Curriculum Developers' Design Challenge:
Integrate Engineering and Science Via Robotics

Mike Ryan, Marion Usselman, and Jessica Gale
The Center for Education Integrating Science, Mathematics, and Computing (CEISMC)
Georgia Institute of Technology

The Next Generation Science Standards now connects science and engineering through a few practices that overlap, or at the very least, align. Portions of the engineering design process included, or translated, in the new standards emphasize: 1) defining problems through identifying criteria and constraints, 2) developing solutions to those problems, and 3) optimizing those solutions to best fit the criteria and constraints. It is now the responsibility of curriculum developers and classroom teachers to determine how these concepts can be included in what is universally acknowledged to be an already tightly filled science educational domain. The solution generally proposed is to *integrate* the science and engineering (NAE and NRC, 2014). This paper will tell the story of one research project's journey into that integration.

The SLIDER project, funded through the NSF DRK-12 program, set out in 2010 to investigate the use of robotics and design to develop conceptual understanding among 8th grade physical science students. The curriculum was built upon the work of Kolodner, et al. (2003), whose Learning By Design™ (LBD) curriculum (which later evolved into Project-Based Inquiry Science™) used design challenges and project-based learning to facilitate learning, later described by NGSS as Disciplinary Core Ideas and Practices. LBD, along with some PBIS, curriculum units usually situated learners in engineering design challenges, or at the least design-based challenges, where students were asked to develop and propose a solution to a problem or challenge after 2-4 weeks of in-class work. The SLIDER project adapted this approach and set out to explore the promise of using robotics and design more prominently in these types of learning experiences to learn their effects and affordances for learning science.

From 2010-2014, the SLIDER team iteratively developed and piloted curriculum units that incorporated LEGO NXT Mindstorm robotics and engineering contexts. Students would develop understanding of energy, motion, and forces as they *engineered* a solution to an authentic traffic accident problem, where they design an automatic braking system to help prevent traffic accidents. Though the SLIDER team was explicitly having students define the problem, iteratively designing possible solutions, and ultimately settling on a solution, the release of the NGSS Frameworks (and the subsequent standards) made the integration of some science and engineering practices more explicit.

The NGSS outlines the crucial science and engineering practices and discusses the similarities and differences between the two. Of the eight practices, only two—*Asking Questions and Defining Problems*, and *Constructing Explanations and Designing Solutions*—are significantly different between science and engineering. This suggests that six of the eight core practices can be effectively mapped together, whereas for the last two, care must be taken if the learning

Presented at the 2016 National Association for Research in Science Teaching (NARST) Annual Conference, Baltimore, MD.

goals for both disciplines are to be effectively covered. In these cases, those learning goals are being infused into the science curriculum.

The other engineering learning goals included in the Framework for K-12 Science Education and the NGSS boils down to:

> *"... defining 'engineering' more broadly in the Framework and NGSS is to emphasize engineering design practices that all citizens should learn. For example, students are expected to be able to define problems — situations that people wish to change — by specifying criteria and constraints for acceptable solutions; generating and evaluating multiple solutions; building and testing prototypes; and optimizing a solution."*

This conception of engineering learning goals became more explicit in the actual NGSS *Disciplinary Core Ideas, ETS1.A, ETS1.B, and ETS1.C*.:

> *"A. Defining and delimiting engineering problems involves stating the problem to be solved as clearly as possible in terms of criteria for success, and constraints or limits.*
> *B. Designing solutions to engineering problems begins with generating a number of different possible solutions, then evaluating potential solutions to see which ones best meet the criteria and constraints of the problem.*
> *C. Optimizing the design solution involves a process in which solutions are systematically tested and refined and the final design is improved by trading off less important features for those that are more important."*

(NGSS, 2013, APPX I, pg. 1)

As the team first conceived and developed the curriculum, it saw great opportunity and affordances to the LEGO's NXT Mindstorm kits. Students obviously could build artifacts or products as they would build a play toy or model. These kits, however, also offered students the ability to program the LEGO build to move within and react to its environment. This allowed the robotic device to become an engineered product. We imagined students designing, testing, analyzing, re-designing, rebuilding, and re-testing many aspects of the model truck featured in our curriculum's design challenge. This would include the chassis, the wheel and tires assembly, the design of the brake arm, and even the program that runs the sensor activated during a potential collision.

Furthermore, the sensors embodied a number of concepts that students struggle with in physical science. The kit's sensors use ultrasound, audible sound, changes in light, reflection, touch-sensing, and infrared. We saw an opportunity to use these sensors to make more explicit topics like waves, electricity, energy, light, and sound, which have historically been difficult for middle school students to grasp because they are literally difficult to see or grasp (Beaton, et al, 1996).

From the beginning we had some design criteria of our own. The curriculum needed to be implementable in a diverse range of *authentic classrooms*, including schools:

- With both low income and high income communities;
- In rural, suburban, and urban settings;
- That are overcrowded (and at times chaotic), as well schools that are controlled and calm;
- Where an array of teacher competencies and strengths exist;
- Operating under the expectations for state standards-based learning.

This presentation will detail the SLIDER project's curriculum development story as it attempted to navigate the newest goals the NGSS presents for science learning. Through four years of iteration and testing, the use of robotics in the curriculum changed significantly. And thus, the engineering experience changed with it.

We will explore these changes through four lenses: Programming, Data Logging, Design and Building, and Management of LEGO Materials. Each view reveals how engineering and design in the curriculum migrated from more open-ended design experiences to become more guided and directed. We see how the robotic device migrated from being a programmable solution to a problem to a *smart device* to collect data during investigations that would inform a solution. We see how data collection migrated from being internally collected by the device to students collecting data externally about the device, usually as an exercise to understand the relationship between two variables in an experiment. Finally, we see how the robotic device and its components present an array of foundational challenges for students and teachers in understanding programming, building, and sensing that are well beyond the scope of science learning.

The SLIDER project's experience provides useful insight on the integration of engineering and science, as presented by NGSS. Many of the obstacles and challenges are rooted in typical incongruences and obstacles that arise from school level factors. Through several contextualized SLIDER project examples, we suggest several changes that will allow a smoother integration and development of understanding in each domain.

References

Beaton, A. E., Martin, M.O., Mulis, I.V.S., Gonzalez, E.J., Smith, T.A., & Kel, D.A. (1996). *Science Achievement in the Middle School Years: IEA's Third International Mathematics and Science Study*. Boston, MA. Center for the Testing, Evaluation, and Educational Policy, Boston College.

Kolodner, J.L., Camp, P.J., Crismond D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School

Science Classroom: Putting Learning by Design™ into Practice. *Journal of the Learning Sciences*, Vol.12, No 4, pp. 495 – 548.

National Academy of Engineering and National Research Council (2014). *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. Washington, DC: The National Academies Press.

National Research Council (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press.

Contributors:
Sabrina Grossman and Jayma Koval, Georgia Institute of Technology