# Innovating Science Curricula with Engineering: A Balancing Act

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In 2009, NSF awarded Georgia Tech a Discovery Learning K-12 (DRK-12) grant to support the *Science Learning: Integrating Design, Engineering and Robotics (SLIDER)* program. SLIDER proposed to create a new 8th grade physical science curriculum, building upon the inquiry and design-based model developed by Kolodner et. al. (2003). SLIDER's project-based inquiry science curriculum infuses physical science with practices drawn from the field of engineering design, while using LEGO NXT robotics as the manipulative and tool. Based on previous experience with established extra and co-curricular K-12 robotics programs (e.g., FIRST LEGO League, and the use of LEGO NXT in engineering and technology classes), we hypothesize that situating physical science learning within engineering design scenarios where students design LEGO NXT robots to solve specific challenges will increase student engagement, motivation, and achievement: a proposition suggested or supported by existing literature (Bratzel, 2007; Brophy, et al., 2008;  Green, 2007; Nagchaudhuri et. al., 2002; Vollsteadt et. all, 2007; Wang, 2007.)

SLIDER curriculum designers and educational researchers, in collaboration with teachers and administrators from three Georgia middle schools, proposed to develop long-duration curriculum units that cover the majority of the $8^{th}$ grade physical science content (primarily force and motion, simple machines, energy, waves, and electricity and magnetism), to implement the curriculum in the schools, and to study the impact on student learning, self-efficacy, motivation, and intent to persist in STEM. The first three years of the project have been dedicated to developing, testing, and revising LEGO robotics-based curriculum units that are true to the tenets of both project-based inquiry and engineering design-based instruction, while covering the required educational standards for science core content and practices. To be effective and sustainable, the curriculum also needs to be mindful of the realities and limitations inherent in our modern system of schools: accountability pressures, regular benchmark testing of students, large classes, and the pervasiveness of annual standardized testing. This paper documents the iterative curriculum development process and design decisions we made in order to balance these often-competing constraints.

**Experimental Design**

Our team, consisting of curriculum developers, educational researchers, and classroom teachers, is developing the SLIDER curriculum through iterative design and implementation cycles, borrowing from design-based research methods (Barab, 2006; Cobb et al., 2003; The Design-Based Research Collective, 2003).  During the SLIDER curriculum design process, successive redesigns are based on multiple sources of data and feedback: task analysis and research on science content learning, alpha-testing of the engineering and LEGO activities in the laboratory (without students), curriculum design with our teachers during professional development workshops, and pilot testing curriculum in authentic contexts (i.e., with our partner teachers implementing the curriculum in their classrooms).  Instruments include design decision logs, classroom observation protocols, surveys, student artifacts, and assessments of science content knowledge.

These SLIDER research efforts have focused on iteratively developing (1) in-house curriculum design methods and (2) project-based inquiry curriculum. To document our research and design decisions and methods, we log design decisions and archive design iterations. These logs and artifacts allow us to conduct retrospective analyses of designs. When combined with student and teacher data from piloting, these retrospective analyses provide a picture of a curriculum design process that continuously balances multiple constraints.

**Curriculum Design Methodology**

Our design methods have incrementally evolved into a process that enables us to design curricula that (1) covers standards for science content and process skills, (2) sequences these concepts and practices using empirical research on student learning, (3) delivers these concepts and practices through engineering challenges, and (4) uses research-based inquiry pedagogy. This method involves starting with national and state frameworks for science and engineering core concepts and practices. The standards then become the basis for backwards design that involves science domain task analysis, literature reviews, and a review of pedagogical content knowledge. We subsequently map science concepts and practices and sequence them in the form of storyboards. In tandem, large "project challenge(s)" are conceptualized and tested for the feasibility of using LEGO robotics and engineering to solve the challenge. The deconstructed content, large challenge, and engineering activities are then enacted within our SLIDER curriculum framework (Ryan & Usselman, 2012)

Our iterative design process, combined with our pedagogical approach to learning, resulted in an evolution in our materials across a number of dimensions:

1. The use of Launcher units to focus on science process skills and habits of mind and to establish a critical classroom culture of inquiry,
2. The level of scaffolding and educational support incorporated into the materials, and
3. The nature of the science and engineering experienced by the students.

Due to the realities and limitations listed earlier, SLIDER researchers continue to adjust and rethink how our materials are actually enacted in our schools, including addressing complicated issues of materials management.

**<u>Moving along the Inquiry and Design Continuum.</u>**

Based on formative data collected during curriculum development and piloting, SLIDER has been forced to eliminate the Launcher unit, provide a more scaffolded learning experience than initially planned, and decrease the amount of open-ended design included in the curriculum materials. Examples of these changes are given below.

**Use of the Launcher**

SLIDER builds upon the foundation developed by Kolodner and colleagues as part of the Learning by Design™ project (Kolodner et al., 2003). Learning By Design™ was subsequently incorporated into the curriculum model published as the *Project-Based Inquiry Science* (PBIS) series for middle school science instruction. The PBIS series promotes the use of a "Launcher" unit at the start of the school year that introduces common classroom inquiry practices, builds science process skills, and establishes the classroom culture for the rest of the year. Though it takes several weeks to implement, the PBIS launcher unit is valuable and can substitute for the traditional unit on the "scientific method" that teachers often start with at the beginning of the school year.

Working with LEGO NXT adds a particular challenge for the Launcher unit, as most students do not enter the class having any proficiency with either building or programming LEGO robots. In order to design from scratch with LEGO, students need time to develop these skills. Therefore the SLIDER curriculum initially began with a Launcher unit that, in addition to introducing critical science process skills and standard classroom procedures, provided a learning sequence to enable students to master simple LEGO build and programming skills. Curriculum developers designed and tested the Launcher unit in-house, and piloted it with teachers in a 1-week summer institute. Based on formative data from each test, the unit was iteratively redesigned for implementation in one school, with 3 teachers and 11 classrooms of $8^{th}$ grade physical science students.

The first half of the SLIDER Launcher unit introduced the students to the LEGO NXT kit, familiarized them with the different pieces, challenged them to explore build techniques, and culminated with a simple design challenge. The second half introduced the basic concept of computational thinking as a series of sequential instructions, took students through the basics of programming the LEGO NXT central processing brick, and culminated with a simple programming challenge. The entire Launcher unit was designed to span 14-16 school days, depending upon implementation pace.

Halfway through the implementation of the Launcher unit it became clear, based on classroom observations and teacher feedback, that in a physical science class that is required to meet defined curricular standards, and where robotic building and programming are definitely not part of those standards, there is not enough time for students to realistically master LEGO NXT build and programming skills. Teachers were under tremendous pressure to "get to the content" that would be tested on benchmark and national standardized tests —i.e. the science disciplinary core ideas. We therefore cut short the classroom implementation; the second half of the Launcher, which taught LEGO programming skills, was not implemented in the school. Based on data collected during the aborted implementation, we redesigned the curriculum and eliminated the Launcher unit as a separate entity. This decreased the time spent on developing LEGO build skills, and eliminated programming instruction entirely. We incorporated all science process skills development and the remaining LEGO management skills into learning sets that concurrently focused on physical science disciplinary core ideas.

**Scaffolding and Learning Supports**

The elimination of the Launcher unit had a profound effect on the curriculum as a whole; without it students do not have a common competence level with using LEGO NXT as a manipulative and no experience programming with LEGO. As a result, later activities had to be more tightly scaffolded and constrained, with LEGO build instructions and downloadable NXT programs provided. As an example, an activity that initially required that students design a braking system for a LEGO NXT robotic vehicle had to be modified so that students build a standard vehicle and brake from LEGO build instructions, download a pre-existing LEGO NXT program to control the brake, and then design an experimental procedure to test different materials on the brake pad. Students subsequently engage in the engineering design process by redesigning the brake pad using a mix of the materials to make it more effective, and testing the effectiveness of their new design. However the whole learning sequence is more scaffolded and defined than initially planned, particularly in terms of the engineering design process, due to the time constraints of the actual classroom.

**The Nature of the Science and Engineering Experience**

Because the new Framework for K-12 Science Education (National Research Council, 2011) explicitly includes engineering practices and core concepts within the domain of science education, and the Next Generation Science Standards makes explicit that science teachers should be including engineering concepts alongside the scientific ones, it is important to address the nature of science and engineering integration in the science classroom and the level of inquiry and engineering design that is practical and feasible.

When working in a core science classroom, the science practices and core concepts outlined by the state and national educational standards have to be the first priority. The Framework for K-12 Science Education describes the differences between science and engineering practices that are, on the surface, rather analogous (National Research Council, 2011). It is not difficult to envision how activities within an engineering challenge can ensure that students develop models, plan and carry out investigations, analyze and interpret data, use math and computational thinking, engage in argument from evidence, and obtain, evaluate and communicate information—all of which are core scientific practices and promote scientific inquiry. However whereas engineers ask questions and define problems that should lead to a concrete solution to a societal problem, scientists seek to understand why something is happening, and instead of designing solutions, they construct scientific explanations to explain the phenomenon.

Within the science classroom, it is crucial that students spend ample time grappling with the underlying scientific concepts and puzzling over why, scientifically, something is happening, not just designing a solution to an engineering challenge. Ultimately the goal in physical science is not for students to learn how to build and program LEGO robots to enable them to solve engineering problems, even if those activities naturally demonstrate physical science concepts. Every engineering challenge and LEGO build included in the curriculum must predictably and explicitly lead the students to a deeper understanding of a specific scientific concept or practice specified in the science standards.

**Conclusions**

The SLIDER curriculum design team has worked to maintain as much engineering as possible in the physical science curriculum. However, when time is a constraint, the emphasis in the learning sequence must be on ensuring that students experience scientific inquiry and construct proper scientific explanations that demonstrate that they have mastered the underlying science concepts, not that they successfully design engineering solutions or master an engineering skill. In the robotic brake example described earlier, we have chosen to require that students design and execute their own experimental procedures to test their brake pad design, thereby promoting scientific inquiry. However due to constraints in the classroom, the LEGO builds have to be tightly controlled and students can only design within narrowly constrained conditions. Those curriculum development decisions impact the nature of the engineering experienced by the students, but are a necessary part of the balancing act.

In light of these conclusions, what needs to change in order to accommodate the various science and engineering learning goals in these classrooms? Integrated STEM learning in K-12 is frequently mentioned as an important part of the solution to the country's looming demographic bubble – a future where there won't be enough STEM-savvy professionals to manage current systems that support our lives and keep us competitive, nor to innovate new ones. Communities and school systems are rapidly creating STEM academies that propose to drive learning through applied engineering experiences and real-world contexts, in the hopes of developing a pipeline of students interested and able to work in a STEM-focused world. These proposed changes often collide head-long into the realities of how we generally *do school*, particularly in those schools that educate the lion's share of our low income students and students of color: 45-50 minutes periods designed around specific domains; over-sized and over-crowded classrooms; lack of good educational resource materials; teachers who lack knowledge of multiple STEM disciplines; and antiquated conceptions of learning among education and community stakeholders. We have arrived at a point where we believe the system itself needs a little *backwards design*. The modern rules and structures of school, particularly those seen in the schools that enroll our most vulnerable children, place many obstacles in the way of more integrated science and engineering learning. We need to develop a good model of what a truly integrated learning experience should look like, and determine how teachers in all types of schools would realistically facilitate that experience and balance the many competing priorities.

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