UL XPLORLABS

PORTABLE ELECTRICAL POWER

EDUCATOR

TENSILE TEST AND DURABILITY

CASE STUDY OF SCIENCE AND ENGINEERING

SCIENTISTS ASK WHY. ENGINEERS ASK HOW.

AGE GROUP
Middle School

CATEGORY
Electrical Power

COMPLETION TIME
3-5 Class Periods

QUESTIONS TO XPLORE

WHAT IS THE MOST DURABLE MATERIAL TO USE FOR AN ENCLOSURE?

Lithium-ion batteries are widely used as a power source in portable electrical and electronic products. While the rate of failures associated with their use is small, several well- publicized incidents related to lithium-ion batteries in actual use (including fires and explosions) have raised concerns about their overall safety. Test standards are in place that mandate a number of individual tests designed to assess specific safety risks associated with the use of lithium-ion batteries. This safety science-based testing helps identify essential construction and performance requirements that address the inherent risks an end product could present.

In this investigation students will use the three core ideas of engineering design – define and delimit an engineering problem, develop possible solutions, and optimize the design solution for a Hoverboard's lithium-ion battery pack and enclosure.

For this investigation the challenge is to select a material that meets certain safety criteria for performance in durability (tensile strength) and heat (thermal performance). It also will need to protect the lithium ion battery pack in a hoverboard from the outside world, as well as protect the user from the battery pack's heat.

THE CHALLENGE

Each team must select and test materials to determine the best performance in durability (tensile strength) and design and construct an enclosure. The enclosure design and material must protect the battery pack from the outside world. The team must also consider a possible consequence of the enclosure – it may trap the heat released from the battery pack and consequently put the user in danger of being burned.

CRITERIA

Part A: Material must pass tensile strength test by supporting more than 1 pound of weight for 2 minutes.
Part B: Material must be able to be formed into the shape of an enclosure that is roughly 8" x 3" x 3".

EDUCATOR

PROBLEM TO BE SOLVED

Over the past 20 years, lithium-ion battery technologies have evolved, providing increasingly greater energy density, greater energy per volume, longer life cycle, and improved reliability. When designing a product, like a hoverboard, that uses lithium-ion batteries, consideration has to be given to the heat the batteries produce as well as protecting the batteries from abuse. Products like hoverboards need an enormous amount of power so batteries (there can be up to 20 in one hoverboard!) are bundled together to form a battery pack. When batteries are bundled together they produce a considerable amount of heat.

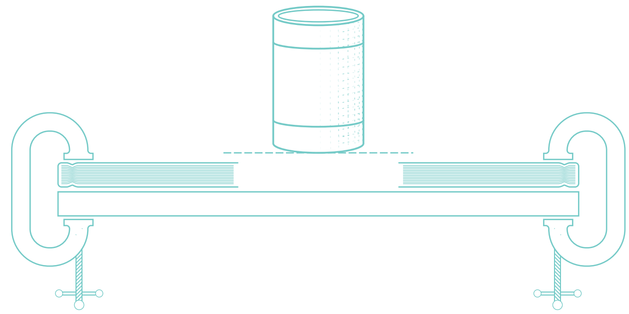
Enclosures help to protect the internal components, like a battery pack, and also keep people from the hazards inside the product. While the enclosure provides the physical protection for components inside a product it's also very important that it doesn't trap too much heat, creating a situation where a person could burn themselves when they touch it, or ride it, like a hoverboard!

Challenge students to design a hoverboard that can stand up to protecting the lithium ion battery pack, hold up to the weight test, as well as keeping the heat from harming someone. Considerations to think about when choosing a material for the hoverboard enclosure:

- **Will it protect the battery pack?**
- **Will it protect us from the heat produced by the battery pack (this will be tested in Investigation #3)?**
- **Is it stable enough for someone to stand on it?**
- **Can it withstand abusive situations (i.e., tossed in a backpack, dropped on accident...hey, it happens!)?**

SUMMARY OF LAB

What types of testing do safety engineers put materials through? One type of testing is tensile performance – the resistance of a material to breaking under tension. But it's not just the strength of the material that matters, the design is also important. The design of the shape needs to protect the battery pack (and other components, but for this lab, we'll focus on the batteries) and keep the unavoidable battery pack heat from harming the user. Will the design shape stand up to the can of soup (represents the relative weight of a hoverboard passenger)?



PART A

Students will test the mechanical strength (durability) of four materials using a tensile test – can the material hold more than one pound for two minutes without sagging, ripping, tearing, stretching, or showing other types of damage? If the material shows signs of wear or damage, students will have the opportunity to change the composition of the material by adding more layers, etc., to retest the material with modifications (redesign).

PART B

Students will use the class data from the tensile test to select a material to build the enclosure for the hoverboard by meeting a set of criteria – the enclosure must be 8" x 3" x 3" and hold more than one pound for two minutes without damage. Other materials may be used to support the structural integrity of the enclosure. The final design must protect the battery and support the weight of one pound.

To extend the lesson, refer to Investigation #3 where the final design is evaluated for thermal transmission to the enclosure surface.

XPLORING THE ISSUE

BACKGROUND INFORMATION FOR TEACHER

SAFETY STANDARDS

The use of lithium batteries is growing globally and with the large number of batteries powering a wide range of products in a variety of usage environments, there have been several reported incidents raising safety concerns. While the overall rate of incidents associated with the use of lithium-ion batteries is very low when compared with the total number of batteries in use worldwide, several publicized examples involving consumer electronics like laptop computers, hoverboards, and electronic toys have led to numerous product safety recalls by manufacturers, the **U.S. Consumer Product Safety Commission**, and others. Some of these cases have been linked to overheating of lithium-ion batteries leading to possible fires or explosions. Standards organizations, such as the International Electrotechnical Commission and UL, have developed a number of standards for electrical and safety testing intended to address a range of possible abuses of lithium-ion batteries.

Just like students are learning to follow procedures in scientific tests, there are specific test standards that safety engineers follow that help determine specific risks associated with the use of lithium-ion batteries. It is this type of safety science-based testing, following the safety standards, that help identify if the way a product is made and/or how it is used can cause harm. Safety scientists follow set procedures to find out what could present a risk to the people who buy and use the product.

As the development of lithium-ion batteries continues to advance and their use in wide varieties of products grows, knowledge regarding the use and abuse of these products and their possible risks is ongoing in the world of safety science and engineering. For that reason, it is important that safety standards continue to evolve and help consumers rely on the safety of energy storage devices as lithium-ion batteries power more and more products.

TRADE-OFFS

It is important to know that engineers and product manufacturers have to make some tough choices called trade-offs. Batteries produce heat, which is unavoidable. More batteries mean more power, but also more heat. They don't want to trap too much heat (thermal transmission to the surface) but also want to protect internal components. Enclosure materials need to protect internal components AND need to be durable, BUT heavier/denser enclosure materials may trap more heat and can be heavier!

MATERIALS

PART A

- 1 set of clamps (or other way to pull material taut)
- 2 thick hard-bound books
- 4 pieces of 5"x7" sized material
- 1 can of soup weighing 16-18 oz.
- Standard metric ruler
- XplorLabs pages or data sheet

PART A NOTES

*It is recommended that students choose materials that will both fail readily and require modifications, along with materials that are more obvious to pass the tensile test. It is also recommended to give students the option to choose materials to bring in from home.

Recommended 5"x 7" materials include: tissue paper, toilet paper, packing paper, corrugated cardboard, paper board, index cards, fabric, duct tape, masking tape, plastic and egg carton lids

**A can of soup weighing 16-18 oz. was selected to represent the shape and weight distribution of a person standing on a hoverboard. The weight of 16-18 oz. was selected to be relative to the size of the hoverboard enclosure. If you have access to weights or other materials that can be substituted, feel free to substitute.

PART B

- Selected material that passed tensile strength test (now, you can use larger or smaller sizes)
- Tape (different types – painters, Scotch, masking, duct)
- Paper clips
- Toothpicks
- Random scraps/sections of materials used in Part A, other materials teacher or students would like to use
- One can of soup weighing 16-18 oz
- A ruler
- Extinguished or inactive handwarmers – bundle of 4 (if available) to use for placing battery pack in enclosure (if inactive, the handwarmers must remain in packaging)
- XplorLabs pages or data sheet

MATERIALS

PART B NOTES

The material cannot be in a pre-built form. In other words, the students need to construct the enclosure at 8"x 3"x 3".

Don't open the handwarmers until you're ready for the thermal transmission test in Investigation 3 – opening the package activates them!

SAFETY CONSIDERATIONS

Typical expectations for students when using scissors/cutting through thick material like cardboard.

HELPFUL TIPS

Refer students to the "When Can I Move On?" sheet to help them decide if their material is ready for moving from Part A to Part B.

Remind students to think about what they are trying to achieve with their enclosure design:

- **Will it protect the battery pack?**
- **Is it stable enough for someone to stand on it?**
- **Can it withstand abusive situations (i.e., tossed in a backpack, dropped on accident...hey, it happens!)?**
- **Will it protect us from the heat produced by the battery pack (this will be tested in Investigation 3)?**

Students may begin working at different paces starting with the tensile test throughout the investigations. Plan ahead with materials and student lab sheets.

ROLES

THE STUFF SUPERVISOR	THE EXPERIMENT EXEC	THE DIRECTOR OF DOCUMENTS	THE PRINCIPAL PRESENTER
Gathers and cleans up materials	Runs the experiment	Reads the procedure to the group and helps the group members with data collection	Shares the group's work with the rest of the class

PROCEDURE TEST PART A - EDUCATOR

ENGAGE

WHAT EDUCATOR DOES

Introduce the challenge. Each team must select a material with the best performance in durability (tensile strength). Design an enclosure that will protect the battery pack from the outside world, hold the weight of a person, and can withstand abusive situations (i.e., tossed in a backpack, dropped on accident). In preparation for Investigation 3, remind students that their enclosure will be tested for thermal transmission and will have to protect the user from the battery pack's heat.

CRITERIA

Part A: Material must pass tensile (mechanical strength) test with more than 1 pound of weight

Part B: Material must be able to be formed into an enclosure

Review data table (or have students design data table) and model proper set-up for the tensile test.

WHAT STUDENTS DO

Follow along in student XplorLab pages for Tests 1A and1B.

Draw the set-up as teacher demonstrates.

XPLORE

WHAT EDUCATOR DOES

Moves around the room asking questions about data, findings, and application for building the enclosure in next test.

WHAT STUDENTS DO

- Each group collects all of the materials for the group.
- Place clamps and books 6.5" apart on table.
- Place first piece of material and suspend between the two books. Secure the material to the books and table using the clamps. Test to make sure the material is not over-stretched.

PROCEDURE TEST PART A - EDUCATOR

XPLORE CONT.

WHAT STUDENTS DO CONT.

- Place the soup can on the material evenly between the books/clamps.
- Begin the stopwatch and time for 2 minutes.
- At end of 2 minutes, use the ruler to measure any "sag" or dip in the material toward the table's surface (see illustration).
- Document any damage or wear on the material.
- Record findings in data table.
- Repeat with all four materials.
- If a material failed the tensile strength test, is it possible to modify the material in a way that it would pass the test (doubling/tripling layers, folding, or possibly combining different materials, etc.)? If so, modify (redesign) the material and test it again.

XPLAIN

WHAT EDUCATOR DOES

Create class data table on board, flip chart, or spreadsheet (see example page 11). Discuss results (orally or as written reflection) – What materials had the highest performance? What materials failed the tensile test? What materials could be modified/redesigned to pass the test?

WHAT STUDENTS DO

Report results in class data table. Discuss results (orally or as written reflection) – What materials had the highest performance? What materials failed the tensile test? What materials could be modified/redesigned to pass the test?

PROCEDURE TEST PART A - EDUCATOR

ELABORATE

WHAT EDUCATOR DOES

Discuss “tensile strength” as defined in student reading.

WHAT STUDENTS DO

Students read “Behind the Scenes: How UL Tests Hoverboards to UL 2272 Requirements Part II” Draw, write, or discuss: What does the tensile test tell us? Why is the tensile test important ? What does modifying a material do for its tensile strength?

What other kinds of tests can we do to get better understandings of our materials for the enclosure?

EVALUATE

WHAT EDUCATOR DOES

Check data and claims/evidence reporting by students in the XplorLabs pages or notebooks.

WHAT STUDENTS DO

Make sure the group spokesperson can defend the materials your group is choosing to build the enclosure based on tensile strength data.

PROCEDURE TEST PART A - EDUCATOR

XTEND

XTENSION

At XplorLabs, to represent real-life conditions materials are subjected to normal and abusive conditions before testing. For one week, expose the 5"x 7" pieces of material that students will test to normal conditions (place on desk, place in cabinet) and abusive conditions (place outside, in sun, on floor under desk, in students' backpacks, etc). After exposure, do tensile test a second time. Record changes in material and changes in pass/fail results.

EXAMPLE OF CLASS DATA CHART

Material	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Overall Class Result
Tissue paper	R/F	R/P	F	R/P	R/P	R/P	Pass with redesign
Bubble wrap							
Foil							
Cardboard							
Construction paper							
P = Pass; F = Fail; R/P = Redesign then Pass; R/F = Redesign then Fail							

PROCEDURE TEST PART B - EDUCATOR

ENGAGE

WHAT EDUCATOR DOES

Remind students of the challenge. Each team must select a material with the best performance in durability (tensile strength). Design an enclosure design that will protect the battery pack from the outside world, hold the weight of a person, and withstand abusive situations (i.e., tossed in a backpack, dropped on accident). In preparation for Investigation 3, remind students that their enclosure will be tested for thermal transmission and will have to protect the user from the battery pack's heat.

CRITERIA

Test 1A: Material must pass tensile (mechanical strength) test with more than 1 pound of weight
Test 1B: Material must be able to be formed into an enclosure

Based on the results from the tensile test, choose a material to build the enclosure. Remember to protect the battery pack. Students may be as creative as they like when designing an enclosure, and protect the battery pack. In preparation for Investigation 3, remind them to consider internal heat of battery pack and external heat of enclosure in their designs.

Review requirements for design drawings (must be labeled, include measurements, include materials used in design).

WHAT STUDENTS DO

Follow along in student lab sheets for Tests 1A and1B.

Draw the set-up as teacher demonstrates.

PROCEDURE TEST PART B - EDUCATOR

DESIGN/BUILD

WHAT EDUCATOR DOES

Moves around the room asking questions about data, findings, and application for building the enclosure in next test.

*Groups may be working at different paces, at different steps in the procedure

WHAT STUDENTS DO

- Each group collects all of the materials for the group.
- Use an inactive battery pack to measure for size and shape.
- Using the material and any of the items from this list, design and build a 3D enclosure for your battery pack that measures 8"x 3"x 3".
- Does the 3D enclosure hold at least 16-18 oz. 1 soup can/1 pound for 2 minutes?
- If the enclosure holds more than one pound, it has passed the tensile strength test.
- If the enclosure cannot hold one pound without stretching, ripping, tearing, falling, or other damage, it has failed the tensile strength test.
- If an enclosure fails, redesign the enclosure and test it again.

XPLAIN

WHAT EDUCATOR DOES

Ask students to explain their designs – look for common features of designs that are passing tests or failing tests.

WHAT STUDENTS DO

Explain designs and rationale behind decisions for shape, structural support materials, design for battery pack placement including materials selected.

PROCEDURE TEST PART B - EDUCATOR

ELABORATE

WHAT EDUCATOR DOES

Ask students to predict the thermal performance of their design.

WHAT STUDENTS DO

Write or tell your group's prediction for thermal performance of the enclosure design. What are the design trade-offs you may have to make to protect the user from being burned from too much heat being transmitted through the enclosure?

Apply the Hazard-Based Safety Engineering process:

- Identify the energy source.
- Is the energy source hazardous?
- Identify means by which energy can be transferred to a body part.
- Identify safeguards that will prevent energy transfer to a body part (think about eliminating the energy transfer, warning about the energy transfer, and/or guarding against the energy transfer).

What are the other heat sources in a hoverboard? (motors, electrical circuits) In this investigation, we are focused on the battery pack, but if you took into account the other parts that generate heat, what changes would need to be made to your group's enclosure design?

PROCEDURE TEST PART B - EDUCATOR

EVALUATE

WHAT EDUCATOR DOES

Check data and claims/evidence reporting by students in their lab sheets or notebooks.

WHAT STUDENTS DO

Make sure the group spokesperson can defend the material your group chose to build the enclosure based on tensile strength data. What are the trade-offs you had to make in your design to protect the battery if it is dropped, crushed, or punctured?

XTEND

XTENSION

Do a series of drop tests, puncture tests, crush tests on the enclosures. Ask the students to create a set of standards, or criteria, for pass/fail.

You can use the following for content development. Scope: The enclosure has to have the strength and rigidity required to resist the possible physical abuses that it will be exposed to during its intended use, in order to reduce the risk of fire or injury to persons.

- Resistance to impact (dropping, falling)
- Crush resistance (similar to garbage compactor, garbage truck)
- Abnormal operations (example – weight, dropping)
- Severe conditions (extreme temperatures)
- Openings in the enclosure cannot allow water to enter (water and electricity do not mix!)

NRC FRAMEWORK

PRACTICE 3: PLANNING AND CARRYING OUT INVESTIGATIONS

PRACTICE 4: ANALYZING AND INTERPRETING DATA

PRACTICE 5: USING MATHEMATICS AND COMPUTATIONAL THINKING

PRACTICE 6: CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

MS-ETS1 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.

SCIENCE AND ENGINEERING PRACTICES

Asking Questions and Defining Problems

- Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. (MS-ETS1-1)

Developing and Using Models

- Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs. (MS-ETS1-4)

NRC FRAMEWORK

SCIENCE AND ENGINEERING PRACTICES CONT.

Analyzing and Interpreting Data

- Analyze and interpret data to determine similarities and differences in findings. (MS-ETS1-3)

Engaging in Argument from Evidence

- Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-ETS1-2)

DISCIPLINARY CORE IDEAS

ETS1.A: Defining and Delimited Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1)

ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.

(MS-ETS1-2), (MS-ETS1-3)

- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3)
- Models of all kinds are important for testing solutions. (MS-ETS1-4)

ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (MS-ETS1-3)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (MS- ETS1-4)

NRC FRAMEWORK

CROSSCUTTING CONCEPTS

Influence of Science, Engineering and Technology on Society and the Natural World

- All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. (MS-ETS1-1)
- The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. (MS-ETS1-1)

MS-PS3 ENERGY

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-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*

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.

SCIENCE AND ENGINEERING PRACTICES

Analyzing and Interpreting Data

- Construct and interpret graphical displays of data to identify linear and nonlinear relationships. (MS-PS3-1)

Constructing Explanations and Designing Solutions

- Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system. (MS-PS3-3)

Engaging in Argument from Evidence

- Construct, use, and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon. (MS-PS3-5)

NRC FRAMEWORK

DISCIPLINARY CORE IDEAS

PS3.B: Conservation of Energy and Energy Transfer

- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. (MS-PS3-4)
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones. (MS-PS3-3)

PS3.C: Relationship Between Energy and Forces

When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. (MS-PS3-2)

ETS1.A: Defining and Delimiting an Engineering Problem

The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. (secondary to MS-PS3-3)

ETS1.B: Developing Possible Solutions

A solution needs to be tested, and then modified on the basis of the test results in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. (secondary to MS-PS3-3)

CROSSCUTTING CONCEPTS

Energy and Matter

- Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion). (MS-PS3- 5)
- The transfer of energy can be tracked as energy flows through a designed or natural system. (MS- PS3-3)

COMMON CORE STATE STANDARDS CONNECTIONS

RST.6-8.3 Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks (MS-PS3-3), (MS-PS3-4)

RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-PS3-1).

WHST.6-8.1 Write arguments focused on discipline content. (MS-PS3-5)

NRC FRAMEWORK

COMMON CORE STATE STANDARDS CONNECTIONS

WHST.6-8.7 Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. (MS-PS3-3), (MS-PS3-4)

RST.6-8.9 Compare and contrast the information gained from experiments, simulations, video or multimedia sources with that gained from reading a text on the same topic. (MS-ETS1-2),(MS-ETS1-3)

MP.2 Reason abstractly and quantitatively. (MS-PS3-1),(MS-PS3-4),(MS-PS3-5)

XPLORING FOUNDATIONAL RISK ASSESSMENT

Start with a discussion that will get the students thinking about safety engineering. Safety Engineers use a Hazard-Based Safety Engineering process where they:

- Identify the energy source.
- Is the energy source hazardous.
- Identify means by which energy can be transferred to a body part.
- Identify safeguards that will prevent energy transfer to a body part (think about eliminating the energy transfer, warning about the energy transfer, and/or guarding against the energy transfer).