SLIDER: Science Learning: Integrating Design, Engineering and Robotics

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Science Learning: Integrating Design, Engineering and Robotics (SLIDER) is an inquiry and project-based learning curriculum designed to teach middle school physical science disciplinary content, science and engineering practices, and cross-cutting concepts within regular middle school physical science classrooms. SLIDER utilizes LEGO Mindstorm ™ NXT kits to investigate and learn about force, motion and energy. During the two 3-4 week units students organize, think about, and design solutions for engineering challenges, and in the process actively engage in investigations, data analysis and scientific argumentation.

The SLIDER materials consist of 1) Two comprehensive workbooks that introduce the challenges and guide students through the activities; 2) Student handouts, data collection sheets, etc.; 3) Videos that help frame the challenges; 4) LEGO build instructions for students; 5) Two-page text-based teacher guides; 6) Videos for teachers that include unit and section overviews, pedagogical support, LEGO build instructions, and science content refreshers; 7) LEGO management strategies; 8) Practice problems; and 9) Assessment rubrics.

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Goals and Philosophy

The SLIDER instructional materials are grounded in a project-based learning (PjBL) model of instruction. In this model, students work collaboratively to solve problems and they learn within group settings as well as individually. They identify what they know, what they need to learn more about, plan how they will learn more, conduct research, and deliberate over the findings in an attempt to move through and solve the problem. Working together in groups allows students to share knowledge and to build off the ideas and knowledge of others. Through the nature of

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this collaborative setting, students often are in the position where they need to articulate ideas, justify decisions, and construct scientific arguments. PjBL promotes content learning and skills development because it focuses on the exchange of ideas and provides motivation for students to seek content knowledge that helps them solve a problem or address a challenge.

There is a large amount of research extolling the benefits of curricula and learning experiences rooted in PjBL. These studies have found that PjBL promotes more active learning of content, the development of problem-solving skills, increased ownership of learning, greater understanding of the nature of science, more flexible thinking, improved collaboration skills, and opportunities for students to become STEM "experts." These advantages are also consistent with the science learning goals promoted in the *Framework for K-12 Science Education* (*Framework*/NRC 2012).

SLIDER uses engineering design scenarios as the context for its PjBL challenges. Engineering design scenarios provide students not only interesting contexts for learning; they also embody the content and skill knowledge of the *Next Generation Science Standards*. Engineering challenges enable teachers to teach content in engaging ways and provide students with opportunities to innovate, create original solutions and experience what engineers actually do. Perhaps for the first time they come to see science, technology, and mathematics as something that exists beyond the classroom, as fields that can be integrated to create a final product, and as areas that they may pursue further in school or as a career.

SLIDER's curriculum design and instructional method grew out of, and is therefore pedagogically similar to, the approach and protocol developed by the *Project- Based Inquiry Science* (PBIS) ™ curriculum, published by It's About Time (Kolodner, et al. 2009). SLIDER has modified and streamlined the PBIS classroom protocols, and specifically incorporates LEGO Mindstorm NXT™ robotics as the instructional manipulative.

LEGOs have been a part of children's learning through play for over 50 years, are highly adaptive and accessible, and can serve as a motivational hook for many children. They are also widely available, relatively economical, reusable, and long lasting. The SLIDER curriculum was designed for classrooms where students work in teams of three students, with each team having its own dedicated LEGO NXT robot that the team does not share with any other students.

Figure 2. LEGO NXT robot.

Most of the activities, however, can be accomplished in schools that have a class-set of LEGO NXT kits, defined here as one kit per every three children in the largest class implementing the program. The SLIDER teacher support materials include guidance on managing the LEGO materials.

Instructional Materials

The SLIDER curriculum is comprised of two units that together develop standards from all three of these NGSS dimensions. The main science concept focus of Unit 1 is Energy (e.g., transfer of mechanical energy, kinetic and potential energy relationship, law of conservation of energy). Unit 2 focuses on Force and Motion (e.g., force, balance of forces, changes in motion, speed, acceleration, mass and inertia relationship).

The level of experiential learning in science curricula is generally conceptualized as “levels of inquiry” (Bell et al. 2005; Banchi and Bell 2008). A common scale of inquiry is shown below:

> ***Level 1. Confirmation Inquiry****—Students confirm a principle through an activity when the results are known in advance.*
>
> ***Level 2. Structured Inquiry****—Students investigate a teacher-presented question through a prescribed procedure.*
>
> ***Level 3. Guided Inquiry****—Students investigate a teacher-presented question using student designed/selected procedures.*
>
> ***Level 4. Open Inquiry****—Students investigate questions that are student formulated through student designed/selected procedures.*

The SLIDER curriculum has been created to promote learning at the *Guided Inquiry* level—i.e. the curriculum materials guide which questions students ask, but the students develop their own experimental procedures, collect and analyze data, look for trends, and support design decisions using evidence and scientific reasoning. The *Framework for K-12 Science Education* describes the similarities and differences between science and engineering practices. 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. Every SLIDER engineering challenge (and its accompanying LEGO design) must therefore predictably and explicitly lead students to a deeper understanding of a specific physical science concept.

At the same time, SLIDER also intentionally incorporates the engineering concepts articulated in the NGSS: *defining problems, proposing and testing solutions, and optimizing solutions*. The engineering challenge plays a key role in the curriculum; it is the context that situates the learners, drives purpose and activity, and allows for science and engineering learning to occur in the same classroom.

Structure of the Curriculum

Each of the two units is divided into three phases.

In phase 1 students….

- Understand the specifications of the problem or challenge.
- Ask questions about phenomena involved.

- Identify possible investigations or models that would help answer questions.

In phase 2 students…

- Iteratively develop and conduct investigations that attempt to answer Phase 1 questions.
- Analyze and explain data to find causal effects.
- Explore science conceptual knowledge to make sense of investigation data and features of the challenge.
- Craft arguments to explain and justify possible components of a challenge solution.

In phase 3 students…

- Design and test multiple solutions to the challenge.
- Explore more science conceptual knowledge to make sense of investigation data and challenge features.
- Iterate on arguments crafted so far.
- Propose an end of unit solution to the challenge.

Students do not progress through all phases in a linear fashion. For example, in Phase 2 students might cycle through two or three iterations before they move onto Phase 3. Additionally, throughout each of the phases students revisit the challenge to reflect on how what they are doing and learning impacts possible solutions to the challenge.

To facilitate students learning in both science and engineering, SLIDER makes use of curricular structures that guide and assist teacher practice. These *SLIDER Curriculum Structures* (SCSs) move students back and forth from the engineering design process of defining problems and designing solutions, to the science skills of asking scientific questions, acquiring knowledge, and constructing explanations. The SCSs are intended to help students understand and participate in the *Science & Engineering (S&E) Practices* referenced in the *Framework for K-12 Science Education*, while providing a format that helps students see their usefulness in solving the challenge.

As students progress through the three phases of each unit they engage in six distinct SCSs, each with its own action and protocol: 1) *Organize the Challenge*, 2) *Explore,* 3) *Share*, 4) *Add to Your Understanding*, 5) *Explain*, and 6) *Reflect & Connect*. These SCSs drive student collaboration, involving all members of the class, but each practice also has dimensions that require individual student work. These SCSs direct students to connect their more recent or smaller experiences to the challenge at-large. They help students share information, reflect on what they have learned, and develop new ideas and connections to pursue during the challenge. For the teacher, the SCSs reveal student understanding and conceptions – i.e. they serve as moments of formative assessment. As students iteratively engage in the SCSs over time within and across units, the nature of the assessment can be more summative.

So far, we have tried to provide a broad sense of the curriculum and its central components: challenge-situated learning, concurrent pursuit of science inquiry and engineering solutions, and a focus on the practices, cross-cutting concepts, and core ideas of NGSS.

Next, let's look more specifically at what happens in each of the units, and how students engage in each of the central components.

Unit 1: The Accident Challenge--Energy

Students learn about a serious issue affecting the *Town of McFarland*:

> *The people of the Town of McFarland have an accident problem at the corner of Main Street and Park Street. During the past year, this heavily used intersection near downtown has been the site of a number of dangerous accidents involving large tractor-trailer trucks hitting smaller cars. Many of the accidents resulted in severe injuries and cars that had to be scrapped. That is, the cars could not be fixed and used again. There have even been fatalities as a result of these car accidents. Your challenge is to assist the town of McFarland to:*
>
> - *Understand why the accidents are causing more damage and injury.*
> - *Investigate the factors that lead to such accidents.*
> - *Design possible solutions to decrease the accidents and injuries.*

Through a mixed use of written text and video, the SLIDER curriculum provides students with a rich context that describes many dimensions of the problem and helps to scaffold possible solutions. The diagram on the next page shows the type of information provided as part of the student materials.

Phase 1 of Unit 1

After students have been introduced to the challenges and issues McFarland is facing, they are presented with several proposals from citizens and city council members about how to deal with these issues. These suggestions include reducing the maximum weight of the trucks, changing speed limits, and even redesigning the intersection. Students learn critical information about the traffic in the town; they review accident statistics, and hear from various constituencies and experts about traffic accidents. They learn about traffic engineers and engineering, and are ultimately asked to play the role of a traffic engineer who must consider the proposals and test some possible solutions.

Phase 1 asks students to identify the problem's criteria and constraints, and then consider scientific questions that might help them gain knowledge to solve the problem. They create a model of the accident scene, test the validity of their model, and propose various investigations to run to see if changes in vehicles and/or driver behavior are contributing to the accidents.

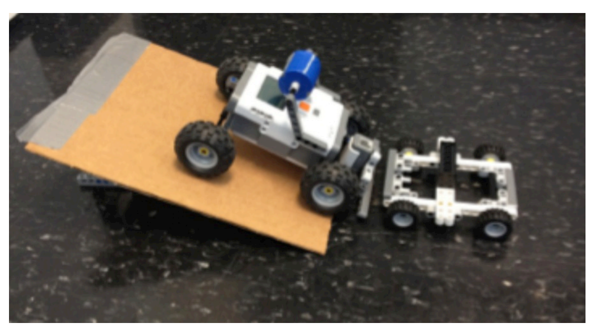

Figure 3. Students create a model of the accident scene.

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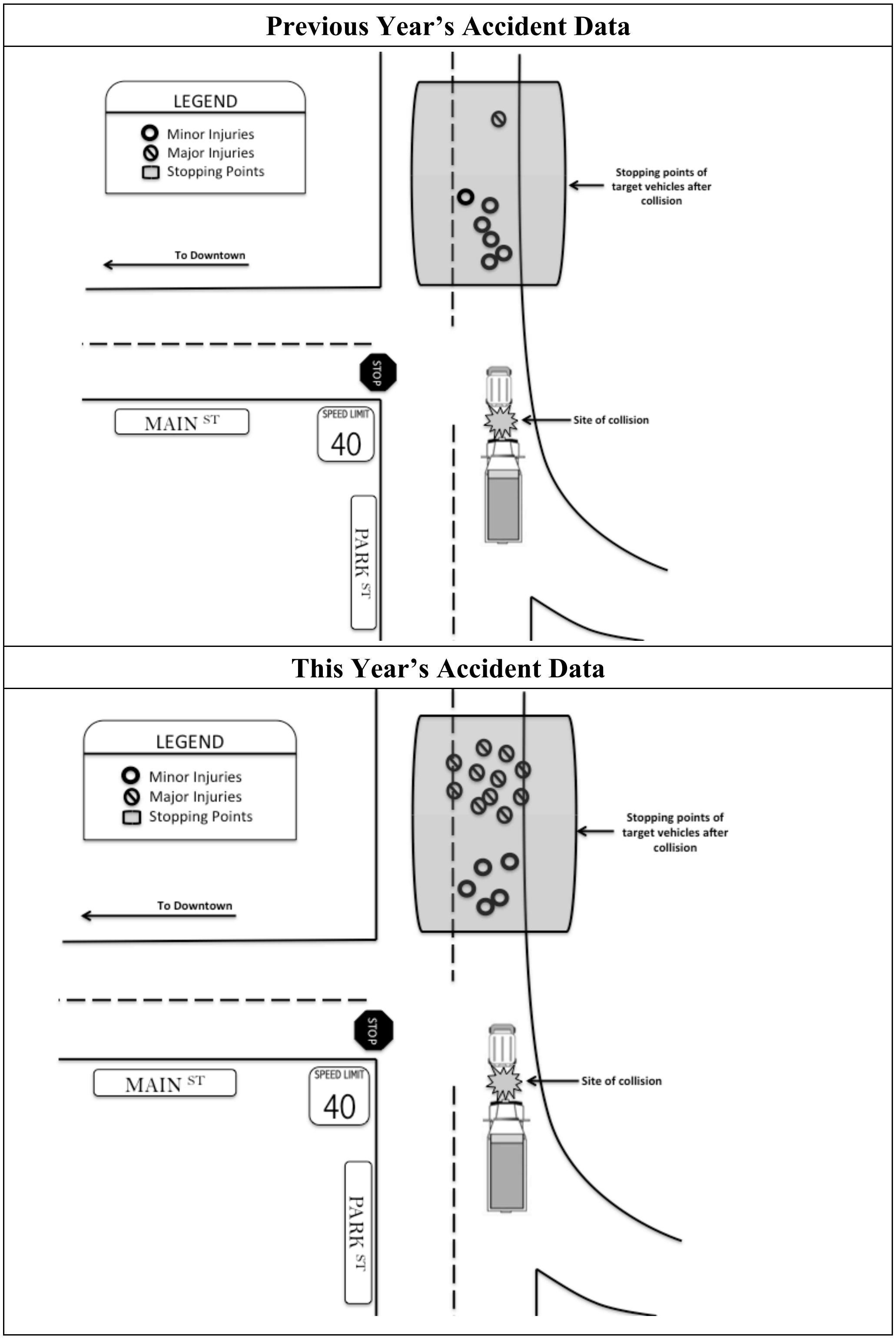

Figure 4. Aerial shot of Accident Challenge intersection and accident data.

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Phase 2 of Unit 1

Students use their model of the accident intersection to gather data about how various conditions might affect the damage and injuries suffered during accidents. In the model, the LEGO truck does not have an engine so students, organized into groups, use ramps of varying heights to create the truck's initial velocity. Because some of the initial ideas involve limiting the maximum weight and/or speed of the truck, or creating lane restrictions, students investigate the effect of changes in mass, speed, and height of the truck rolling down a ramp and colliding with a LEGO car at rest waiting at the intersection. As students change these variables and collect data, trends emerge about the transfer of energy. After each group has run five or six investigations that reveal some facts about energy, the groups present their model, the experiments they ran, and the experimental data to the rest of the class. It is after these investigations and presentations that the teacher engages in more traditional direct-instruction on the concepts of energy transfer, potential and kinetic energy, and conservation of energy.

At this point students, armed with science content knowledge, return to the questions asked in Phase 1 to identify more relevant investigations they would like to run. They gather data once again, share it with other groups, and the teacher again engages in more direct instruction about the science concepts at work. Throughout this cycling, students are developing scientific arguments for, or against, the ideas or opinions offered by the citizen and city council in Phase 1. Using a Claim-Evidence-Reason framework for argumentation (adapted from McNeill & Krajcik, 2012), students iteratively craft and edit arguments as they collect more data from their model and learn more through the direct instruction on science concepts.

Phase 3 of Unit 1

Students are now ready to return to the challenge and to make recommendations on the ideas submitted by the citizens and city council during Phase 1. Using the Claim/Evidence/Reasoning format, students draft a final set of arguments for or against the ideas. Students are also provided the opportunity to design and share their own new set of traffic rules for the vehicles in the area of the intersection. Of course they must heed all of the criteria and constraints identified in Phase 1. Here, the evidence and reasoning (science content knowledge) must be strong to either support or refute a claim (or citizen's idea).

The three phases of Unit 1, and the *SLIDER Curriculum Structures* (SCSs) in each phase are summarized in Table 1.

Table 1. Phases and Curriculum Structures in Unit 1

In Phase 1 students…	
Organize the Challenge	• Record criteria and constraints from the challenge • Determine the questions they wish to ask of a model that could simulate the accidents at the intersection
Explore: *Modeling*	• Build the model to simulate trucks hitting cars at the intersection, develop a procedure to run the model consistently and usefully, and record and compare data from each set of tests. • Determine the type of investigations they would like to conduct with their model to isolate variables that might be contributing to the accidents.
In Phase 2 students…	
Explore: *Investigating Accidents with Your Model*	• Design investigations and collect data on different variables that affect kinetic and potential energy in a system. • Use digital simulations to adjust variables similarly to and beyond their test model.
Share: *Results of Your Investigations*	• Create poster presentations to share data collected and review trends. • Review the procedures and analysis of each other's work to identify errors and discuss sound scientific practice and measurement.
Add to Your Understanding: *Energy*	• Define and practice with the concept of energy transformation. • Use simulations to identify variables that can affect the amount of energy in a system and how it transfers. • Define and practice with the relationship between kinetic and potential energy in a system.
Explain: *Argument For or Against New Traffic Rules*	• Review claims made by citizens and search their data to find evidence in an argument for/against those claims. • Connect various claims and evidence to the science content knowledge learned so far.
In Phase 3 students…	
Reflect and Connect: *Answer The Accident Challenge*	• Address and evaluate each citizen's idea as a traffic engineer might, using evidence from the model and science content knowledge to support or refute the proposed idea.

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Unit 2 : The Brake Challenge—Force and Motion

The second unit begins with a request from the factory whose trucks are involved in the accidents at the intersection:

> *The company has noticed that many of their trucks have been involved in severe accidents across the state and nation (not just in McFarland). Most of these car accidents were similar to the accidents in McFarland and involved their trucks hitting the back of a car (rear end collisions). The company would like to examine the braking systems of its truck fleet to determine whether it should invest in an automatic braking and collision warning system. A system such as this would eliminate the reaction time of the truck driver in stopping the truck and potentially allow the stopping distance to be 40-100 feet shorter. Your challenge is to assist the company by:*
>
> - *Investigating how the automatic braking system might reduce stopping distance.*
> - *Investigating the factors that might improve the braking system.*
> - *Designing a new brake that improves upon its current performance.*

Once again, students progress through the three phases in the unit, each with similar features and activities of Unit 1 (see Table 1). Of course there are some differences and additions to this unit, including that students actually design a physical artifact (a truck with an automatic brake). This makes the engineering design focus more explicit, and those additions will be highlighted in our review of Phase 3 for this unit.

Phase 1 of Unit 2

Students begin this phase by watching some videos of trucks braking hard or engaging emergency brakes. These videos and a series of iterative discussions inspire students to think about how a rolling vehicle or object actually comes to a stop and how that motion varies depending upon the situation. Students review the criteria and constraints of the new challenge, sharing any ideas they have about possible brake design. Then they complete a short investigation to see how different surfaces affect the time it takes the truck to coast to a stop once it has come off the end of the ramp. The teacher does not confirm or correct any conceptions or ideas the students might have. This is simply an exercise in understanding what students know about force and motion (formative assessment) and to have students generate some investigations they could conduct to better understand the factors that cause something to stop.

Phase 2 of Unit 2

Students quickly realize that in answering the challenge, modifying road surfaces to improve the brake performance isn't a likely option. But they know that they need to figure out how to change the forces acting on the truck. Students return to their Unit 1 truck design and modify it. They add the *automatic emergency brake*, which uses the LEGO NXT computer, the kit's light sensor, an NXT motor, a brake arm assembly, and a simple computer program.

The NXT light sensor can detect when the surface it is scanning changes from light to dark. In Unit 2, the truck rolls off the ramp and crosses a strip of black tape to trigger the sensor. This models the automatic braking systems that use distance to detect that a possible collision is eminent. When the sensor is tripped, the brake arm assembly drops to the floor, and the brake pad drags behind the truck along the floor causing the truck to slow to a stop. Students test initial performance of the basic brake design. This provides a baseline braking distance the students know is too long. It also ensures that students know how to actually test the brake and become familiar with its operation.

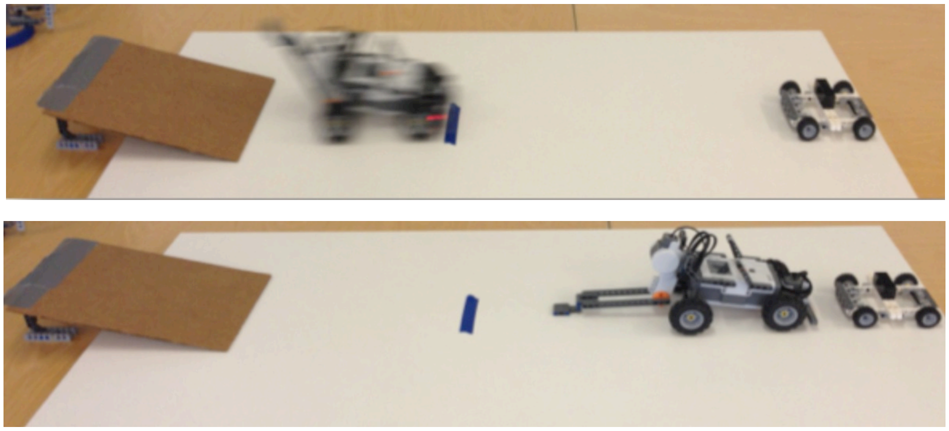

Figure 5. Students test their brake designs to see if the truck can stop before hitting the car.

Because some of the initial ideas involve changing the brake's pad materials and pad design, students investigate how different brake pad materials affect the truck's stopping distance. As students change these variables and collect data, trends surrounding concepts like balance of forces, changes in motion, friction, speed, acceleration, mass and inertia become apparent. Only after the investigation does the teacher engage students in more direct instruction about the relevant science concepts. Most notably, students learn to identify forces, draw simple force diagrams, and determine the balance of forces in an event. As in Unit 1, the students conduct multiple cycles of investigation/analyses/sense making, and iteratively craft arguments about how the brake ought to be designed, supporting claims with evidence and scientific reasoning.

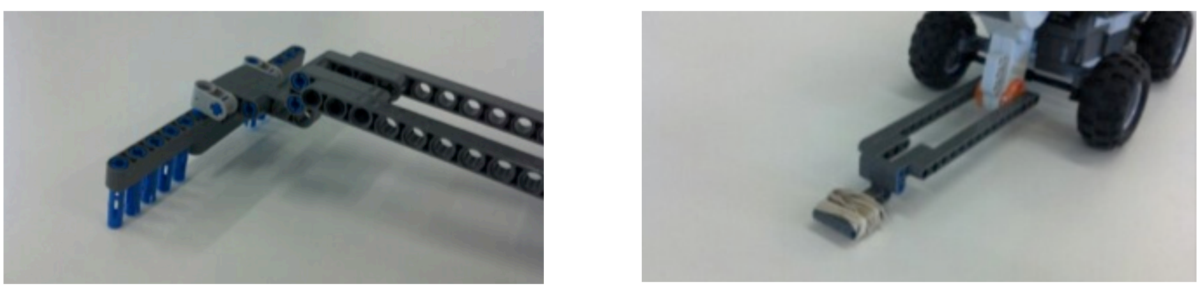

Figure 6. Students evaluate two different brake designs.

Phase 3 of Unit 2

Students are now equipped with data from multiple investigations and with an array of scientific disciplinary concepts about forces and motion. The challenge is then modified, and the students are told that for reasons of safety, the brake program and motor can only generate 50% of the downward push of its original design. However the trucks must still meet the stopping distance challenge. Since none of the original materials or basic brake arm pads meet the challenge, students now move into more of an engineering design mode. They must create a new design, combining materials and brake pads to meet the challenge. In order to focus on optimization, each LEGO piece and pad material has been assigned a cost. High friction materials and large break pads, both of which generate high friction and a large imbalance of forces, are the most expensive. Students attempt to design brakes that meet the product specifications and cost the least amount of money. At the end of the unit students present their final designs and test data, while supplying an argument for their design supported by evidence and reasoning. The three phases of Unit 2, and the *SLIDER Curriculum Structures* (SCSs) in each phase are summarized in Table 2.

Table 2. Slider Curriculum Structures in Unit 2

In Phase 1 students…	
Organize the Challenge	• Record criteria and constraints from the challenge • Determine the questions they wish to investigate that would help them determine how different brake designs make vehicles stop differently.
Explore: *Modeling*	• Briefly compare how various surfaces affect the motion of a coasting vehicle. • Generate (as a class) an operational definition of forces and how they affect moving objects
In Phase 2 students…	
Explore: *Investigating Accidents with Your Model*	• Design investigations and collect data on different variables that affect forces acting on the truck as it starts, accelerates, slows, and then stops. • Students investigate the amount of friction generated by different materials attached to the brake pad.
Share: *Results of Your Investigations*	• Create presentations to share data collected and review trends, informing each other of the performance of different materials and basic brake assemblies tested. • Review the procedures and data analysis from different groups to identify errors and discuss sound scientific practice and measurement.
Add to Your Understanding: *Energy*	• Define and practice with the concept of forces, net force, and balance of forces. • Define and practice with the concept of net force and its effect on changes in motion.
Explain: *Argument For or Against New Traffic Rules*	• Draft arguments about various materials they've tested, supporting the claims with evidence collected during investigations and with reasoning discussed during class. • Review claims made by other groups about the performance of a certain materials and search their data to find evidence for/against those claims.
In Phase 3 students…	
Reflect and Connect:	• Address and evaluate each brake design solution, using evidence

Answer The Accident Challenge	from tests and science content knowledge to support the design.

Alignment with Next Generation Science Standards

As shown in the table below, the core ideas and practices that students engage in during the SLIDER units can help students achieve several performance expectations from the Next Generation Science Standards, both in physical science and in engineering design.

Table 3. Performance expectations from the NGSS addressed in SLIDER Units

SLIDER Units	One			Two		
Phase	1	2	3	1	2	3
Physical Sciences						
MS-PS2-1 Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.						
MS-PS2-2 Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.						
MS-PS3-1 Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.						
MS-PS3-2 Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.						
MS-PS3-5 Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.						
Engineering Design						
MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.						
MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.						
MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.						
MS-ETS1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.						

Future Modifications

The SLIDER staff is working to publish the SLIDER curriculum materials and teacher support materials as interactive e-books. This will allow videos, simulations, and build instructions to be embedded directly in the text, greatly facilitating ease of use. These materials will be freely available on the SLIDER website.

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