given initial prototype design that highlights the sync problem
Generalization	**Principle 3** Make the process the product	Get the robots to do your routine in sync	Create a toolkit for synchronizing that will work for any routine
Explanation	**Principle 4** Communicate ideas to a client	Create routine to demonstrate to others	Create toolkit for a dance team choreographer to understand, use, and adapt

Table 1. Features of the RSD problem setup and framing that were redesigned from the initial version to the current version.

work is involved. In one implementation of the STEM unit that preceded RSD, a student had a revelation part way through the activity: "This is math!" he said, and subsequently dropped out of the discussion. This is not to say that math is diametrically opposed to interest. On the contrary, the student had been participating quite willingly in the math-based activity up until that point. We should instead interpret the student's comment to mean that our treatment of the subject had exhausted its initial "coolness" and not done enough to replenish that interest.

In order to increase the level of "coolness" retention over time, the original STEM activity was redesigned from an inquiry activity in which students verified given mathematical relationships to a dance synchronization activity. The addition of music styling and dance choreography provided a positive reminder of the "coolness" of the project every time students ran their robots to the music—even as their intermediate solutions didn't yet get their robots to dance fully in sync!

Additionally, RSD included a second level of interest-retention as part of a larger structural revision toward being a design-based activity. In the original STEM activity, students performed a series of simple tasks in a predefined order, with a discussion of mathematics principles after each. This produced an ordered series of concepts, but lacked a strong common thread or end goal.

The redesigned RSD unit, by contrast, is design-based (Sadler, Coyle, & Schwartz, 2000). Students are given a "cool" theme up front as their design goal—robots that dance together—and reminded and encouraged to connect their efforts back to this theme at every step. Doing so is an important part of the design process (aligning work to goals), but also reinforces the connection of the work to the context. In essence, the design process' insistence on contextualization helps the new RSD problem to continue to dispense "cool" over time.

The dual problems of attaining and sustaining student interest should be addressed deliberately but naturally through the design of the activity's problem and structure. RSD builds on strong, attractive themes (robotics and dance) to get students' attention, and then employs a student design-based structure to actively ensure that the activity remains connected to those themes.

Principle 2 – Motivate On-Target Thinking Through Foregrounding

Maintaining interest—difficult and requisite though it may be—is not all that is necessary to achieve the learning objectives of the lesson. Students also need to become cognitively engaged with the target math ideas.

Designing effective learning activities so that they align with target objectives requires more than just a checklist matched to a list of standards. In fact, the fewer boxes you try to check off in a lesson, the better. Instead, the content must be targeted, precise, and narrow (Silk & Schunn, 2008). One way to do this is to repeatedly "foreground" the desired content while temporarily pushing other concepts into the background. This helps to ensure that students are devoting their time and effort to the parts of the problem that will be most beneficial to their learning of the target ideas.

In the initial RSD design, students were asked to design a robot dance routine and to implement it on several robots with different wheel sizes. In doing so, we believed students would have to address the underlying proportional relationships between robots with different-sized wheels.

Instead, students focused on specifying dance routines. Students spent up to 12 hours developing precise choreography and measuring each dance move individually. Only after this lengthy process was completed did they begin to think about the issue of synchronizing across different robots.

Certainly, measurement is relevant, related, and contextually appropriate, but was not the target of the unit. Allowing students to focus on measurement added instructional time without doing anything to address the target ideas. Measurement did not receive the proper treatment either.

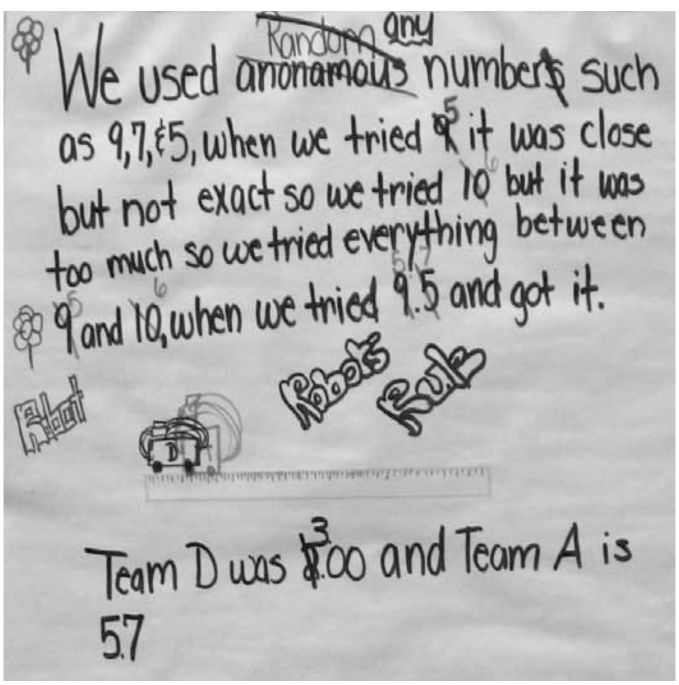
The revised version of RSD attempts to foreground the challenging aspects of the synchronization problem, while moving to the background the related but noncentral problems. We do this by providing an initial prototype design in the form of a "given" dance routine specification and a "control" robot that they can compare their results against side-by-side. Additional "givens" include a working program (to minimize programming as a distraction) and a careful choice of robots that makes the lack of synchronization obvious (Photo 2). See Sadler et al. (2000) for other examples of providing initial prototype designs and the advantages of doing so.

The initial prototype design intentionally makes the desired focal problem (lack of synchronization) very salient to students, thus pushing it to the foreground as all the other concepts are being pulled to the background. In the revised RSD design, students are able to begin thinking about the target content—proportionality—on the very first day of instruction. They recognize right away that different robots are not in sync and begin the key work to solve that problem using ideas related to proportionality.

Effective learning requires that content be targeted and specific. The target content must be brought to the forefront, and other concepts—even closely related ones—subsumed into the background. RSD uses an initial prototype design to foreground the target proportionality content, and provides "givens" to keep related-but-not-central concepts from competing for attention.

Principle 3 – Motivating Generalization by Making the Process the Product

Even after students are actively interested and thinking about the target aspects of the design problem, challenges remain in getting them to think about the mathematics at a deep level. The essence of mathematics understanding is to be able to describe the general aspects of situations—referred to as generalization. In many lessons, once students solve a concrete problem, there is rarely an



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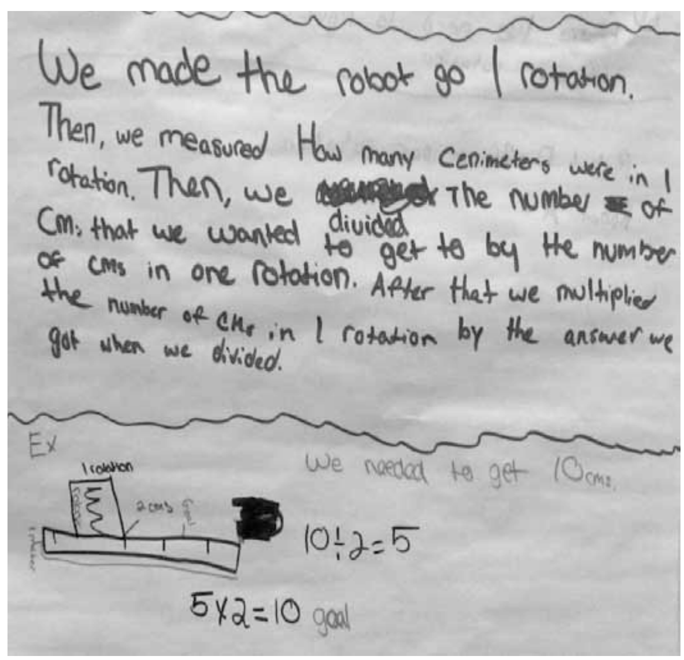

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Photo 3. Examples of student solutions to synchronizing straight distances. A guess-and-check solution (left) and a more general solution (right).

inherent incentive for figuring out the more general problem. For example, after a student successfully programs a robot to move forward 50 centimeters, that experience rarely motivates him or her to figure out a general relationship between the size of the robot's wheel and how far it moves. We found that if we really want this mathematical generalization to happen, then we can't just ask for it as an additional thing to do. Instead, we make mathematical generalization the primary focus from the beginning and make the generalization itself be the actual final product.

We designed our initial RSD unit assuming that by asking students to make a dance routine that would incorporate a range of different moves (at different distances, angles, and speeds) and a range of different size robots (that varied on their wheel size and track width), that they would need to generalize their understanding to solve the problem. Contrary to our expectations, students spent their efforts getting their dance routine to "look" synchronized. Consistent with this, the majority of synchronization solutions that students developed were versions of guess-and-check in which they continually tweaked parameters in their program until the robots looked visibly in sync with each other (Photo 3). These solutions did not give them insight into the underlying general relationships.

In the RSD redesign, we revised the problem setup so that the generalization task wasn't just an add-on, but was an essential part of any solution. We were inspired by model-eliciting activities (MEAs)—developed originally for middle school mathematics classrooms, but used increasingly in undergraduate engineering settings (Hamilton, Lesh, Lester, & Brilleslyper, 2008). A main principle of MEAs is that authentic, real-world situations are carefully chosen such that the situation itself motivates a need to create a general mathematical model. To this end, we made a subtle, but substantive change to how the problem was presented to students. Instead of a synchronized dance routine being the final product, the students' goal was to make a "mathematical toolkit" for synchronizing dancing robots with any dance routine. In doing so, from the start of the unit, we emphasize that the end goal is a general solution, and that the particular dance routines and robots we were using were just examples to help us get to that more general end goal. Solving the immediate, concrete goal (i.e., getting the two example robots to be in sync for the given example routine) was desirable, and probably also a necessary step along the path, but was no longer sufficient as an ending point.

Principle 4 – Motivating Explanation by Incorporating a Client

As a final concern, even when we were successful at getting students to develop general mathematical solutions, it continued to be challenging to get them to communicate their ideas explicitly. Students can learn a lot by simply explaining their ideas to themselves and to others (Lombrozo, 2006). But explanations are also important because they are the primary way teachers can assess what students understand. Similar to generalization, too often in classroom activities students see requests to explain their thinking as an additional thing to do without being centrally important for solving the problem. Our fourth design principle was to modify the problem setup so that students' end goal wasn't to design something that they understood, but rather, to design something that someone else, a client,

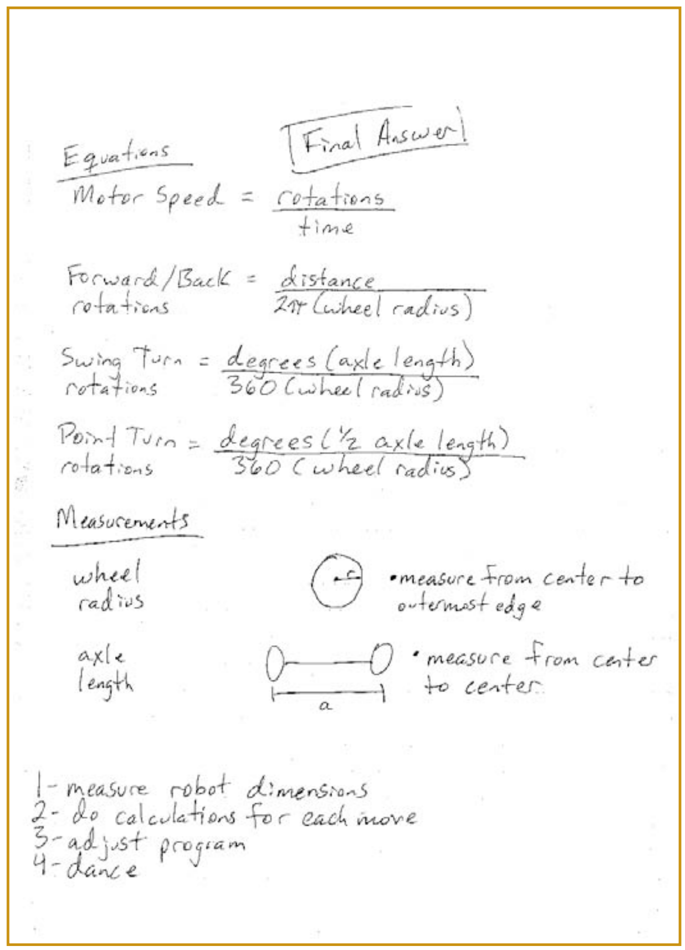

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Photo 4. Example of a complete solution, but one that only provides the steps to follow rather than explaining why the quantities used were included and why they have the relationships that they do.

could understand. Again, we were inspired by MEAs, which make use of client-driven tasks to motivate communication of ideas. (For an excellent example of the redesign of an activity according to MEA principles see Lesh, Hoover, Hole, Kelly, & Post, 2000.) By incorporating a client into the design goal, the activity provides an authentic reason for students to explain their thinking.

In RSD, the original design goal was for each team of students to create its own dance routine that would work on all of the robots. Although we asked each team to share resulting ideas, there was nothing in the problem itself that made explaining those ideas necessary. Our revised design challenges students to design a synchronized toolkit for a fictional client—a dance team captain who choreographs routines for robots. The client is requesting a synchronization toolkit that will be easy to understand and adaptable to many different dance routines. This change combines aspects of generalization from Principle 3 with the need to communicate the ideas in a way that the client will understand and be able to use effectively.

In addition to how the problem is presented, our experience suggests that we need to provide further support for students in providing these explanations as the activities are enacted. That is, even though the problem is now better framed to motivate explaining, actual forming of high-quality explanations will still be difficult. In many cases, students generate explanations that are limited to descriptions of what steps to do (i.e., what to measure, what to calculate, what to put in the program and where. (See Photo 4.) These types of explanations don't clarify what the steps mean, why and how they work, or how they could be adapted, which would be much more useful for communicating understanding to the client. To help students, we need to provide them with multiple opportunities to explain their ideas, to have real clients that the students must explain to (especially clients who aren't familiar with the robots), to model higher-quality explanations they can use as examples, and to provide timely feedback. When these resources are provided, students are able to generate higher-quality explanations that communicate deep understanding.

Conclusion

Overall, this process of redesigning robotics problems according to these principles takes time and effort. But we believe that it is doable and worth the effort because of the payoff in learning mathematics at a deep level.

Robot Synchronized Dancing

Bots-N-Sync is a robot dance team that specializes in doing synchronized dances—many robots doing the same dance moves at the same time. They are hugely popular thanks to the power of the Internet. They record videos of their routines and post them on YouTube. Although they have only completed two routines so far, both videos have gone viral with millions of viewers.

The Problem

The team is growing a large and devoted fan base by encouraging their fans to submit dance routines online on the team's website. The captain of the *Bots-N-Sync* team likes to see if a routine is good by getting the entire dance team do the routine together. The problem is that each dance routine is designed for the team's original robot, *Justin Timberlake,* but the robots on the dance team are all different. When the captain first downloads a dance routine to all the robots, each robot moves in different ways, and they are definitely not in sync with each other. In the past, when the team worked on just one dance routine at a time and with only their original team of robots, "guess-and-check" to adjust each move individually for each robot was tiresome but did work. Now, though, with routines being submitted each day and the increasing pressure from fans to put out fresh videos, they need a much better solution.

Your Job

Create a "how to" toolkit that the *Bots-N-Sync* captain can use to modify submitted dance routine programs so that all of the dancers do the routines in sync with each other. New dance routines are submitted often, and new dancers will be joining the team regularly. So, a good toolkit would work for the current dance routine, but an ideal toolkit would be easy to use or adapt for new routines and new robots. An ideal toolkit would also include explanations of why the solution works, so the captain can easily understand how it works and how it can be adapted later for other similar situations. Your toolkit can utilize words, numbers, graphs, pictures, and/or any other form that effectively conveys your ideas and meets the needs of your client, the *Bots-N-Sync* captain.

And, because this occurs in the context of a technology education activity, it effectively bolsters both subjects.

As you redesign your technological design problems, the iterative redesign attitude is a good one to hold. The principles provide some clues regarding whether changes have improved the task and where critical improvements are still needed: (1) Are students interested to see the problem through?; (2) Do they talk about the math that you are trying to teach?; (3) Is the math simple, numerical equations obtained by guess-and-check, or do the students develop general equations?; and (4) Do students provide explanations about the math in their solutions?

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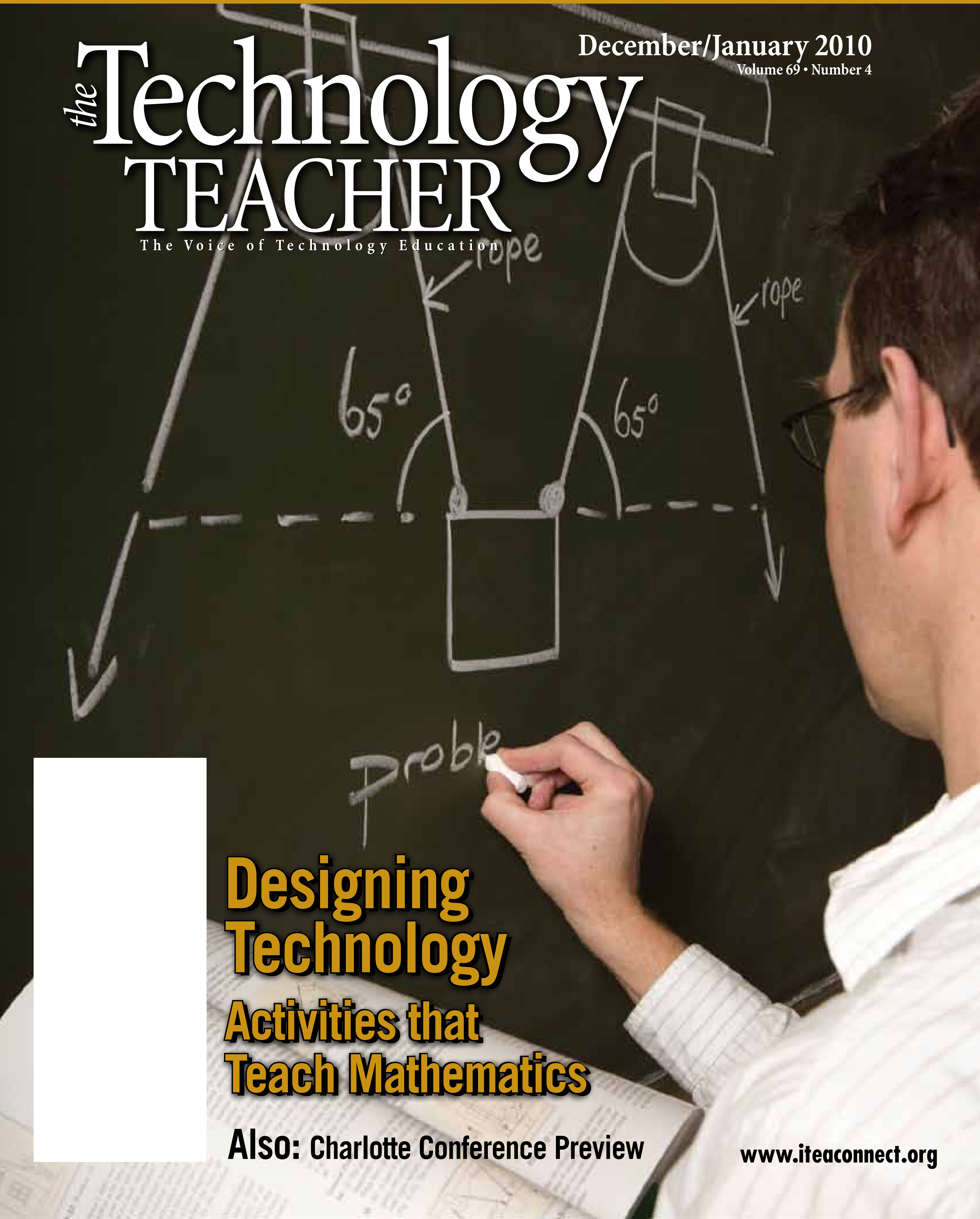

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