STEM in a Shoebox

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STEM in a Shoebox

(Category: Evaluation of Programs/Curricula)

Introduction

In the College of Engineering at Carnegie Mellon University, our faculty, staff and students are often asked to attend STEM events and visit schools to share STEM content with K-12 math and science classes. Requests are sometimes well in advance of the delivery date but can also be received at the last minute, with little time for adequate preparation. We are exploring a solution to this challenge that will serve to increase the participation of our STEM outreach volunteers and provide the recipients with a more complete STEM experience. The proposed solution is the advance preparation of stand-alone kits, complete with a scalable lesson plan, that will fit in a container with the approximate size of a 'shoebox' and will be stored and catalogued in the engineering and science library.

The original intent of the kit approach was to facilitate the College of Engineering's collective inclusion of more stakeholders at the university (the library and maker space, for instance). In addition, teachers in the local school districts have had valuable input and look forward to the collaborative creation of additional kits.

This paper is primarily about the process of creating a kit and scalable lesson plan that can be used for informal outreach as well as incorporated into larger broader impact initiatives. At Carnegie Mellon, this process has been developed by an interdisciplinary team from the College of Engineering, the Engineering and Science Library, the Engineering Research Accelerator, IdeATe (Integrative Design, Arts and Technology) Lab, and the Leonard Gelfand Center for Service Learning and Outreach.

Background

Our College of Engineering is committed to the promotion of STEM and our faculty, staff and students are very active in STEM outreach activities. Examples of annual activities include:

- Summer Engineering Experience for Girls
- Summer Center for Climate, Energy, and Environmental Decision Making
- Carnegie Science Center Events (including Girls Rock Science and Sci-Tech Days)
- Allegheny Intermediate Unit HS School Apprentice Program
- Engineers' Week events on campus and at the Carnegie Science Center

We believe that our effectiveness will improve if we can address some challenges. One challenge is the limited availability of hands-on activities that are readily available for transport to schools and other STEM related events, such as those at the Carnegie Science Center. The kit initiative, whereby the kits are stored and catalogued in the Engineering Science Library, is a potential solution to this problem. Second, it is often difficult for our faculty, staff and students to understand and therefore target the skill and knowledge level of the students that we intend to engage and enlighten. One potential solution to this second challenge is to prepare scalable lesson plans that can guide the presentation based on the grade level of the students. As an additional benefit, the lesson plan creation process has allowed the promotion of intentional dialogue and exchange with the students and educators that are the ultimate beneficiaries of the kits.

Literature Review

Learning is enhanced when the student is actively engaged in the process[1]. When reviewing possible activities for the STEM in a Shoebox kits the team sought to select activities that require students to practice behaviors including observation, experimentation, data collection, analysis, and iteration to improve their designs. This approach is aligned with the *Framework for Implementing Quality K-12 Engineering* which notes, "Engineers use a variety of techniques, skills, processes, and tools in their work. Students studying engineering at the K-12 level need to become familiar and proficient with some of these techniques, skills, processes, and tools.[2]" The kits are designed to be used in different contexts, from short term demonstration experiences to activities which involve students in partial design challenges that require them to collaborate with their peers to solve a problem or answer a question. Recognizing that engineering has connections to science, mathematics and technology learning that is already taking place in schools[3], the instructional guides which accompany the kits include relevant vocabulary and background information enabling the presenter to connect the engineering activity to prior knowledge and to ensure that students are able to apply the correct terms within the context of the activity.

Even though various STEM educational resources and construction toys are available commercially, the distinct goal of our STEM in a Shoebox program is to offer enrichment with custom-made activities and support documents. A few similar programs were identified and reviewed to examine how these services were developed. We asked the following questions:

- What is the cost of a kit, particularly how much was spent on kit consumables?
- How did the program assess its success?
- Were some willing to share specifics about building their kits, including potential copyright issues?

At North Dakota's Grand Forks Public Library (GFPL), grant monies from IEEE and the ND State Library allowed for the purchase of materials for their STEM kits. Worth noting is that their STEM library activities are made possible through cooperation with the Dakota Science Center (module developers) and the University of North Dakota College of Engineering and

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[1] Brophy, S., Klein, S., Portsmore, M., Rogers, C.; *Advancing Engineering Education in P-12 Classrooms*; Journal of Engineering Education, 2008.
[2] Committee on Standards for K-12 Engineering Education; *Standards for K-12 Engineering Education?* National Academies Press, 2010.
[3] Moore, T.J., Glancy, A.W., Tank, K.M., Kersten, J.A., Stohlmann, M.N., Forster D.; Smith, K. A.; *A Framework for Implementing Quality K-12 Engineering*; American Society for Engineering Education, 2013.

Mines. The GFPL's model supports the creation of STEM modules for their STEM Kids programs held afterschool in the GFPL.[4] The modules incorporate typical elementary school lesson plans. The time needed for creating supporting documents to accompany STEM kits became an important consideration for this outreach effort. Each shoebox would include materials for the activity and consist of a description, related keywords and glossary, an outline of goals, as well as, lesson plans and student activity sheets for various grade levels.

The aim for our inaugural STEM in a Shoebox is to allow for the use of STEM kits outside of the University's physical library spaces. As similarly planned at Carnegie Mellon University, Mayville State University, North Dakota is an example of a program whose kits are available via the library's catalog. With an award from the Institute of Museum and Library Services, Mayville State University's Byrnes-Quanbeck Library also created a STEM kit collection reservation system, called Kitkeeper. The system allows area teachers to search by the kit's name or by STEM subject or grade level.[5]

The STEM Lending Library at the West Tennessee STEM Hub offers a one-month loan period for teachers to borrow K'NEX kits. It is one example of higher education institutions partnering with industry and K-12 school systems to enrich STEM learning. In their STEM Hub Fact Sheet for 2016, they note: "92% of teachers report the STEM Lending Library materials increase interest in math, science, and engineering with their students."[6] Plans to assess the suitability of the kits at Carnegie Mellon include a kit user voluntary survey. Modifications to any kits may be made based on feedback received.

The STEM Kit Library at Colorado State University's Education & Outreach Center, College of Natural Sciences also loans to local teachers. Their production lab has the ability to customize kits, including downloadable brochures, use the fewest consumables possible, and incorporate math and science notebooks. They have a method in place to weekly test them with students at their STEM Friday program.[7]

Carnegie Mellon is inspired by others with successful STEM kit programs and will create its own unique STEM kits. Some parts contained in "the shoebox" can be fabricated using available equipment at its IdeATe collaborative "makerspace" facility housed at the University's Hunt Library.

Project Description

In order to address the challenges noted above, our team agreed that:

- Hands-on activities are more effective in engaging K-12 students

[4] Grand Forks Public Library. "STEM Kids." Grand Forks, ND. Accessed January 27, 2017. http://www.gflibrary.com/index.aspx?NID=332.
[5] Mayville State University. "STEM KIT Checkout (Kitkeeper)." Accessed January 27, 2017. http://www.mayvillestate.edu/community/stem/stem-collaborative-cataloging-project
[6] West Tennessee STEM Hub. "STEM Lending Library." Accessed January 27, 2017. http://westtnstem.org/teachers/stem-lending-library
[7] Colorado State University, College of Natural Sciences. "STEM Kit Lending Library." Accessed January 27, 2017. http://www.cns-eoc.colostate.edu/stemkits.html.

- Participation at local outreach events can be limited by the
  - availability of hands-on activities
  - amount of time required to prepare for the event
- Outreach events can vary in length of time as well as grade level of the students

The proposed solution was the preparation of stand-alone and self-contained kits that would be stored and catalogued in the engineering library. The kit would include all of the necessary consumable and non-consumable components necessary to conduct the activity and/or demonstration. In addition, the kit would include a scalable lesson plan that could be optimized based on the available time as well as the grade level of the student participant. The kit and lesson plan might be used by one of our colleagues or may (eventually) be borrowed by a K-12 teacher.

Sources

Ideas for kits are readily available. Through the IdeATe lab and other rapid prototyping engineering classes, there is a collection of projects and ideas that are to be advanced through the development of a kit. Likewise, through our summer programs, broader impacts initiatives and other outreach events, we have a queue of activities that would be suited for kit creation.

Kit

The kit itself will contain components to be used for the implementing the activities. Those components might be consumables (that must be replenished after use) or non-consumables. And, to the extent possible, we intend to make the non-consumable components in our IdeATe lab or other maker space using laser cutting and 3D printing technology which will make it possible to produce many kits of the same type, say for an entire classroom activity, simply and economically. In the future, if there is interest, we may consider having the 'maker files' available for teachers so that they can ultimately build (3D print) their own kits, thus eliminating the need to borrow them. We chose the ‘shoebox’ dimension as a manageable size for ease of storage in the library as well as transport to off-campus events.

Lesson Plan

According to recommendations from the Committee on Integrated STEM Education (National Academy of Engineering and National Research Council of the National Academies), “Programs that prepare people to deliver integrated STEM instruction need to provide experiences that help these educators identify and make explicit to their students connections among the disciplines.” [8] The aim of the kits is to provide instructors with exactly this type of support by inclusion of specific learning goals, with the understanding that other unexpected learning may also be revealed.

Lesson plans have been thoughtfully and flexibly designed to accommodate different age levels as well as different durations for delivery of the activity. This framework for the lesson plan is shown in The Activity Overview, Table 1, a matrix where the target age groups are defined as

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[8] [5]Honey, M., G. Pearson, G., and H. Schweingruber, eds.. *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. *National Academy of Engineering and National Research Council.* Washington, D.C.: The National Academies Press, 2014. Accessed January 27, 2017. https://www.nap.edu/catalog/18612/stem-integration-in-k-12-education-status-prospects-and-an.

Grades 4-6 (Aware), Grades 7-9 (Assess) and Grades 10-12 (Analyze) the activity time durations are estimated to be 10 minutes (Engage), 30 minutes (Explain) and 60 minutes (Evaluate.)

Table 1: Activity Overview (example from the Ramp Racer kit)

Activity Overview – note that activities are additive (60 minute activity should be prefaced by the 10 and 30 minute activities) (Also, please See data collection sheets in Appendix.)

Grades\Time	**10 Minutes (Engage)**	**30 Minutes (Explain)**	**60 Minutes (Evaluate)**
4-6 (More details in Appendix …) *Be AWARE of ..*	Demonstrate the ramp and experiment with different features to produce different results. Talk about other examples where this information might be relevant to real world situations	Assemble the ramp and give short explanations about each feature (slope, truck and payload, material in the run-out length). Let the students experiment afterwards. Ask the students to write a sentence or 2 about their observations	Introduce concepts of physics and math. Experiment with the activity and collect data related to slope, weight, travel distance. Graph the data, use the graphs to make predictions, then test your predictions.
7-9 (More details in Appendix) *Be able to ASSESS …*	Ask students to make predictions then test their predictions and discuss the results based on the variables of slope, weight, and friction. Talk about other examples where this information might be relevant to real world situations	Have students assemble the ramp while explaining how it relates to the activity concepts. Map a strategy to test the different variables. Run each test; collect and graph the data. Ask the students to write a sentence or 2 about their observations	Have the students develop a hypothesis and develop the tests to prove their hypothesis. Graph the data, use the graphs to make predictions, then test your predictions.
10-12 (More details in Appendix) *Be able to ANALYZE ..*	Have the students assemble the ramp then determine the velocity of trucks while changing the variables of slope, weight, and friction (run-out materials). Discuss principles of physics, geometry and trigonometry. Talk about other examples where this information might be relevant to real world situations	Have students assemble the ramp while explaining how it relates to the activity concepts. Map a strategy to test the different variables. Run each test; collect and graph the data. Discuss how the kit might be modified to determine acceleration. Ask the students to write a sentence or 2 about their observations.	Have the students develop a hypothesis and develop the tests to prove their hypothesis, including force and acceleration. Graph the data, use the graphs to make predictions, then test your predictions.

Ramp Racer Example

The Ramp Racer (fabricated from laser cut acrylic), originated as a student project in a rapid prototyping course. With this as the starting point, the campus collaborators (from the engineering department, outreach and the engineering library), began to meet and conceptualize the content of a *Ramp Racer* kit and lesson plan. The premise was to allow student participants to explore the concepts of gravity, speed, and momentum while beginning to understand the potential effects of variables such as mass, slope, and friction. Components of the kit include:

- Ramp and wall (with associated assembly pieces)
- Weights (pennies and dimes)
- 'Hot Wheels' trucks (4)
- Fabric
- Sandpaper
- Measuring tape
- Protractor
- Stopwatch
- Kitchen scale
- Pencils, erasers, rulers
- Data collection sheets and graph paper

The associated lesson plan (included as Attachment 1, and grade specific lesson plans in Appendices A, B and C)) is scalable both in terms of the target age group as well as the time available for the event. The Activity Overview for the Ramp Racer is presented above in Table 1. The age groups are defined as Grades 4-6 (Aware), Grades 7-9 (Assess) and Grades 10-12 (Analyze) the activity time durations are estimated to be 10 minutes (Engage), 30 minutes (Explain) and 60 minutes (Evaluate.) Data collection and graphing are also elements of the exercise, especially in the 'Evaluate' phase of the optional levels of immersion in the topic matter. Appendix D provides the student worksheet for data collection.

There is a 'general' portion of the lesson plan that includes: abstract, key words, the Activity Overview, a paragraph about real world relevance, thoughts about how students might relate, material list, glossary, anticipated student questions, recommended readings, thoughts about 'what could possibly go wrong,' and safety suggestions. Appendices to the lesson plan include specific instructions for each grade level as well. In each section we support the teacher or presenter with a mapping relevant to the Next Generation Science Standards as well as provide a 'Connection to Engineering and Careers.' With regard to the latter, here is the paragraph created for the 4-6th grade instruction appendix:

> Engineers are often posed with a question or challenge, such as: which variables (slope, weight, friction) cause the truck to travel the farthest, the fastest, the shortest, or the slowest? To give a definitive answer, they will have to provide mathematical and scientific proof, but to get started, they might just run some simple experiments to get a basic understanding of the problem and the general effect of the variables. With a basic understanding and the ability to collect the supporting data, the engineer can then develop the mathematical equations (or proof) that will allow for the development of a reliable and replicable engineering solution.
>
> To think like an engineer, one must be curious (what is the problem?), methodical (how can I parse the problem down into smaller, more management components?), objective (is there more than one way to solve the problem?), analytical (what are the principles of math and science that allow us to define the

problem and the solution?), and practical (what is the most cost effective and reliable way to solve the problem?) This exercise allows us to explore some of the traits of an engineer.

Specifically, civil and mechanical engineers might be inclined to use the principles of math and physics that are explored in this exercise.

Kit Maintenance and Storage

The library is a natural outreach partner to the STEM community with a goal to provide materials to enrich all of the university constituents from faculty and staff to our students of all levels – and to include our local community of educators' K through 12. The Engineering and Science Library will assist with the collection of kits from their inception by cataloguing each item, maintaining the supply levels in each as they are vended and returned, and to promote and advertise their use and availability. The Engineering and Science Library at Carnegie Mellon University is committed to the goal of "Impacting society in a transformative way – regionally, nationally, and globally – by engaging with partners outside the traditional borders of the university campus."   This unique partnership is a model that provides the College of Engineering with management system for lending of the kits and provides the Engineering and Science Library with a creative opportunity to meet their intended goal of expanded engagement.

Next Generation Science Standards

In addition to developing a lesson plan that can guide users of the kit, this team also chose to assist the classroom teachers in helping to define the relevance to their math or science class. We chose the Next Generation Science Standards as our guide. The mapping of the NGSS on to the activities of the kit might not be direct, but it provides a useful guideline for the teachers and therefore provides encouragement for adoption of the kit. Please see the appendices in the draft lesson plan for an example of the identification of standards relevant to the targeted grades.

Beta Testing

The version of the Ramp Racer lesson plan discussed in this paper is the result of 2 focus sessions with middle school teachers. In addition, we have taken the Ramp Racer kits to science fairs as well as into 2 middle school classrooms. At a science fair, time (and attention spans) are limited, so the Ramp Racer activity will allow for the exploration of 1 or 2 variables. Science fair events have been manned by faculty or staff but by undergraduate students as well. Undergraduate students have not only made construction suggestions to improve the Ramp Racer kit but have also become secondary beneficiaries of the experience. At science fair events, children of a variety of ages will stop by, often in groups and sometimes with a parent or teacher. The individual performing the demonstration will have to gauge both the content and length of the demonstration because distractions will dictate the attention level of the visitor.

The classroom, with teacher participation, provides some different observations. When first provided with the lesson plan, the teachers have rewritten and adapted it to be consistent with the flow of their respective classes and the learning level of their students. Second, the kit requires a limited number of tasks and therefore can only be used effectively with 4 or 5 students. One immediate take-away from the classroom experience is that the kit lends itself to a long program as opposed to a short program. When the teachers and students begin to engage with the kit, they can generate new variables to explore and or different ways to configure the physical components kit. We also recognized that the lesson plan and data collection sheets provide a framework, but the teachers will modify the materials based on his or her knowledge of their respective students.

Next Steps

The Ramp Racer is ready for use by those performing outreach at a science fair or in a classroom. We are in the process of identifying additional kits following the same format for the lesson plan. We imagine that the through the creation and beta testing of additional kits, we will continue to optimize the structure of the lesson plan.

In addition, we need to begin to develop metrics for the assessment of the effectiveness of the kits. Assessment data might include but is not limited to:

- Are teachers using the kits and for what grade levels?
- Are the kits complimenting their lesson plans?
- How many students have interacted with the kits?
- Are their students gaining a better understanding of the field of engineering through the use of the kits?
- Are our faculty members, staff and students using the kits? How much activity is the Library managing with the kits lending program?

Data might be collected via student activity sheets, teacher observations, and surveys. Kit instructors will be asked to complete when finished using the kits. Kits will be analyzed for modifications accordingly. Our future proposals to foundations as well as possible government and industry entities will be strengthened by: a better 'track record' of the effectiveness of the kits, the network that we are able to enhance with local K-12 teachers, and the ongoing meetings and discussion of the STEM Outreach Committee.

Conclusion

The methodology described for design and use of the Ramp Racer kit for a variety of student levels provides the framework for future kit development. We have received a grant from Carnegie Mellon to develop more kits about a range of engineering and science topics to include: forensic science, construction of a tiny house, lemon based batteries and electrical energy conversion. Additional topics will be generated from faculty and student research interests as well as the rapid prototyping class in the IdeATe Lab. We will work toward obtaining future funding sources from government, foundations and industrial sources to grow the repository of kits.

ATTACHMENT 1

Title

Ramp Racers – Physics and Engineering

Abstract

In this activity, participants will observe how different elements determine how far and how fast an object can travel. Materials in the kit include a ramp and some 'Hot Wheels' trucks. The angle of the slope of the ramp can be adjusted and the mass of the cars can be increased by adding weight (pennies and dimes). Participants will explore the relationship between weight, slope and friction by measuring the distance traveled by the truck given the change in variables. With data collected from enough trials, the participants will be able to estimate travel distances based on slope angles, masses, and surfaces (with different friction coefficients). Data will be used to graph the effects of the variables to determine how they interact with each other. For an added level of complexity, the speed and acceleration of the car can be used to help determine the amount of force that is acting on the car at particular ramp settings.

Keywords

Newton's laws of motion, physics, engineering, geometry, trigonometry, potential energy, kinetic energy, momentum, data collection and graphing, cars, incline or slope, mass, velocity/speed, gravity, friction, mass, acceleration, Pythagorean Theorem, angles, unit conversion, cause and effect, causation, variable

Activity Overview – note that activities are additive (60 minute activity should be prefaced by the 10 and 30 minute activities) (Also, please See data collection sheets in Appendix D.)

Grades\Time	10 Minutes (Engage)	30 Minutes (Explain)	60 Minutes (Evaluate)
4-6 (More details in Appendix A) *Be AWARE of ..*	Demonstrate the ramp and experiment with different features to produce different results. Talk about other examples where this information might be relevant to real world situations	Assemble the ramp and give short explanations about each feature (slope, truck and payload, material in the run-out length). Let the students experiment afterwards. Ask the students to write a sentence or 2 about their observations	Introduce concepts of physics and math. Experiment with the activity and collect data related to slope, weight, travel distance. Graph the data, use the graphs to make predictions, then test your predictions.
7-9 (More details in Appendix B) *Be able to ASSESS …*	Ask students to make predictions then test their predictions and discuss the results based on the variables of slope, weight, and friction. Talk about other examples where this information might be relevant to real world situations	Have students assemble the ramp while explaining how it relates to the activity concepts. Map a strategy to test the different variables. Run each test; collect and graph the data. Ask the students to write a sentence or 2 about their observations	Have the students develop a hypothesis and develop the tests to prove their hypothesis. Graph the data, use the graphs to make predictions, then test your predictions.

10-12 (More details in Appendix C) *Be able to ANALYZE ..*	Have the students assemble the ramp then determine the velocity of trucks while changing the variables of slope, weight, and friction (run-out materials). Discuss principles of physics, geometry and trigonometry. Talk about other examples where this information might be relevant to real world situations	Have students assemble the ramp while explaining how it relates to the activity concepts. Map a strategy to test the different variables. Run each test; collect and graph the data. Discuss how the kit might be modified to determine acceleration. Ask the students to write a sentence or 2 about their observations.	Have the students develop a hypothesis and develop the tests to prove their hypothesis, including force and acceleration. Graph the data, use the graphs to make predictions, then test your predictions.

Real World Relevance

An understanding of physics, velocity, acceleration, force, dynamics, friction, geometry, etc is important for most engineering disciplines. In particular, Ramp Racer activity can be related to Civil and Mechanical engineering. When planning a road, civil engineers must take hills into account so that motor vehicles can travel safely on them. If a slope is too steep, vehicles and occupants may risk damage and injury due to excessive weight and/or acceleration. It is essential to be able to predict what the angle of the slope of a road should be in order for cars remain safe in as many conditions as possible. Even if the roads were to become frictionless from rain or snow, it is the responsibility of the engineers to address those issues. In other cases, engineers may also consider ramps and slopes when thinking about walkways or supply lines. People need to be safe when walking and materials need to be intact when moving from one location to another. Having the right (or properly engineered!) settings may be the difference between safety and disaster.

How might students relate?

Bicycling, for instance. If you were bicycling down a steep slope and into a run-out of rough gravel you might not travel as far as if you hit a run-out of ice!

Skateboarding might be another example. If you let the skateboard travel on its own if might exhibit one behavior. However, if you add your weight to the skateboard and travel down the same slope on to the same run-out surface, the velocity and travel distance might just be a bit different!

Others …. Waterslide? Ski jump? Sled riding?

Materials (per kit, 4-6 students per kit)

- Ramp and wall (with associated assembly pieces)
- weights (pennies and dimes)
- 'Hot Wheels' trucks (4)
- fabric (not in photo)
- sandpaper (or other material)
- measuring tape
- protractor (2)
- stopwatch (2)
- kitchen scale
- Pencils, erasers, rulers
- Data collection sheets
- Graph paper (not in photo)

Glossary

- *acceleration – the rate at which the speed of a moving object changes over time*
- *force – strength or energy exerted*
- *friction –* the force that opposes the relative motion of two objects in contact. Friction is always parallel to the two surfaces in contact and acts in the direction that opposes slipping. Static friction is the force that opposes the start of motion. Kinetic friction is the friction between objects in contact when they are in motion. The force of friction is directly proportional to the magnitude of the normal fore and depends on the coefficient of friction (μ); different materials have different friction coefficients, for instance ice will have a lower coefficient of friction than sandpaper (or other material)
- *geometry* - a branch of mathematics that deals with points, lines, angles, surfaces, and solids
- *gravity* – the force of attraction by which terrestrial bodies tend to fall toward the center of the earth
- *kinetic energy* – the energy of a body or a system with respect to the motion of the body or of the particles in the system
- *mass* – the quantity of matter as determined from its weight
- *momentum* – force or speed of movement; impetus, as of a physical object or course of events
- *Newton's Three Laws of Motion*:
    1. An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.
    2. The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.
    3. For every action, there is an equal and opposite reaction.
- *potential energy* – the energy of a body or a system with respect to the position of the body or the arrangement of the particles of the system

- *Pythagorean Theorem* - the square of the length of the hypotenuse of a right triangle equals the sum of the squares of the lengths of the other two sides: $a^2+b^2=c^2$ where 'a' and 'b' are sides of the right triangle and 'c' is the hypotenuse
- *trigonometry* – a branch of mathematics that deals with relationships between the sides and angles of triangles
- *variable* – able or likely to change or be changed
- *velocity (speed)* – the time rate of change of position of a body in a specified direction. Velocity is a determined by dividing distance travel by the time required to travel that distance.

General Anticipated Student Questions

What kind of cars are we using? (Chevy Silverado, Hot Wheels)
What does this have to do with real life? (Refer to "World Relevance")
Can we race with the cars? (Yes)
How can we make the car go the fastest or the farthest? (Experiment and find out.)
Is one car better than the others? (You tell me!)
Can we play with the coins? (That is not part of the activity. And, you cannot take them, either.)

Recommended Readings and Internet Connections

- http://ideate.xsead.cmu.edu/gallery/projects/car-ramp
- http://examples.yourdictionary.com/cause-and-effect-examples.html
- http://www.physicsclassroom.com/class/circles/Lesson-3/Gravity-is-More-Than-a-Name
- http://www.physics4kids.com/files/motion_friction.html
- http://csep10.phys.utk.edu/astr161/lect/history/newton3laws.html

Caveat emptor – what could possibly go wrong?

- Ramp breaks – fix it! Perhaps use a book to support? Do not force pieces into place, they should fit together with gentle pressure.
- Stop watched do not work – use cell phone
- Scale does not work – one penny = 2.5 grams, one dime = 2.2 grams, one truck = 46.5 grams
- Trucks are sticking to ramp – recheck configuration and clean surface
- Trucks do not travel in a straight line – be careful in the placement of the truck at the top of the ramp – be sure that they are aligned as straight as possible
- End barrier is getting pushed out of the way – weight the barrier with a book or other heavy object
- Coins are flying out of truck – try to secure with tape, but you will probably have to re-weigh
- Truck are flying off the table – shorten the run-out distance or try placing an object, like a book, next to the run-out material
- **NOTE: when taking measurements or recording time, please be sure to conduct 3 tests and average the results.**

Safety Suggestions

- Please be careful with the materials so that they do not break. This may result in sharp edges that may cause injury. This risk may include the edges of the sand paper.
- Be wary of small pieces of plastic and coins for choking hazards.

<u>Appendix A</u> – Lesson Plan for Grades 4-6

Pre-requisites (use only for reference)

Prerequisite Knowledge: Basic math (addition, subtraction, multiplication, division), general concepts (units, gravity, velocity), using a ruler or tape measure and protractor (to measure angles)

Connection to Engineering and Careers

Engineers are often posed with a question or challenge, such as: which variables (slope, weight, friction) cause the truck to travel the farthest, the fastest, the shortest, or the slowest? To give a definitive answer, they will have to provide mathematical and scientific proof, but to get started, they might just run some simple experiments to get a basic understanding of the problem and the general effect of the variables. With a basic understanding and the ability to collect the supporting data, the engineer can then develop the mathematical equations (or proof) that will allow for the development of a reliable and replicable engineering solution.

To think like an engineer, one must be curious (what is the problem?), methodical (how can I parse the problem down into smaller, more management components?), objective (is there more than one way to solve the problem?), analytical (what are the principles of math and science that allow us to define the problem and the solution?), and practical (what is the most cost effective and reliable way to solve the problem?) This exercise allows us to explore some of the traits of an engineer.

Specifically, civil and mechanical engineers might be inclined to use the principles of math and physics that are explored in this exercise.

Learning Goals

Understanding Cause and Effect: Engineering often employs the concept of cause and effect. Particular scenarios may look interesting from their results, but it is also important to know how those conclusions came about. The principles of cause and effect can bring more meaning to a situation by answering the question of *what* (the effect) happened and *why* (the cause). If the effect is a favorable one, it would be nice to know the cause in order to reproduce the results. It is also still good to know the cause of a bad effect in order to implement ways to prevent it. Figuring out how something happened is not always the simplest thing as many factors may be involved. However, if all of those factors as well as their effects on the results and each other can be discovered, recreating and controlling the results with intended derivatives becomes a simple task.

After the conclusion of this activity (and dependent upon the duration of the activity), students should be AWARE of the exercise concepts and be able to answer the following questions:

- If we change variables, why are the results different?

- What is data and why is it important to collect and understand data in order to solve problems (based on experience of estimating distance traveled or time and then plotting data such as slope angle, time, and/or mass vs. distance travelled or speed)?
- How does graphing help us to use data to make predictions?
- In one sentence, what did you learn?

Guidelines *(10 minutes [Engage], 30 minutes [Explain], 60 minutes [Evaluate]). These are only suggestions: please feel free to create your own trials and experiments with the variable of slope, weight and friction.*

1. For preparation and prior to working with the students, be sure to review the 'Glossary' terms
2. <u>Ramp assembly</u>
    a. 'Engage' <u>-- before the activity</u>, assemble the ramp with a level runway ending with the 'wall' at a distance least 50 cm away – this distance may be adjusted depending upon the speed at which the truck travels (ie – distance might be too short to get a reasonable time measurement).
    b. 'Explain'- -- have students help to build ramp
    c. 'Evaluate' – let the students build the ramp
3. Explain the different features of the ramp and how the trucks move with gravity. Slope angle can be set at 10°, 15°, 20°, or 25°. Show how the angles can be measured with the protractor (optional.) The trucks can be filled with coins to make them heavier. A tabletop runway can be layered with fabric or different grits of sandpaper (or other material) to modify the truck speed if desired.
4. Set the ramp at 20° and demonstrate how the truck (without weight) travels down the ramp and travels a horizontal distance along the table top. Ask the following questions, then demonstrate to find the answer:
    a. 'Engage'
        i. If we make the ramp less steep, will the truck travel faster or slower?
        ii. If we make the ramp steeper, will the truck travel faster or slower?
    b. 'Explain'
        i. If we make the ramp less steep, will the truck travel faster or slower? Time how long it takes and record the data.
        ii. If we make the ramp steeper, will the truck travel faster or slower? Time how long it takes and record the data.
        iii. Determine velocity: distance (horizontal path plus length of ramp) divided by time.
    c. 'Evaluate'
        i. Ask the students to make predictions with respect to slope and ask them to predict their predictions. Make 3 trials, timing how long it takes and record the data.

        ii. Determine velocity and graph results

5. Set the ramp at 20° again and add ten coins to the truck bed. Again, demonstrate how the truck travels down the ramp and travels a horizontal distance along the table top. Ask the following questions, then demonstrate to find the answer:
    a. 'Engage'
        i. If we add weight, will the truck travel faster or slower?
        ii. If we reduce weight, will the truck travel faster or slower?
    b. 'Explain'
        i. If we add weight, will the truck travel faster or slower? Time how long it takes and record the data.
        ii. If we reduce weight, will the truck travel faster or slower? Time how long it takes and record the data.
        iii. Determine velocity: distance (horizontal path plus length of ramp) divided by time.
    c. 'Evaluate'
        i. Ask the students to make predictions with respect to weight and ask them to predict their predictions. Make 3 trials, timing how long it takes and record the data.
        ii. Determine velocity and graph results
6. Set the ramp at 20° again and add ten coins to the truck bed. Then, place sandpaper (or other material) along the horizontal travel path. Again, demonstrate how the truck travels down the ramp and travels a horizontal distance along the sandpaper (or other material) surface. Ask the following questions, then demonstrate to find the answer:
    a. 'Engage'
        i. If we make the horizontal surface more 'rough', will the truck travel faster or slower?
        ii. If we make the horizontal surface more 'smooth', will the truck travel faster or slower?
    b. 'Explain'
        i. If we make the horizontal surface more 'rough', will the truck travel faster or slower? Time how long it takes and record the data.
        ii. If we make the horizontal surface more 'smooth', will the truck travel faster or slower? Time how long it takes and record the data.
        iii. Determine velocity: distance (horizontal path plus length of ramp) divided by time.
    c. 'Evaluate'
        i. Ask the students to make predictions with respect to the 'friction' factor of the horizontal path and ask them to predict their

predictions. Make 3 trials, timing how long it takes and record the data.

ii. Determine velocity and graph results

7. Review how changing the various characteristics of the ramp changed the results.

Curricular Framework – Next Generation Science Standards

Standards are different for Fourth Grade, Fifth Grade, and Sixth Grade. Fifth and Sixth Grade performance expectations do include the PS2 Disciplinary Core Idea (*Forces and Interactions*) from the NRC Framework upon which this lesson is based and which include 1) Forces and Motion and 2) Types of Interaction. However, in Fourth Grade, the PS2 Disciplinary Core Idea is not included with performance expectations. In the case of Fourth Grade, however, this lesson does begin to work with the more general performance expectations of "“students are expected to demonstrate grade-appropriate proficiency in asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, constructing explanations and designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information."

For Fifth Grade, while the connection to PS2 is connected to Space Systems, Ramp Races provides an entry into other situations of the gravitational force on Earth:

- 5-PS2-1. Support an argument that the gravitational force exerted by Earth on objects is directed down. [Clarification Statement: "Down" is a local description of the direction that points toward the center of the spherical Earth.] [Assessment Boundary: Assessment does not include mathematical representation of gravitational force.]

For Sixth Grade (Middle School Physical Science), the PS2 Disciplinary Core Idea of Forces and Interaction becomes more developed in terms of objects movement and the physical interactions between objects and within systems of objects. The standards for Middle School are delineated in detail in the next section: Appendix B (Lesson Plan for Grades 7-9).

<u>Appendix B</u> – Lesson Plan for Grades 7-9

Pre-requisites (use only for reference)

Prerequisite Knowledge: data gathering, graphing, mass, velocity, gravity, friction, prerequisites from Appendix A

Connection to Engineering and Careers

Engineers are often posed with a question or challenge, such as: which variables (slope, weight, friction) cause the truck to travel the farthest, the fastest, the shortest, or the slowest? To give a definitive answer, they will have to provide mathematical and scientific proof, but to get started, they might just run some simple experiments to get a basic understanding of the problem and the general effect of the variables. With a basic understanding and the ability to collect the supporting data, the engineer can then develop the mathematical equations (or proof) that will allow for the development of a reliable and replicable engineering solution.

To think like an engineer, one must be curious (what is the problem?), methodical (how can I parse the problem down into smaller, more management components?), objective (is there more than one way to solve the problem?), analytical (what are the principles of math and science that allow us to define the problem and the solution?), and practical (what is the most cost effective and reliable way to solve the problem?) This exercise allows us to explore some of the traits of an engineer.

Specifically, civil and mechanical engineers might be inclined to use the principles of math and physics that are explored in this exercise.

Learning Goals

Understanding Force: Many physical factors affect what happens in the world. One of the most prominent are forces or "a push or pull acting upon an object as a result of its interaction with another object" (the Physics Classroom). There are several different types of forces that can interact with each other and behave in particular ways as stated in Newton's Three Laws of Motion. In this activity, the forces that can be observed comes from gravity and friction, but those forces may also be influenced by the angle of decent and mass. These forces are always active, even on a small ramp with two Hot Wheels trucks.

After the conclusion of this activity (and dependent upon the duration of the activity), students should be able to EXPLAIN the exercise concepts and be able to answer the following questions:

- What is the relationship between slope and gravity?
- What is the relationship between mass and gravity?
- How does friction impact velocity?
- What is data and why is it important to collect and understand data in order to solve problems (based on experience of estimating distance traveled or time and then plotting data such as slope angle, time, and/or mass vs. distance travelled or speed)?
- How does graphing help us to use data to make predictions?

- In one sentence, what did you learn?
- How can we use the Pythagorean Theorem to help calculate the total horizontal distance that the trucks travel?

Guidelines *(10 minutes Engage], 30 minutes [Explain], 60 minutes [Evaluate]). These are only suggestions: please feel free to create your own trials and experiments with the variable of slope, weight and friction.*

1. For preparation and prior to working with the students, be sure to review the 'Glossary' terms
2. Ramp assembly
    a. 'Engage' -- before the activity, assemble the ramp with a level runway ending with the 'wall' at a distance least 50 cm away – this distance may be adjusted depending upon the speed at which the truck travels (ie – distance might be too short to get a reasonable time measurement).
    b. 'Explain'- -- have students help to build ramp
    c. 'Evaluate' – let the students build the ramp
3. Explain the different features of the ramp and how the trucks move with gravity. Slope angle can be set at 10°, 15°, 20°, or 25°. Show how the angles can be measured with the protractor (optional.) The trucks can be filled with coins to make them heavier. A tabletop runway can be layered with fabric or different grits of sandpaper (or other material) to modify the truck speed if desired.
4. Set the ramp at 20° and demonstrate how the truck (without weight) travels down the ramp and travels a horizontal distance along the table top. Ask the following questions, then demonstrate to find the answer:
    a. 'Engage'
        i. If we make the ramp less steep, will the truck travel faster or slower?
        ii. If we make the ramp steeper, will the truck travel faster or slower?
    b. 'Explain'
        i. If we make the ramp less steep, will the truck travel faster or slower? Time how long it takes and record the data.
        ii. If we make the ramp steeper, will the truck travel faster or slower? Time how long it takes and record the data.
        iii. Determine velocity: distance (horizontal path plus length of ramp) divided by time. Determine Length of ramp using the Pythagorean Theorem and compare to measured length.
    c. 'Evaluate'
        i. Ask the students to make predictions with respect to slope and ask them to predict their predictions. Make 3 trials, timing how long it takes and record the data.
        ii. Determine velocity and graph results

5. Set the ramp at 20° again and add ten coins to the truck bed. Again, demonstrate how the truck travels down the ramp and travels a horizontal distance along the table top. Ask the following questions, then demonstrate to find the answer:
    a. 'Engage'
        i. If we add weight, will the truck travel faster or slower?
        ii. If we reduce weight, will the truck travel faster or slower?
    b. 'Explain'
        i. If we add weight, will the truck travel a faster or slower? Time how long it takes and record the data.
        ii. If we reduce weight, will the truck travel faster or slower? Time how long it takes and record the data.
        iii. Determine velocity: distance (horizontal path plus length of ramp) divided by time. Determine Length of ramp using the Pythagorean Theorem and compare to measured length.
    c. 'Evaluate'
        i. Ask the students to make predictions with respect to weight and ask them to predict their predictions. Make 3 trials, timing how long it takes and record the data.
        ii. Determine velocity and graph results
6. Set the ramp at 20° again and add ten coins to the truck bed. Then, place sandpaper (or other material) along the horizontal travel path. Again, demonstrate how the truck travels down the ramp and travels a horizontal distance along the sandpaper (or other material) surface. Ask the following questions, then demonstrate to find the answer:
    a. 'Engage'
        i. If we make the horizontal surface more 'rough', will the truck travel faster or slower?
        ii. If we make the horizontal surface more 'smooth', will the truck travel faster or slower?
    b. 'Explain'
        i. If we make the horizontal surface more 'rough', will the truck travel a faster or slower? Time how long it takes and record the data.
        ii. If we make the horizontal surface more 'smooth', will the truck travel faster or slower? Time how long it takes and record the data.
        iii. Determine velocity: distance (horizontal path plus length of ramp) divided by time. Determine Length of ramp using the Pythagorean Theorem and compare to measured length.
    c. 'Evaluate'
        i. Ask the students to make predictions with respect to the 'friction' factor of the horizontal path and ask them to predict their

predictions. Make 3 trials, timing how long it takes and record the data.

ii. Determine velocity and graph results

7. Review the activity findings and answers questions about how the activity relates to the different physics concepts mentioned at the beginning of the activity.

Curricular Framework – Next Generation Science Standards

The Next Generation Science Standards for middle school in the area of "Forces and Interactions" focuses on helping students understand ideas related to why some objects will keep moving, The PS2 Disciplinary Core Idea is broken down into: 1) Forces and Motion and 2) Types of Interaction. Below are the standards addressed in Ramp Racers:

MS. Forces and Interactions Students who demonstrate understanding can:

1. MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.* [Clarification Statement: Examples of practical problems could include the impact of collisions between two cars, between a car and stationary objects, and between a meteor and a space vehicle.] [Assessment Boundary: Assessment is limited to vertical or horizontal interactions in one dimension.]
2. 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. [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry.]
3. MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. [Clarification Statement: Examples of devices that use electric and magnetic forces could include electromagnets, electric motors, or generators. Examples of data could include the effect of the number of turns of wire on the strength of an electromagnet, or the effect of increasing the number or strength of magnets on the speed of an electric motor.] [Assessment Boundary: Assessment about questions that require quantitative answers is limited to proportional reasoning and algebraic thinking.]
4. MS-PS2-4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects. [Clarification Statement: Examples of evidence for arguments could include data generated from simulations or digital tools; and charts displaying mass, strength of interaction, distance from the Sun, and orbital periods of objects within the solar system.] [Assessment Boundary: Assessment does not include Newton's Law of Gravitation or Kepler's Laws.]
5. MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact. [Clarification Statement: Examples of

this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically-charged pith balls. Examples of investigations could include first-hand experiences or simulations.] [Assessment Boundary: Assessment is limited to electric and magnetic fields, and is limited to qualitative evidence for the existence of fields.]

Appendix C – Lesson Plan for Grades 10-12

Pre-requisites (use only for reference)

Prerequisite Knowledge: Newton's Three Laws of Motion, geometry, Pythagorean Theorem ($a^2 + b^2 = c^2$), prerequisites from Appendix B

Connection to Engineering and Careers

Engineers are often posed with a question or challenge, such as: which variables (slope, weight, friction) cause the truck to travel the farthest, the fastest, the shortest, or the slowest? To give a definitive answer, they will have to provide mathematical and scientific proof, but to get started, they might just run some simple experiments to get a basic understanding of the problem and the general effect of the variables. With a basic understanding and the ability to collect the supporting data, the engineer can then develop the mathematical equations (or proof) that will allow for the development of a reliable and replicable engineering solution.

To think like an engineer, one must be curious (what is the problem?), methodical (how can I parse the problem down into smaller, more management components?), objective (is there more than one way to solve the problem?), analytical (what are the principles of math and science that allow us to define the problem and the solution?), and practical (what is the most cost effective and reliable way to solve the problem?) This exercise allows us to explore some of the traits of an engineer.

Specifically, civil and mechanical engineers might be inclined to use the principles of math and physics that are explored in this exercise.

Learning Goals

Understanding Force: Many physical factors affect what happens in the world. One of the most prominent are forces or "a push or pull acting upon an object as a result of its interaction with another object" (the Physics Classroom). There are several different types of forces that can interact with each other and behave in particular ways as stated in Newton's Three Laws of Motion. In this activity, the forces that can be observed comes from gravity and friction, but those forces may also be influenced by the angle of decent and mass. These forces are always active, even on a small ramp with two Hot Wheels trucks.

After the conclusion of this activity (and dependent upon the duration of the activity), students should be able to EXPLORE the exercise concepts and be able to answer the following questions:

- What is the relationship between slope and gravity?
- What is the relationship between mass and gravity?
- How does friction impact velocity?
- What are Newton's 3 laws of motion and how do they relate to this exercise?
- What is data and why is it important to collect and understand data in order to solve problems (based on experience of estimating distance traveled or time and

then plotting data such as slope angle, time, and/or mass vs. distance travelled or speed)?

- How does graphing help us to use data to make predictions?
- In one sentence, what did you learn?

Guidelines *(10 minutes [Engage], 30 minutes [Explain], 60 minutes [Evaluate]). These are only suggestions: please feel free to create your own trials and experiments with the variable of slope, weight and friction.*

1. For preparation and prior to working with the students, be sure to review the ‘Glossary’ terms
2. <u>Ramp assembly</u>
    a. ‘Engage’ <u>-- before the activity</u>, assemble the ramp with a level runway ending with the ‘wall’ at a distance least 50 cm away – this distance may be adjusted depending upon the speed at which the truck travels (ie – distance might be too short to get a reasonable time measurement). ‘Explain’- -- have students help to build ramp
    b. ’Evaluate’ – let the students build the ramp
3. Explain the different features of the ramp and how the trucks move with gravity. Slope angle can be set at 10°, 15°, 20°, or 25°. Show how the angles can be measured with the protractor (optional.) The trucks can be filled with coins to make them heavier. A tabletop runway can be layered with fabric or different grits of sandpaper (or other material) to modify the truck speed if desired.
4. Set the ramp at 20° and demonstrate how the truck (without weight) travels down the ramp and travels a horizontal distance along the table top. Ask the following questions, then demonstrate to find the answer:
    a. ‘Engage’
        i. If we make the ramp less steep, will the truck travel faster or slower?
        ii. If we make the ramp steeper, will the truck travel faster or slower?
    b. ‘Explain’
        i. If we make the ramp less steep, will the truck travel faster or slower? Time how long it takes and record the data.
        ii. If we make the ramp steeper, will the truck travel faster or slower? Time how long it takes and record the data.
        iii. Determine velocity: distance (horizontal path plus length of ramp) divided by time. Determine Length of ramp using the Pythagorean Theorem and compare to measured length.
    c. ’Evaluate’
        i. Ask the students to make predictions with respect to slope and ask them to predict their predictions. Make 3 trials, timing how long it takes and record the data.
        ii. Determine velocity and graph results

5. Set the ramp at 20° again and add ten coins to the truck bed. Again, demonstrate how the truck travels down the ramp and travels a horizontal distance along the table top. Ask the following questions, then demonstrate to find the answer:
    a. 'Engage'
        i. If we add weight, will the truck travel faster or slower?
        ii. If we reduce weight, will the truck travel faster or slower?
    b. 'Explain'
        i. If we add weight, will the truck travel faster or slower? Time how long it takes and record the data.
        ii. If we reduce weight, will the truck travel faster or slower? Time how long it takes and record the data.
        iii. Determine velocity: distance (horizontal path plus length of ramp) divided by time. Determine Length of ramp using the Pythagorean Theorem and compare to measured length.
    c. 'Evaluate'
        i. Ask the students to make predictions with respect to weight and ask them to predict their predictions. Make 3 trials, timing how long it takes and record the data.
        ii. Determine velocity and graph results
6. Set the ramp at 20° again and add ten coins to the truck bed. Then, place sandpaper (or other material) along the horizontal travel path. Again, demonstrate how the truck travels down the ramp and travels a horizontal distance along the sandpaper (or other material) surface. Ask the following questions, then demonstrate to find the answer:
    a. 'Engage'
        i. If we make the horizontal surface more 'rough', will the truck travel faster or slower?
        ii. If we make the horizontal surface more 'smooth', will the truck travel faster or slower?
    b. 'Explain'
        i. If we make the horizontal surface more 'rough', will the truck travel faster or slower? Time how long it takes and record the data.
        ii. If we make the horizontal surface more 'smooth', will the truck travel faster or slower? Time how long it takes and record the data.
        iii. Determine velocity: distance (horizontal path plus length of ramp) divided by time. Determine Length of ramp using the Pythagorean Theorem and compare to measured length.
    c. 'Evaluate'
        i. Ask the students to make predictions with respect to the 'friction' factor of the horizontal path and ask them to predict their

predictions. Make 3 trials, timing how long it takes and record the data.

   ii. Determine velocity and graph results

7. Review what was learned and relate the activity to Newton's Three Laws of Motion.

Curricular Framework – Next Generation Science Standards

The Next Generation Science Standards for high school in the area of "Forces and Interactions" focuses on helping students understand ideas related to why some objects will keep moving, The PS2 Disciplinary Core Idea is broken down into: 1) Forces and Motion and 2) Types of Interaction. Below are the standards addressed in Ramp Racers:

1. HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]
2. HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]
3. HS-PS2-3. Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.* [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.]
4. HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [Assessment Boundary: Assessment is limited to systems with two objects.]
5. HS-PS2-5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. [Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]

Appendix D

Name ____

Ramp angle: ______________ degrees

Roadbed surface (check one): ☐ Tabletop ☐ Fabric ☐ Sandpaper ☐ Other ______________

Truck only

Mass (grams)	Distanc (cm)	Time (sec) – make 3 trials then calculate the average (shaded cells)				Average Velocity (cm/sec) calculate 3 times and determine the average (shaded cells)			
Weight 1:	50								
Weight 2:	100								
Weight 3:									
Average weight:									

Truck with 5 coins

Mass (grams)	Distanc (cm)	Time (sec) – make 3 trials then calculate the average (shaded cells)				Average Velocity (cm/sec) calculate 3 times and determine the average (shaded cells)			
Weight 1:	50								
Weight 2:	100								
Weight 3:									
Average weight:									

Truck with 10 coins

Mass (grams)	Distanc (cm)	Time (sec) – make 3 trials then calculate the average (shaded cells)				Average Velocity (cm/sec) calculate 3 times and determine the average (shaded cells)			
Weight 1:	50								
Weight 2:	100								
Weight 3:									
Average weight:									