**Lesson Plan: The Egg Drop**

**Project Overview**

**Overview:** *In the* ***Science in the Real World Series*** *of projects, students and teachers are presented with opportunities to apply knowledge and information to solve real world problems. Harvard researcher Dr. Tony Wagner writes that “In today’s world, knowledge and information are commodities, easily accessed through the Internet; the challenge is to help students understand how to apply that knowledge in creative ways.” The importance of applying knowledge to new contexts serves as one of the fundamental principles that frames new international science and engineering curriculum strategies such as the Next Generation Science Standards in the U.S. and the Central Board of Secondary Education’s national curriculum of India.*

The study of forces and their impact on the physical world is an essential aspect of physics. In this project, students are guided towards investigating how the choice of material and the design of structures directly impact how an object is affected by the physical forces of tension and compression. Explorations about the relationships between forces, material choices, and structural design are essential elements of engineering that can be applied to a diverse range of real world problems.

**Sample Lesson:** Through the application of Autodesk software, students will experience a new twist on the classic egg drop physics project. In a traditional science classroom setting, the constraints of time and varied levels of student skills in drawing and model fabrication generally limit the degree of complexity and quality of structures developed as solutions to preventing a fragile egg from breaking upon impact when dropped from a high elevation. In this series, we demonstrate how the traditional constraints of time and fabrication skills can be surmounted by creating a virtual model in 123D Design, which can subsequently be rapidly translated into a physical prototype with the use of 123D Make software and laser cutting. The technical video and additional software tutorials available online are intended to empower students with the creative skills to imagine and generate their own creative designs for a sophisticated egg drop structure. **Like all the projects in this series, the specific lesson example is intended to be illustrative of the process that could be applied to any physical engineering project where the production and testing of a physical prototype can enhance student understanding of essential scientific concepts.**

**Software**: Autodesk 123D Design, Optional: Autodesk 123D Make

**Time:** 5 hours

**Subject(s):** Science, Art

**Grade Levels:** 9–12

**Concepts Addressed**

* **Gravity** is an attractive force that exists between two or more bodies of mass, and is relative to the mass of the bodies and their distance to one another. In practice we are usually concerned about the gravitational force exerted by the Earth due to its mass and its close proximity, but it is worth noting that other large bodies of mass can exert measurable gravitational forces, such as the sun and moon. If the distance between an object and the center of the earth is considered constant (as the difference is negligible in most cases), then the gravitational force (Fg) exerted by the Earth on an object is equal to the objects mass multiplied by the acceleration of gravity (g), which is a constant 9.8 meters per second per second. The force of gravity (Fg) is also known as an object’s weight.
* An object is in **free fall** if the only force acting on it is the force of gravity. This situation is very rare, as it implies that there is no air resistance. If an object is truly in free fall on the surface of the earth, its acceleration will be 9.8 meters per second per second.
* **Air resistance,** or **drag**, is a force that resists the movement of an object while traveling through a fluid, such as air. Much like friction, it is caused by the exterior surface of a moving object in contact with air. Actually calculating the air resistance of an object is very difficult, as it is dependent on the shape, velocity, and surface finish of an object, as well as the density of the air, wind speed, and the humidity. In general the larger the cross-sectional area and the higher the velocity, the greater the air resistance will be.
* **Terminal velocity** is the velocity of a falling object when its drag (air resistance) equals the force of gravity, at which point a falling object will travel at a constant velocity. Terminal velocity can be used as an indicator of how aerodynamic shapes of similar weights are. For example, a feather’s terminal velocity is much lower than that of a similarly weighted bean.
* **Momentum** is defined as the product of a body’s velocity and its mass (momentum = velocity\*mass). Momentum is a conserved quality; in other words, in any closed system the sum of all momentum stays constant. When determining the outcome of collisions, this quality is particularly useful when coupled with kinetic energy.
* **Pressure** is defined as a force applied to an area.
* **Rapid prototyping technologies** that include laser cutting and 3D printing enable students to produce physical prototypes for engineering and scientific inquiries. These physical artifacts offer students the opportunity to test ideas as a way to deepen their understanding of discipline-specific content.
* **Software** such as 123D Design enables students to translate conceptual ideas into virtual prototypes to support understanding of science and engineering concepts.

**Learning Outcomes**

As a result of participating in this project, students will be able to:

* Describe the dynamic relationship among materials, structures, and the forces that impact them.
* Describe how gravitational forces affect a falling object, and understand the formula F = M A.
* Demonstrate skills in using Autodesk 123D Design software to generate multiple concepts for a light-weight structure that will protect a fragile egg from breaking upon impact with the ground.
* Demonstrate skills in using 123D Make software to generate templates for a structure built from interlocked sections of corrugated cardboard.
* Describe how laser cutting technology can be used to rapidly prototype a design generated in 123D Make.
* Demonstrate skills related to incorporating virtual and physical representations of applied science explorations into a variety of presentation formats that can include written essays, and oral and visual presentations.
* Demonstrate competence in effectively utilizing digital media.

**Prerequisites**If you have not used any of the Autodesk software before, we recommend that you view and test out these free online tutorials:

For **Autodesk 123D Design,** go to <http://www.123dapp.com/howto/design>

For **Autodesk 123D Make,** go to <http://www.123dapp.com/howto/make>

In order to complete the sample project, refer to the following technical videos

* Egg Drop LV 1
* Egg Drop LV 2
* Egg Drop LV 3
* Egg Drop LV 4

**Key Terms   
  
*Gravity*** is an attractive force that exists between two or more bodies of mass, and is relative to the mass of the bodies and their distance to one another.

***Center of gravity*** refers to the average location of the weight of an object. In general, determining the center of gravity (cg) is a complicated procedure, because the mass (and weight) may not be uniformly distributed throughout the object.

***Acceleration*** is a change in speed over a period of time; the higher the acceleration, the faster the change in speed. For example, if a car goes from 0 miles per hour (mph) to 60 mph in 2 seconds, it has a higher acceleration than if the car goes from 0 mph to 40 mph in 2 seconds. Acceleration is a rate of change of speed; *no* change means *no* acceleration. If something is moving at constant speed, it is *not* accelerating.

***Speed*** is a measure of how fast an object is moving. It describes a change in position with time, or more simply put, how far an object will travel over a given period of time. This measure is given in units of distance per time (that is, miles per hour or feet per second).

***Free fall*** is a situation where the only force acting on an object is the force of gravity. This situation is very rare, as it implies that the object is falling yet there is no air resistance. If an object is truly in free fall on the surface of the earth, its acceleration will be 9.8 meters per second per second.

***Crumple zones*** are areas of an object designed to deform and crumple in an impact, as a means to absorb the energy of a collision. The fronts of most automobiles are designed as crumple zones to protect the passengers from frontal collisions.

***Cardboard*** is a generic term for paperboard products, but the term commonly refers to corrugated container board.

***Laser cutters*** are computer-controlled machines used to cut sheets of various materials.

***Air resistance or drag*** is a term used in fluid dynamics that is sometimes referred to as air resistance or fluid resistance. Friction is one of multiple factors that influence the amount of drag encountered by a body moving through a fluid such as air or water.

***Kinetic energy*** is the **energy** possessed by a body in motion. It is calculated as one half the mass of the body times the square of its speed.

***Potential energy*** is stored energy, such as the energy stored chemically in a battery, the gravitational energy due to the position of a body such as roller coaster car sitting at the top of the drop, the energy stored in a spring, or energy stored in molecular bonds.

**Key Terms: Autodesk 123D Design**

***Gallery*** contains examples of models completed in 123D Design.

***Groups*** contain one or more objects, as well as other groups.

***Intelligent snapping*** allows a 2D or 3D primitive to be dragged onto any geometry and snap to the nearest face or edge.

***Kits*** contains custom parts and pre-built kits.

***Navigation tools*** are used to move around the scene. These include, pan, orbit, and zoom.

***Patterns*** create circular, rectangular, path, and mirrored patterns.

***Redo*** is a command that allows the user to return to a previous action that had previously been removed through the Undo command.

***Select-based options*** displays only the relevant options based on the selected 2D or 3D primitive.

***Undo*** is a command that enables the user to remove up to 30 of the last actions taken in Autodesk 123D Design*.*

***View cube*** is used to look at and orbit around the scene.

**Key Terms: Autodesk 123D Make**

***Import*** is the first feature in 123D Make, and it allows the user to open models from their computer.

***.STL*** and ***.OBJ*** are the two file types supported by 123D Make. STL stands for stereo lithography and is a common file format that most solid modeling programs can export. The OBJ file format is commonly used by 3D surface modeling software.

***Stacked slices*** cross sections your 3D model, cutting it into slices you can glue and stack on top of one another. Use the Dowels option to make it easier to line up and assemble your model. You can re-create the model using any flat material you can cut.

***Interlocked slices*** cuts your 3D model into two stacks of slotted slices. Lock them together in a grid, like when building a 3D puzzle. This uses less material than stacked slices.

***Curve*** cuts slices perpendicular to a curve, resembling ribs. Use this for organic shapes, such as for modeling a brontosaurus. Also, use the Navigation tools to help rotate your view to see the curve.

***Radial slices*** cuts your 3D model into radiating slices from a central point. Use this for a round symmetrical object, such as a vase.

***Folded panels*** separates your 3D model into 2D segments of triangular meshes. These segments (panels) are folded multiple times, then attached using one of ten different joint types. Use paper, cardboard, even sheet metal.

***Slice direction*** allows the user to alter the angle at which their model is sliced. This function also allows the curve of the curved slice method to be altered.

***Modify form*** contains a few simple tools to help reduce slicing errors and the ability to hollow models. These tools alter the entire model, not just the selected slice.

***Assembly step*** allows the user to observe how the model should be assembled, and preview the assembled model.

***Get plans*** is where the user chooses one of three file formats for the finial sliced plans. If you only have access to an ink printer, you will most likely want to export the slices as a PDF.

**Discussion Guide**

**Essential Project Conceptual Questions**

* Why is it important to understand how falling objects are affected by gravity?
* How might knowledge derived from a project such as the egg drop be used to examine engineering design challenges related to areas as diverse as packaging, automotive design, or landing a rover on Mars?

* How does material choice impact how a design will fare in terms of protecting a falling egg from breaking?

How will the addition and subtraction of mass from a structure that protects an egg influence the amount of force exerted on the egg on impact with the ground?

* How can a parachute or wings possibly alter the rate of acceleration of an object falling in earth’s gravitational field?

**Essential Project Design Questions**

* From what height will the egg drop container be dropped?
* What type of surface will the egg drop container be landing on?
* What physical characteristics of a raw egg need to be considered in order to design an effective egg drop container?
* What shapes and sizes of egg drop containers will offer maximum protection for the egg?
* How will air resistance factor into the design of the egg drop container?

**Teacher Preparation**

1. Read the Design Thinking Guide.
2. Review the technical videos associated with each lesson.
3. Be prepared to partner with your students in learning the new software techniques.
4. Show students how to find help in the curriculum and use the software Help feature.
5. Point out which videos the students need to catch up on if they need reference.

**Day-to-Day Plans**

As noted at the start of this lesson plan, the specific project presented below and documented in the accompanying technical videos is intended to illustrate the process that could be applied to any number of experiments or engineering challenges that address forces and motion.

**Hours 1–2:**

**Understand: *Watch and Listen***   
To establish a solid foundation for the egg drop project, students need to have a clear understanding about the importance of understanding the forces at play and applying basic engineering principles and strategies. The best starting point is to carefully review the project design brief. Distribute the student pre-test and have students spend 10 to 20 minutes developing their responses to the questions. Your next job is to facilitate a student discussion built around the pre-test questions. These can be conducted as a full class or small group discussions.

**Explore: *Develop a Knowledge Base***Through the Explore process, you want students to consider the objectives, identify and explore the forces at work, and think critically about how to apply their ideas to a simple engineering project. This understanding helps inform students’ decisions in the Define phase. A good place to start is to form teams in which students can discuss the essential project conceptual and design questions listed above. An important first step in the Explore phase involves conducting a thorough review of common shock-absorbing and padding design features, while considering what is and is not feasible for your egg protector.

**Define: *Clarify Requirements***

This critical stage in the design process involves establishing the criteria for the project. In order to create the most effective egg drop container possible, you need to understand specific parameters related to factors such as dimensions, materials used, construction techniques, physical properties of eggs, and forces acting upon the egg and container. This requires identifying important aspects of gravity, acceleration, force absorption, and the functional design requirements. In this phase, it is also critical for students to identify criteria relative to the physical nature of the product, such as strength, durability, ease of use, comfort, and safety.

**Note**: *Open the Design Criteria Worksheet to help you in completing the Define and Explore phases.*

**Hours 3–4**

**Ideate: *Creativity***In order to develop their own interpretive design for a vessel that would protect an egg from the impact of a fall, students must base their interpretive design on the criteria that they have documented in the Define stage. This means they have completed their research in order to subsequently justify why their design reflected the specific design features used and the technological elements. Students can initiate the Ideate stage in a number of ways: by developing sketches on paper, building quick study models out of materials such as paper or clay, or just simply start by using Autodesk 123D Design. This is the time for students to come up with as many ideas as possible for their product. While you want students to explore many concepts, remind them that it is good practice to keep some of the design criteria in the back of their minds as they explore ideas. Throughout the Ideate phase, a variety of techniques can be used to visualize a wide range of possibilities: Inventor software, simulation, and basic exploratory designs. The goal is to get students to visually communicate to themselves and others the essential direction that they will take and refine in the next phase of prototyping.

**Prototype: *Test***In this phase, students translate key concepts derived from the Ideate phase into virtual and possibly physical prototypes with the software. Students can watch the technical learning videos, explore the datasets from the example project, and refer back to the online tutorials as they learn the skills that transform their concepts into reality. Encourage students to assist each other in learning the software.

**Hours 5–6**

**Refine: *Almost There***In this phase, you want your students to leverage the power of the software to refine aspects of the design. As students proceed through this phase, remind them to keep referring back the basic criteria that they previously established. Encourage students to engage in a mental practice of asking themselves whether their egg drop protector is well matched to its intended function, and appropriately takes into account the strength, weight, size, and shape of an egg.

**Solution: *Final Presentation***This phase is vital for preparing students for future success in school, careers, and life in general. The Solution phase is when you ask students to demonstrate how this project has helped them expand and enhance the *four Cs* of their learning and innovation skills: critical thinking, communication, collaboration, and creativity.

Instruct the students to prepare and conduct small group presentations that capture the important aspects of each of the previous phases. Ideally, students should be aware from the outset that the results of their efforts throughout the design phase will culminate in a final presentation.

**Note**: Emphasize that a successful presentation must clearly define the problem that guided the design, and articulate the key criteria that are addressed in the solution.

Stress the importance ofusing software tools to visualize, animate, and present in the same way real professionals do every day.Remind students that many colleges, universities, and employers place high value on digital portfolios that convey how a student thinks, works with others, generates creative solutions, and communicates ideas and knowledge through a variety of written, visual, and oral formats. By investing effort into this project, your students will be one step closer to their goals for careers and/or college.

**Note**:If time is limited, you may opt to have students share their final presentations electronically. This provides an opportunity to generate feedback from peers and teacher.

**Differentiated Instruction**

* + Encourage students to review the lesson and skills videos in small groups.
  + Have small teams of students collaborate to complete one design criteria worksheet by dividing up the work.
  + Identify specific websites that students can use for the Define and Explore stages.
  + Provide some students with a set of predefined design criteria and background content to modify the Define and Explore stages.
  + Have small groups collaborate on the Ideate, Refine, Prototype, and Presentation stages. Have some students focus on the development of physical sketches and sketch models while collaborating with team members who focus on digital prototyping.
  + Provide students with self and peer evaluation forms to be filled out at the completion of each phase.
  + Provide students with models of successful student presentations with clear examples of each design phase.

**Non-Native Speakers**

* Encourage students to tap into their own culture and life experience to discover prior knowledge of the project topic.
* Provide English/first language translation dictionaries and/or electronic translation devices.
* Allow the student to prepare materials in their primary language and have it translated later.
* Pair ELL students with native English speakers.
* Provide a translator for viewing of videos.

**Special Needs Students**

* Provide prefabricated modeling components.
* Engage the help of aides to assist in physical sketch modeling and prototypes.
* Accommodate students by allowing additional time and/or reducing the scope of project requirements.
* Provide any necessary accommodations for access to technology such as alternative input devices, larger font sizes, speech recognition, and so on.

**STEAM Connections**

**Background**

STEAM stands for the integration of science, technology, engineering, art, and math. The study of force-absorbing designs provides a perfect intellectual environment to engage students’ excitement and have them consider all of the many aspects of design that will go into their egg drop vessel, and expand them to relate to their problems in the world.

Science

* During space exploration, scientists have been challenged by the deployment of rovers and landers to the Moon, Mars, Venus, and Titan. Like the egg drop process, these landers effectively fall a great distance and land while protecting their fragile contents. Unlike the egg drop, however, the environmental conditions these landers experience differ greatly from the surface of the Earth. Choose one of these celestial bodies and research how their environments would alter your egg drop design and which technologies the landers used that may help to inform your design. Consider factors such as speed of entry, weight of object, surface on which to land, other forces besides gravity, and so on.
* Using what you know about the specific parameters of your egg drop experiment, such as the height of the drop; the landing surface; the mass, weight and design of your egg protector; and fundamental laws of motion and force (F = M\*A) to create a simple mathematical model to approximate the velocity and energy before the impact, and the maximum acceleration during the impact using video footage.

Technology

* Many features of egg drop models are similar to modern safety features found in automobiles. For example, the fronts of cars are designed to crumple in on themselves, directing much of the force of collision into bending the material itself, and towards the sides of the car and away from the driver and passengers. Additionally, air bags deploy in the case of a crash so that the force of a crash or collision is spread over several inches, greatly reducing the apparent force. Examine other modern safety features and discuss which of them can be applied to an egg drop model.
* Laser cutting provides a high degree of precision, and allows for assembly of constituent pieces, mass production, reproducibility, and rapid prototyping. However, like all things, there are disadvantages to using this technology. Compare traditional egg drop models with the laser-cut cardboard models made in 123D Make. What are the advantages and disadvantages of each style?

Engineering

* An alternate experiment to the egg drop involves launching the egg containing model from a trebuchet. Trebuchets are catapults that have been used for hundreds of years in sieges and warfare. A rotating arm with a counterweight on one end is used to harness the power of gravity itself and transfer it to an object on the other end of the arm, throwing it through the air. What additional concerns would you have to take into account, and what might a successful design look like?
* In the technical videos, the egg drop model is made from corrugated cardboard. What is the purpose of corrugated cardboard? How can the form and structure of a lighter object actually be engineered to be stronger than a heavier design? Investigate why recycling paper and cardboard is a commonplace practice. How much and what types of cardboard are made with recycled material? Why does cardboard lend itself to recycling and reuse?
* Engineers and designers must calculate internal stresses of the components while under load. In the past, this type of analysis would take days to perform. However, with the use of computers, it is possible to perform this task in minutes using finite element analysis (FEA) software. Autodesk Inventor has such a software package built into it under the Stress Analysis environment. Use Inventor to create an FEA of the egg drop container by applying the loads you expect to be exerted to the system. See how much force your system deflects and note the maximum internal stresses. How might you alter your design to reduce force on your egg?

Art

* The intersection of practical functionality with aesthetic appeal is a fascinating realm in which two apparently contrasting concepts can interact with amazing results. Consider the sample egg drop holder, a sphere with cross sections at many different angles. Where do you see similar forms in artworks around the world?
* Form and function do not have to be in direct competition with each other. Consider the most basic design requirements of the egg drop vessel. What functions do the different design features need to serve? How can your design features also be fashioned to be artistically and aesthetically pleasing as well?

Math

* A *safety factor* is a concept used to strengthen a part beyond what the original part was meant to withstand. For example, a pull-up bar is likely to have a safety factor of 8 or 9, that is to say, it was designed to hold eight or nine times as much weight than it was originally intended for. Research how engineers and designers commonly use safety factors to gain a better understanding of the product development process. Next, calculate as best you can the safety factor of your egg protector. From what height could you drop an egg in the protector without breaking it?
* Record a few egg drop models and an egg dropped from the same height with a video camera. Later, use a computer to determine the height and time frame by frame of each drop, then graph the data alongside an ideal calculated acceleration curve. Compare each graph and write a short summary of the similarities and differences between them. Then, propose causal mechanisms for the discrepancies you measured, if any.

**Alignment with Math and Science**

The accompanying Math and Science matrices provide the teacher with suggestions regarding various concepts and operations that could be presented and reinforced through the projects.

**Science and Math Matrices**

Projects in the Digital STEAM Workshop create opportunities for teachers and students to connect concepts in Math and Science to real-world projects. For example, with the egg drop experiment, students could develop math projects around variables such as material volumes and weight of the protector or calculations regarding drop height and forces on the egg upon impact. The geometry and algebra inherent to most design projects, as well as the strong physics components of this particular project, are all excellent areas to explore further, either individually or in teams.

**Math Matrix**

|  |  |  |
| --- | --- | --- |
| **Grade 7** | **Grade 8** | **Algebra I** |
| Area | Ratios and proportions | Systems of linear equations |
| Volume | Area | Ratios and proportions |
| Ratios and proportions | Volume | Area |
| Modeling | Transformations | Volume |
| Graphing | Systems of linear equations | Transformations |
|  |  | Quadratic equations |
|  |  |  |

|  |  |  |
| --- | --- | --- |
| **Geometry** | **Algebra II** | **Trigonometry** |
| Area | Systems of linear equations | Use of vectors |
| Volume | Modeling | Determine forces acting on materials and objects |
| Transformations | Linear inequalities | Determine distances, speed, acceleration |
| Calculating measurements indirectly | Right triangle trigonometry | Triangle trigonometry for indirect measurement |
| Cartesian coordinates | Cartesian coordinates | Coordinates: Cartesian, polar |
| Right triangle trigonometry | Production costs of modular parts |  |

|  |  |
| --- | --- |
| **Pre-Calculus** | **Calculus** |
| Linear equations | Area of complex shapes |
| Inequalities | Volume of complex shapes |
| Multivariable equations | Forces |
| Trigonometry | Vectors |
| Calculating indirect measurements | Optimization |

**Science Matrix**

|  |  |
| --- | --- |
| Materials and material finishes | Forces on objects |
| Composition and characteristics of eggs | Simple machines |
| Adhesives | Energy conservation |
| Force distribution and reduction | Laws of motion |
| Makeup of molecules | Aerodynamics and air resistance |
| Gravity, force, mass, and acceleration | Friction |
| Strength and weight of materials | Confidence or error margins |

**Build It**  
When you ask adults what they remember most about school, the answer often refers to something they produced, something they built, wrote, performed, or generated through some form of visual media. Such activities can take extra time, but the benefits are worth it.

**Extension Ideas**

* Use Autodesk® 123D Design software to develop an object to develop a launcher for an egg, one that could shoot an egg without breaking it.
* Use Autodesk® 123D Design software to model other engineered shock absorbers, such as springs, hydraulics, or elastic materials.

**Assessment Processes**  
The assessment process for all of the projects in this curriculum provides students with formative feedback for each of the essential design phases. The rubrics that are included as a separate document guide students in knowing what is expected for each phase and the criteria used to evaluate the quality of the work. For each project, students complete a self and peer evaluation. These include a reflective narration for each phase, accompanied by a point score derived from the rubric. These evaluations are accompanied by a teacher evaluation that also includes a narrative and numerical score for each phase along with a cumulative score. The STEAM questions, Extension Ideas, and the optional Build It activity offer students an opportunity to take what they learn in the assessment process and apply that knowledge to enhance the quality of their work and increase their scores.