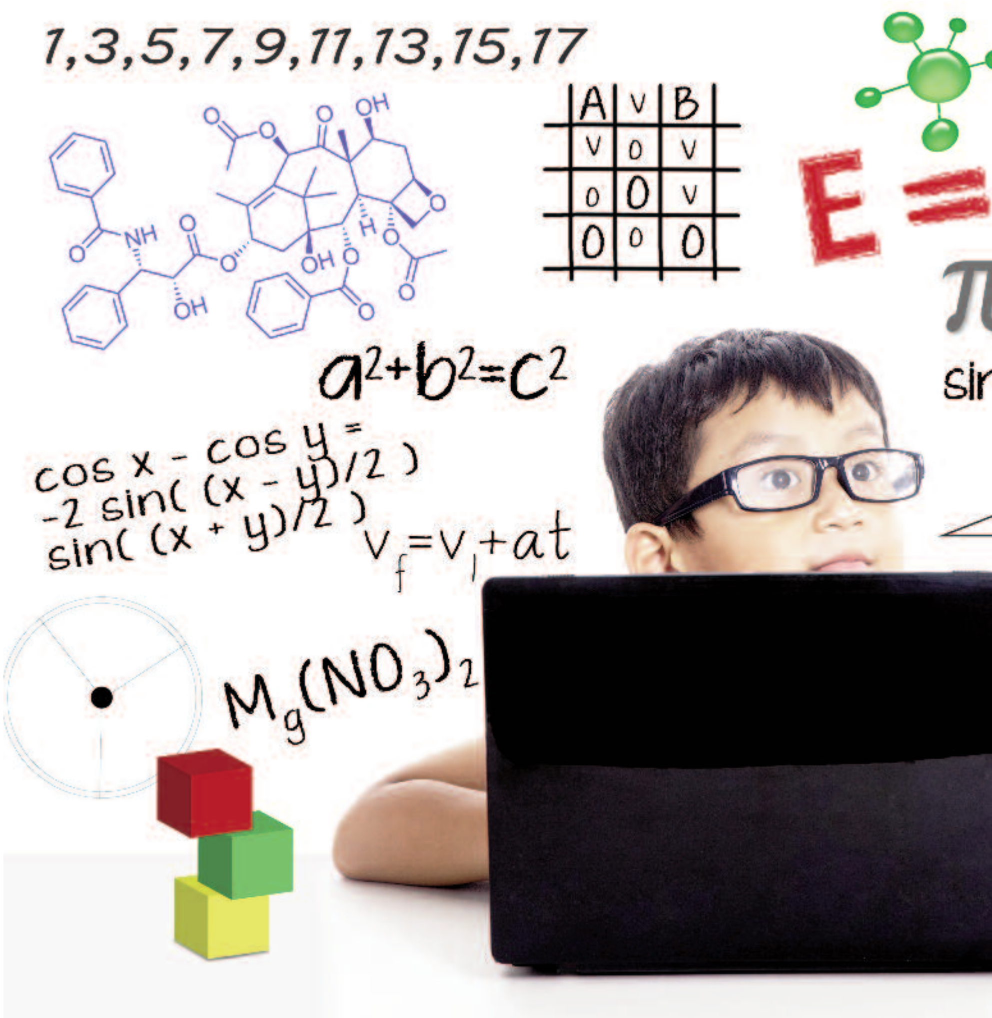
Understanding STEM Education and Supporting Students Through Universal Design for Learning

James D. Basham and Matthew T. Marino

Despite an increased national focus on science, technology, engineering, and mathematics (STEM) instruction, students with disabilities continue to struggle with STEM content at both the K–12 and postsecondary levels. As a result, very few students with disabilities pursue STEM careers. The universal design for learning (UDL) framework can be utilized to engage students and increase the usability of STEM curricular materials. Understanding efficacious instruction and assessment strategies can help teachers provide effective instruction for a wide range of learners.



The science, technology, engineering and mathematics (STEM) fields offer numerous life and work-related opportunities for students with disabilities (Basham & Marino, 2010). In many countries, including the United States, careers requiring an applied understanding of STEM are quickly replacing traditional manufacturing jobs (Kaku, 2011). Unfortunately, the United States ranked 27th in science and 30th in

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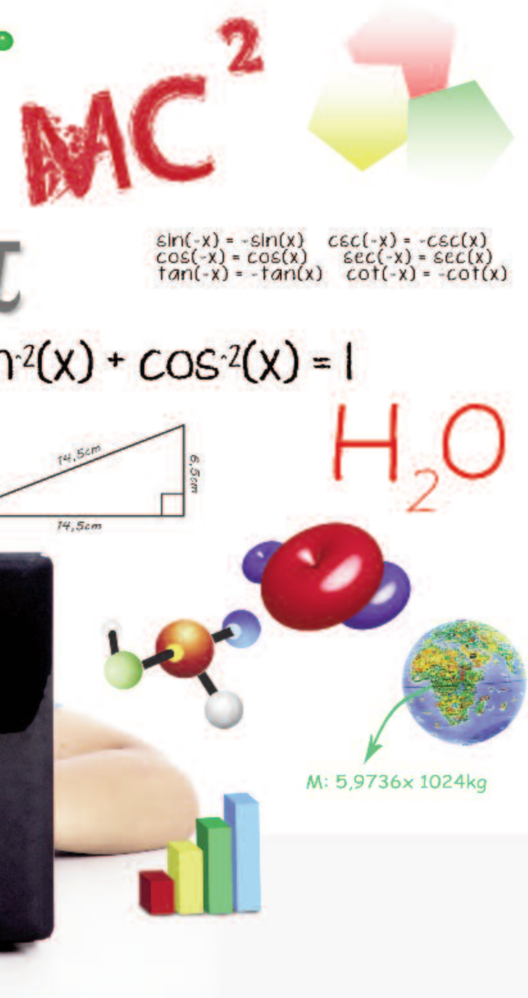
mathematics on the latest Program of International Student Assessment (Baldi et al., 2007). Students with disabilities perform even lower than their peers without disabilities on these standardized measures and often become disenfranchised with STEM content as early as middle school (Marino, 2010). One of the outcomes of this disengagement is that students with disabilities rarely enter the STEM workforce, even though many are highly capable of making valuable contributions (Leddy, 2010).

The success of students with disabilities who participate in general education STEM classes is directly linked to teachers' abilities to understand students' unique learning needs and problem-solving abilities (Marino, 2010). In addition, both special and general education teachers need a practical understanding of STEM education with an emphasis on how to integrate and scaffold STEM learning experiences. Incorporating the principles of universal design for learning (UDL) can enhance the accessibility of STEM curricular materials and improve educational experiences for a wide range of students with diverse learning needs (CAST, 2011a).



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What Is STEM Education?

STEM education represents a symbiotic relationship among the four interwoven fields. To be successful during STEM learning experiences, students need to be able to move beyond low-level cognitive tasks (e.g., recalling facts in isolation) and gain a foundational understanding of the content, which enables high-order thinking skills. However, as Dalton, Morroco, Tivnan, and Mead (1997) noted in their seminal study, students with disabilities who participate in science learning activities frequently: (a) have limited prior knowledge, (b) are reluctant to pose questions, (c) are less likely to have a plan for solving problems, (d) struggle to implement teacher recommendations, (e) have difficulty with inductive and deductive reasoning, and (f) seldom transfer knowledge to other contexts. In addition, these students often have fundamental misconceptions about scientific phenomenon, which leads to further struggles during the inquiry process (Jacobson & Archodidou, 2000). Samsonov, Pedersen, and Hill (2006) pointed out that struggling learners often require a great deal of teacher scaffolding to manage the vast amount of information necessary to solve complex problems such as those included in STEM curricula. Therefore, it is imperative that STEM teachers design engaging curricular materials that offer a wide range of metacognitive and content-specific instructional supports.

STEM in the Classroom

Teachers need a fundamental understanding of what STEM encompasses before they can develop curricular materials that meet students' needs. The concept of STEM extends across content areas (e.g., science, math, language arts, and art/design) by encouraging students to develop solutions that incorporate a variety of disciplines (Basham, Israel, & Maynard, 2010). The foundation of STEM education lies in engineering, which many educators see as the least relevant to K–12 education; Katehi, Pearson, and Feder (2009) recently noted that of the four letters in the acronym, the "E" is the least understood and utilized. They recommended that K–12 education focus on (a) engineering design; (b) developmentally appropriate knowledge and skills for mathematics, science, and technology; and (c) the adoption of engineering "habits of mind."

STEM Is Engineering Design

Engineering design is primarily about problem solving and developing solutions that take into consideration what engineers call *constraints*. For example, a city with a traffic congestion problem that is affecting the flow of commerce will turn to an engineering firm for solutions. The engineering firm will investigate the scope of the traffic congestion and the constraints associated with solving the problem. Constraints may include political implications, budget limitations, timelines, and available resources. The firm pulls together a team of engineers from multiple disciplines within engineering to solve the congestion problem, using technology to design several mock-up traffic solutions to test prior to full-scale implementation. Once in the field, engineered solutions often include monitoring mechanisms (e.g., electronic probes) so that the product (e.g., subway system, bridge, car sharing system) gathers continual data that informs future problem solving and redesign.

Teachers can apply engineering design in multiple contexts for students with disabilities, by creating engaging learning environments and encouraging students to identify and solve problems in their communities. The engineering design process can be applied over extended time periods so that students become immersed in the learning environment. For example, teachers could establish a STEM investigation where students participate in a semester-long problem-based learning experience that includes working with a team to solve a local problem (e.g., working with a local organization and team of scientists and engineers to enhance the water quality of a local river system). This type of in-depth investigation allows students to see the relationship between STEM design, research, and implementation of the solution. This approach also can contribute to transition planning, by providing students with multiple STEM-related occupation exploration and even job-shadowing opportunities (e.g., engineers, surveyors, construction work, etc.).

Because problem solving can be a complex task for students with disabilities (Marino, 2010), teachers should employ a variety of evidence-based teaching practices, such as explicit teaching (McCleery & Tindal, 1999), guided inquiry supporting multiple literacies (Palincsar, Magnusson, Collins, & Cutter, 2001), and instructional scaffolding (Lynch et al., 2007), as well as incorporate technology tools (e.g., iPads, books, movies, software) to enhance students' content knowledge and metacognitive skills. AccessSTEM (2002–2013) identified several technology-based scaffolds teachers should consider when students engage in STEM learning activities, including (a) captioned videos and films; (b) visual, aural, and tactile instructional demonstrations; and (c) spellchecker and grammar-checking tools.

Like engineers, special education teachers need to consider the *design* being proposed and implemented within a STEM-focused learning environment. In education this is often called *instructional design,* generally defined as the consistent design of educational experiences for providing reliable instructional outcomes (Reiser & Dempsey, 2007). Special education teachers also face design constraints: political implications related to legal mandates, the state/local curriculum, requirements for how student learning is going to be measured, budget limitations, the timetable associated with actual planning and instruction, and existing resources (including technology). Another consideration is the need to develop instruction through an iterative design process. Special education teachers should continually gather data and conduct analysis of curricular materials in order to improve future problem solving and redesign to accommodate learner variability.

STEM Is Appropriate Knowledge and Skills

Katehi and colleagues (2009) emphasized that engineering education should encompass developmentally appropriate knowledge and skills in science, mathematics, and technology. Contrary to many common education practices, engineering does not assign learning to stand-alone subject areas; engineers use their understanding of subject-area knowledge and associated skills to leverage understanding and make use of tools to solve problems and test solutions (Katehi et al., 2009). For instance, addressing a city's congestion problem, engineers would develop and test potential solutions while considering constraints that emerge from a detailed understanding of physics and nature. In this example, if the proposed solution was to develop a mass-transit system (e.g., a subway), an engineer would consider the impact that existing variables such as water, sand, wind, and earthquakes might have on the proposed system. The engineer developing a subway would test, generally through virtual and scaled modeling, what effects a 7.0 or 8.0 magnitude earthquake might have on the proposed system.

How might this example translate to your classroom? One idea would be to have students conduct their own earthquake shake tests by designing a shake plate and building a mock-up home (see, e.g., YouTube video demonstrating how engineers build and test scale models at http://www.youtube.com/watch?v=9X-js9gXSME&feature=endscreen&NR=1).

STEM Is Engineering Habits of Mind

Katehi and colleagues' report (2009) also called for schools to adopt engineering "habits of mind" that entail "(a) systems thinking; (b) creativity; (c) optimism; (d) collaboration; (e) communication; and (f) attention to ethical considerations" (p. 5). This mindset can be incorporated into the day-to-day classroom environment and instructional activities (see Table 1).

Enter Universal Design for Learning

After operationalizing an understanding of STEM, educators should implement it through a curriculum design process. As a framework, UDL uses multiple means of representation, expression and action, and engagement to plan curriculum for presumed and known levels of learner variability (CAST, 2011b). UDL stipulates that curriculum, instruction, and related materials should provide multiple representations of key concepts, principles, and vocabulary. In a technology-enhanced STEM context, this can be accomplished by presenting information using graphics, simulations, video, and sound (Curry, Cohen & Lightbody, 2006).

From the UDL perspective, a *curriculum* encompasses everything that a learner encounters within a learning experience including curricular standards and goals, instructional materials and tools, and instruction, as well as the means by which outcomes are assessed. As an instructional design framework, UDL uses both instructional practices and modern instructional materials and tools (e.g., technology) to provide an engaging learning environment for as many learners as possible. A measurable focus of UDL is to enable each learner to actively and cognitively engage in targeted learning, with a specific focus on making all learners "expert learners." UDL-IRN (2011) suggests that four critical elements be present within an instructional environment for it to be considered UDL-based: clear goals, intentional planning for learner variability, flexible methods and materials, and timely progress monitoring.

Clear Goals

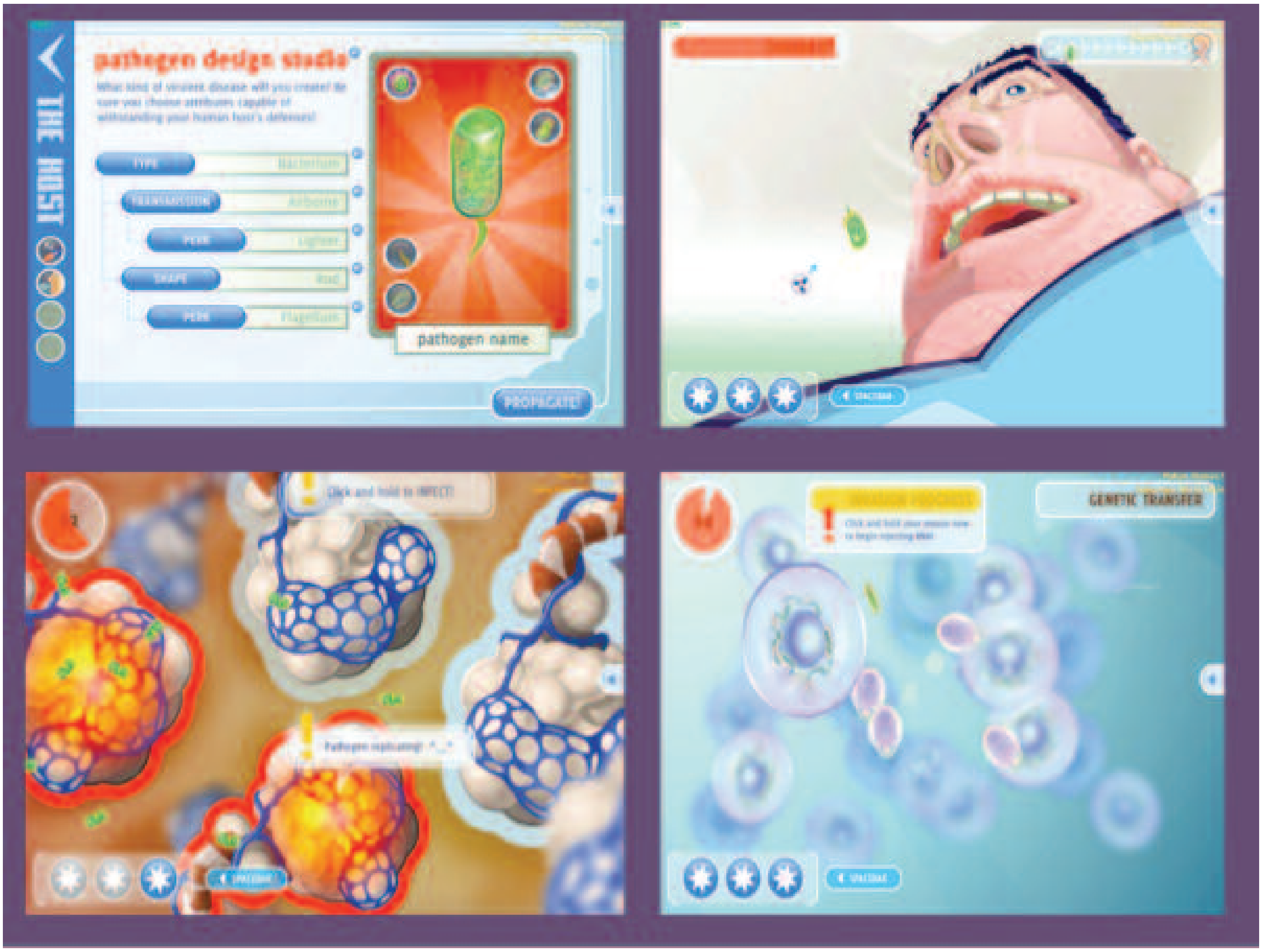
Instruction should have clear goals that are separate from the means for completing the task, and these goals also should be thoroughly understood by the teacher and clearly communicated to students. In order to align planning with instruction and instruction with assessment, teachers need to have a full understanding of the big ideas behind the actual goal. *Big ideas* can be defined as intended outcomes that interlink and provide conceptual and relational understanding to content (e.g., how to problem solve, the importance of living in a self-determined manner, how to think critically, understanding relationships between and among subject areas). Understanding the big ideas allows teachers to design a clear measurable instructional focus that disregards superfluous content and experience. Communicating goals and big ideas clearly to students encourages individual learners (as well as the teacher) to focus, self-regulate, and monitor their levels of cognitive, emotional, and physical engagement.

How can teachers use technology to help students obtain a conceptual understanding of these big ideas? Educational video games are an engaging way to enhance STEM instruction. Perhaps you are trying to teach students about how to prevent the spread of infectious diseases. In Filament Games's award-winning UDL-based STEM video game "You Make me Sick!" (see http://www.filamentgames.com/projects/you-make-me-sick), players are challenged to engineer a bacteria or virus based on the unique attributes of different human hosts (see Figure 1). The game provides different levels of challenge, appealing to a broad range of students; students can choose existing bacteria, such as *salmonella*, or they can engineer their own. The game takes the player from a virtual macro-level view of the

Table 1. Encouraging Engineering "Habits of Mind"

Systems thinking	Have students use graphic organizers to visually represent concepts, and discuss relationships between and among variables in day-to-day real-life situations.
Creativity	Provide assignments that require imagination or have students develop multiple solutions to problems in their own lives.
Optimism	Encourage students to develop workable solutions to problems large and small. Provide students with examples of how cultures and societies have overcome situations through science and engineering (e.g., fixing a dangerous intersection in the local community, infrastructure such as water and electricity, history of aviation, system-level solutions for overcoming the Great Depression, the eradication of polio in many countries around the world).
Collaboration	Use cooperative groups, collaborative whole-class or team projects, and co-teaching. Challenge-based learning can provide students with engaging, collaborative experiences for understanding and solving real-world local and global problems. Visit the Challenge-Based Learning web site (http://www.challengebasedlearning.org/) for implementation guides, including considerations for supporting a wide range of learners and experiences.
Communication	Provide students with understanding through explicit instruction and an opportunity to practice communication skills in face-to-face as well as real-world online environments (e.g., e-mail, text messages, Facebook, Edmodo, LinkedIn).
Ethics	Encourage, model, and require ethical thinking and rationalization as students work in teams to design solutions and solve problems. Model desired behavior through the use of strategies such as think-alouds.

Figure 1. Example of Multiple Means of Representation: Video Game "You Make Me Sick!"



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environment (e.g., inside the kitchen of a person with less than ideal health and hygiene habits) through the infection process. As the game progresses players are virtually transported inside the human body, through the bloodstream, to a microscopic level where they infect a cell while being chased by white blood cells. This type of technology-enhanced STEM instruction provides students with a conceptual understanding of how diseases are spread and, thus, how they can be prevented—in a way that was unobtainable in the classroom just a few years ago.

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Intentional Planning for Learner Variability

Instruction should be intentionally planned so that it is personally challenging for all learners. In planning for learner variability, teachers should take into account specific considerations such as individual and group strengths, weakness, abilities, understanding of background knowledge, and motivation for participating in the learning.

UDL helps teachers consider student-level variability as well as content and physical accessibility (CAST, 2011a). For instance,

- Quinn, a student with a learning disability in reading, is failing his sixth-grade science class because he doesn't do his homework or perform well on paper and pencil tests. His teacher, Ms. Nielson, presumes he cannot grasp the content and/or will not perform in science. However, Quinn does well on lab experiences, which he enjoys, but he is not allowed to participate in labs until he's answered questions from the book. Ms. Nielson relies heavily on the textbook as a means for students to access new information: Three nights a week she assigns students to read a section of the chapter, answer questions, and then come to class prepared to complete a hands-on lab in small groups. Quinn's reading ability is below the grade level of the book. He has issues with decoding and comprehension. Therefore, this learning process is inaccessible for him.

- Deon is also in sixth-grade science. He quickly completes all of the book assignments, does well on the exams as well as labs, and also does exceptionally well on state-assessments. Because of his exemplary performance he is being considered for the gifted program. His teacher considers Deon the model student, when in actuality Deon is unchallenged and bored with science. He does not know why understanding science is important to life; he is focused simply on maintaining good grades.

What do these cases teach us about UDL and STEM? Prior to planning the instructional experience, teachers need to consider learner variability in their classrooms, including individuals with identified disabilities, students who are considered average, and students who are gifted. National Geographic's JASON Project (see http://www.jason.org/), a comprehensive curriculum that integrates classroom instruction with current research from around the world, can enhance STEM learning for these students. JASON uses an array of modalities to present STEM concepts and vocabulary including videos, webinars, chat forums, interactive concept maps, digital labs, live in-person events, and video games. Students like Quinn can benefit from alternative representations of traditionally text-based data, and students like Deon encounter increased levels of challenge that heighten engagement. JASON also includes an online "mission center" where teachers can create individual accounts, customized assessments, and assess students' field journals.

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Flexible Methods and Materials

During the instructional process, teachers should target specific methods and materials, including but not limited to modern technology, that will engage learners and provide multiple ways for students to gain information and express their understanding. The primary focus of this critical element is to design the instructional experience so that it supports both desired outcomes and learner variability. Purposefully using multiple means of representation, expression and action, and engagement maximizes success for all learners. Planning should focus on how the system, not simply a single teacher, can provide an accessible and meaningful learning experience for all learners. Simply because UDL focuses on using multiple options for supporting learning, it does not presuppose pedagogy or preclude the need to organize and scaffold the experience for learners.

Based on the variability and intended outcomes, teachers still need to identify appropriate evidence-based strategies and type of instruction (e.g., explicit, guided, full inquiry, or a combination) to use in the instructional experience. Intended outcomes and variability also should guide the targeted use of a menu of instructional tools for supporting knowledge and information representation, engagement, and expression and action toward demonstrating understanding.

Quinn excels in hands-on experiences and learning from his peers, yet in his classroom he is not allowed to complete the hands-on lab peer-group experience until his bookwork is done. The design of the learning environment does not take into account his variability. Deon, although considered a model student because he performs well on assessments, is actually bored, lacking bigger understanding, and performing below his ability level. When planning to meet learner variability, it is critical to consider desired outcomes, how outcomes are going to be measured, the appropriate pedagogy, and tool usage.

Quinn might be provided with more explicit instruction (McCleery & Tindal, 1999) and strategies such as concept/cognitive maps (Blankenship, Ayres, & Langone, 2005) for understanding relationships and foundational content. Because Ms. Nielson has 25 other students, she needs to consider how this more explicit instruction might take place, either using a co-teaching model, small group instruction for those who need it, or through the use of technology such as video demonstrations or simulations. A STEM-minded teacher might provide Quinn with a digital book that includes text, images, audio, movies, and simulations (see Apple in Education, 2012) or an interactive book that integrates a social learning network (see Inkling, http://www.inkling.com/), allowing Quinn to communicate with his peers when he has questions. It should not be presumed that the technology alone would meet all of Quinn's needs; he also requires other scaffolds and strategies, such as a cognitive map to guide his understanding of the content.

Deon's supports are not all that different from Quinn's; again, variability considerations take into account both pedagogy and learning resources. Deon's learning experience should encourage performance beyond the state learning standards. For Deon, this means providing additional challenges at his level. Deon's teacher can provide opportunities for more self-guided learning and include a greater focus on inquiry. Although Quinn's purposes for using digital books would be different from Deon's, this technology can also be used to support Deon's variability.

Whereas Quinn might choose to demonstrate his understanding of two major concepts in a chapter by developing a video that can be used to teach the concepts to his peers, Deon might choose to demonstrate understanding of the relationships among atoms, resistance, and circuits using a graphic organizer or visual presentation (e.g., Prezi, http://prezi.com/). The UDL process recognizes that two students studying the same STEM content will develop different types of understanding. Encouraging other teachers and your students to recognize that these different levels of understanding are completely acceptable will keep students engaged and maximize learning.

Timely Progress Monitoring

Throughout the instructional process, continually monitoring student progress, using a variety of assessment practices, is necessary in order to measure student progress toward acquiring the intended instructional goals and "big ideas." Teachers also should use progress monitoring to develop new understandings that can inform future instructional designs.

Using varied and continual data points that are based on authentic tasks (e.g., wire a simple or parallel circuit, discuss an occupation that is keenly interested in circuits) enables teachers to reflect on the success of the "design" of an instructional experience. This process is done through continually answering four questions:

1. Did all classroom learners meet the intended outcomes of the instructional experience?
2. How did existing or newly found learner variability and design variables contribute to these outcomes?
3. What worked well (and not so well) within the instructional experience?
4. What, if any, redesign is needed to maximize outcomes for all learners?

Under the UDL framework, teachers provide options for students to carry out different activities to demonstrate understanding. To reduce the complexity of grading, the assignments might be graded on the same rubric and may incorporate technology to support the submission and grading process. The design of all assessment and progress monitoring tools should target the acceptable ranges of the determined critical understandings, outcomes, and big ideas.

Final Thoughts: It's About Design

Providing all students, and especially those with disabilities and diverse learning needs, meaningful access to STEM education is primarily about effective curriculum design. This design should account for a range of variables including

- The academic standards and the big ideas associated with instruction.
- The learner variability present in the learning environment.
- The use of flexible instructional methods and materials.
- How data is being gathered for timely progress monitoring.

Like engineers, special education teachers should take on the habits of mind. Develop system-level thinking skills with your students. Think creatively, approach problems with optimism, encourage collaboration, communicate with a purpose, and focus on ethics—with an eye toward providing outcomes that support self-determined learners to live and work in a globalized society. Accept STEM instructional design as an iterative process. There are times where the design, even using proven practices and evidence-based practices will not provide the desired results. When a design fails, look for evidence that supports the reason for the failure, take that evidence into consideration, and move forward with the next design solution.

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