Title: Physics and Engineering: Motion by Design

Length of Course: Full Year (2 semesters; 3 trimesters; 4 quarters)

Subject Area – Discipline: Laboratory Science ("d") – Physics

CTE Sector: Engineering and Architecture

CTE Pathway: Engineering Technology

Grade Level(s): 9-12

Prerequisite(s): Algebra 1 or IM 1

Course Overview:
In Physics and Engineering: Motion by Design students apply principles of physics and engineering to an iterative cycle of product design. In this year-long, integrated, college-preparatory course, students will develop an understanding of fundamental physics concepts in kinematics, mechanics, mechanical and electromagnetic waves, and electricity/electromagnetism while exploring robotics, computer programming, computer aided design (CAD) and rapid product development. Working individually and in teams, students complete a series of design challenges to develop key skills in computer programming, 3-D modeling software, engineering technology, and physics concepts. The course culminates with competition-ready, semi-autonomous devices presented as marketable products designed to serve a specific purpose in the local community. These projects promote critical thinking, communication, collaboration, creativity and provide a foundation for data collection, analysis, reflection, presentations and technical writing skills. By successfully completing the course, students will be prepared for success in college science and engineering as well as in high-demand careers like automation and advanced manufacturing.

Course Content:

Unit 1 - The Design Process/Kinematics

In this introductory unit students will explore the questions "how do things move?" and "what is motion?" The goal of this unit is for students to develop kinematic concepts of motion and apply this knowledge to a design challenge. In the unit, students will also be introduced to the design cycle that will be used for the remainder of the year as a tool to solve multiple engineering design problems. The design challenge in unit one is to build a device that must accomplish one of the four possible goals: move a specified distance, project an object over a specified range, launch an object vertically a specified height, or stop a moving object at a specified distance. Through this investigation students apply their understanding of kinematics to analyze motion by making measurements and calculations as well as exploring the need for transportation and logistics.

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Unit 1 - Assignments

A. Important Innovations in Transportation.

Students will create a digital media presentation documenting a significant historical engineering innovation in transportation. Students will research their chosen innovation in the context of history. The presentation will explain the engineering behind the innovation and show how it influenced commerce, travel, warfare, and/or culture.

B. Motion Device Design Challenge

One of the primary goals of this assignment is to ensure students utilize the Engineering Design Cycle. It is imperative that the cycle is emphasized throughout each stage of the unit as students research, design, build, test, and present their final project. The design challenge in unit one is for students to work in teams to build a device demonstrating motion in one of four different ways. Key deliverables in this process are: 1) a scaled, three-view and isometric blueprint of their vehicle. The blueprint must include all relevant measurements of the parts that will make up the vehicle. 2) the prototype vehicle which will be constructed based on the approved blueprints from common classroom/office materials 3) a technical report that includes a description of the action of the vehicle with all appropriate kinematic equations hypothesizing the motion and destination of the object. The technical report must also include a list of vehicle components including costs, and a data table showing the results from testing and the changes that were made to improve the performance of the vehicle. The final testing of the vehicle will take place in a showcase format where teams of students present their development process and the performance of the vehicle to a group of their peers.

> **Note: Unit one culminates in the completion of this assignment, but students should be introduced to it towards the beginning of unit one. The work of assignments 3 and 4 then occur concurrently as the unit progresses.

C. One Dimensional Motion

Students will investigate a series of objects moving in one dimension to construct an understanding of kinematics. Basic kinematic equations will be introduced through research and experimentation. Each equation will be dissected and the relationships between distance, velocity, acceleration, and time will be tested using a steel ball placed at various positions on a ramp with alternating inclinations. Velocity tubes and constant velocity vehicles will be used to make measurements and calculations. Ticker tape timers will be used to calculate the freefall acceleration of gravity. Data will be extrapolated and the relationships will be graphed. Students will apply the concepts developed in this assignment to the analysis of the motion of their vehicles for the design challenge.

D. Projectile Motion

After researching catapults and trebuchets and their design changes throughout history, students will design and fabricate a water-balloon launcher fitted with a device to measure angles. Under controlled tests, they will have to hit a target placed at a specific distance within a specified number of attempts. Data analysis in this assignment will help define design characteristics of the projectile device used in the culminating activity.

Unit 2 - Mechanics (Force and Energy) w/ CAD and 3D Printing

The field of Classical Mechanics deals with the study of bodies in motion, specifically the physical laws that govern bodies under the influence of forces. In this unit the exploration of motion shifts to the question, "what causes something to move?" The design process that was introduced in the first unit will be refined and enhanced as students are introduced to computer aided design (CAD); an essential skill engineers need to design and document their work. Through a series of scaffolded experiences students will investigate Newton's Laws and mechanical work and energy. They will then apply this learning to produce and analyze, using diagrams and physics equations, a 3D printed model of a simple machine. The ideas and assignments developed in unit two will be important for setting the stage for understanding electric motors in unit three.

Unit 2 - Assignments

A. Newton's Laws

The ability to explain, calculate, and apply force and energy concepts will be essential to students' success in this course. In this assignment students are building familiarity with these concepts. Students conduct research on Isaac Newton and his Three Laws of Motion in order to develop a historical context for the study of motion, including the use of free body diagrams to show different forces acting on an object to determine the net force. Students will demonstrate this understanding through a series of practice exercises where they draw free body diagrams and calculate acceleration and force using F=ma. Online simulations are also used to allow students to observe changes to inputs (ex. mass, force, direction) and outputs (ex. acceleration).

Using the vehicle designed in unit one, data will be collected to find the average force and acceleration.

B. Introduction to CAD/ 3D Printing

This assignment introduces the concept of computer-aided design and its uses as a computer technology for design and design documentation. Students use CAD to draw curves and figures in two dimensional (2D) space; or curves, surfaces, and solids in three dimensional (3D) space. In the first activity students measure a circle, draw their circle using a CAD software, add a third dimension to design a cylinder, and finally through a series of exercises make a simple rotating pulley. Students are also being introduced to additive manufacturing through the use of 3D printers. By researching types of 3D printers and techniques used in 3D printing, students will gain familiarity with additive manufacturing technologies including rapid prototyping, materials, resolution, and the possibilities and limitations of the types of 3D printers that are currently available. Students will print the pulley they designed using CAD software for use in the subsequent block and tackle assignment.

C. Block and Tackle

In this activity teams of students will investigate the physical aspects of a simple multi-part "machine" as a tool that uses energy to perform an intended action or motion. They will build a block and tackle using the pulley designed in the "intro to CAD" assignment. The goal of the activity is to design and build a block and tackle with a specified mechanical advantage that is capable of lifting a weight. Students will use a force scale to measure the input force and also the distances and directions moved (input and output). From these measurements students will calculate work and mechanical advantage, ultimately coming to realize that a simple machine is a device that simply transforms the direction or magnitude of a force.

D. Creating a Simple Machine Model using CAD and 3D Printing

Teams of students will apply their understanding of simple machines and CAD to create a working simple machine model (screw, inclined plane, lever, gear, wheel and axle) of their own design. The students need to follow the steps in the design process to generate their model. This model will be drawn in CAD and printed using a 3D printer. The students will display their model to the class in a gallery walk format that will include having students measure and calculate the mechanical advantage and work of each model. Students will then produce a written peer critique of at least two different models where they evaluate they end-use application.

E. Geneva Wheel

As a culminating assignment, the students will draw and print a working Geneva Wheel, a device that produces intermittent rotary motion through a gear mechanism that transforms continuous rotational input into intermittent rotational output. Through working with gears, students will continue to develop an awareness of the importance of precision and tolerance. Finally, they will appreciate that fabrication "by hand" would involve time, cost and craftsmanship. By utilizing modern engineering technology, students will see the added value of reduced time, lowered cost and increased component precision. To fabricate the Geneva Wheel students will generate three drawings: a base, a crank (input) and a wheel (output), and determine the angles from the number of slots in the wheel. Students will associate Newton's Laws with the motion curves for external slots, and the discontinuity in the acceleration when the drive pin enters and leaves the slot producing an intermittent rotary motion. In addition to the drawing and physical prototype students will also be asked to have a simple technical report that includes key physics and mathematical concepts and calculations related to motion of the Geneva Wheel they designed. The completed Geneva Wheel will be tied in and utilized in the culminating project for unit three.

Unit 3 - Robotics with Electricity and Electromagnetism

When we merge electricity and motion, we give birth to robotics. Recent technological innovations have allowed access to open-architecture products, generating new solutions to local problems and a new generation of inventors who are producing microprocessor-controlled, semi-autonomous or fully autonomous, servo-based devices to accomplish tasks previously unimaginable. In this unit, students will unite key physics principles, related to electricity and electromagnetism, with robotics; ultimately leading to the design and fabrication of a robotic device that can deliver multiple objects across a teacher-designed course.

Unit 3 - Assignments

A. Crafting the Device Chassis (Design and Build)

In this assignment students are designing a robot that will be capable of carrying objects of various size and weight through a course of multiple turns. To accomplish this, students must accurately parse a specification (in this task the exact challenge parameters and rules are determined by each teacher). Once key characteristics are isolated, students use 3D modeling software to generate a digital sketch of a device chassis. It is recommended that students use industry-standard drivers and handheld fastening tools to construct the device according to the submitted design. As the students build the chassis of the robot they also need to apply physics concepts learned in earlier units including weight, friction, speed and acceleration, mechanical advantage, work, and torque. Once the initial prototype is fabricated, students provide an oral presentation of their chassis' using scaled drawings and field oral/written peer critique. Presenters use Newton's Laws of motion to argue the superiority of their design by identifying relationships between design parameters and how the device implements production efficiency, accelerates using mechanical advantage, and balances the mechanical stress of each union.

B. Testing the Prototype

Students evaluate the quality assurance (QA) component of the design process as it relates to data collection and analysis of a manufacturing cycle by publishing a Quality Control report. Using diagnostic tools within a product's Integrated Development Environment (IDE) or service program, students ensure all components are connected and operate as expected. Additional tests include alternative circuit designs (ranging from adding or reducing resistance to relay operation); and, system power consumption with an emphasis on reducing the instantaneous current demand (where students clearly delineate the difference between instantaneous and stabilized current) created by component activation.The students produce a report which includes tabular data and digital images to authenticate product testing including the impact of torque (calculations must be evident). Critical load areas of the design are analyzed by comparing pre and post-use images of the structural component connections. The manufacturing report will also include inspection stamps, full-color images of each structural joint, a brief summary of the manufacturing process, and recommended changes for a future revision. Any changes to the original design must be articulated using as-built/revised drawings.

C. Coding the Robot

Coding allows engineers to manipulate components to exert a change of state on a device. In this assignment, students will learn how to code their robotic device using industry-standard methodologies and a hardware-defined language. First, students produce pseudo-code (a flowchart) to articulate programmatic operation. The flowchart is the foundation for generating the code used by the device. This flowchart can also be used as a recording document for diagnostic data produced during testing. Within an IDE, students generate a fully documented (comments at each line) computer program using more than two variables, loops, and/or arrays to manipulate a servo-based device. Students synthesize the basic necessities of a device/processor-specific program including: definitions, classes, constants, and variables with each annunciated using device-specific nomenclature.

Integrated instruction focused on light and sound wave models helps finitely limit the range of data produced by IR and Sonar sensors which are identified at specific I/O ports. Instruction in data storage methodologies is essential to ensure students have a range of storage options available for programming. Students will produce code to analyze input data eventually leading to specific navigation sequences and the monitoring of components to ensure continued robot operation.

D. Analyzing Circuits

This assignment draws on fundamental physics principles in electricity and electromagnetism to allow students to analyze component circuitry and input/output data. By the end of this unit, students will have a dynamic device ready to move a payload in the most efficient nature - one which autonomously reacts to its environment using electrical data to adapt to changing tasks. Students will collect data through a variety of tests and address the re-design step in the engineering design cycle to ensure the device performs optimally. Using Ohm's law (V=IR) and the equations for electric power (P=IV), students measure and calculate power consumption and its impact on device performance. Further, using varied loads and plotting current demand, students compare the overall system power capacity under multiple scenarios including low and high-load states (e.g. 10g load versus a 100g load). Students use data collection and analysis to drive alternative methodologies.

Students will research electromagnetism and differences between motor and servo operations which will provide the foundation for data-based prediction and use of I/O data-driven class methods. Students will then determine the components needed to perform the final navigation task of this unit, e.g. integration of the Geneva Wheel as a payload locking/unlocking device. The design process should ultimately guide students through the steps of building, testing, redesigning, and finally demonstrating the finalized device to move the specified payloads (varying in weight and/or dimension) throughout a teacher-defined course in an autonomous state.

Unit 4 - Maker Challenge

The final unit of Physics and Engineering: Motion by Design is a student designed capstone project that serves as a summative assessment of the physics and engineering principles developed over the course of the year-long class. In this "Maker Challenge" students will work in teams to design and build, or significantly repurpose, a product that will solve a problem, need or want.

As part of the culminating "Maker Challenge," students will identify physics principles as they exist in the world and implement principles of the engineering process that include collaboration, research and analysis, problem solving skills, and design solutions.

Following are suggested competition parameters:

RULES AND CONSTRAINTS:

- Product must be an original creation designed specifically for the Maker Challenge
- Must identify physics and engineering concepts within design solution
- Project must make use of 3D modeling software and 3D printed parts
- Prototype must respond autonomously and selectively through a microprocessor-controlled architecture (example Arduino) to a particular condition or situation – (example: response to light, sound, etc). This response should include either linear or rotational motion to produce a mechanical output.
- Participants must be in teams of 2 – 5 members.

DELIVERABLES:

- Physical Prototype (must include 3D printed parts and an integrated microprocessor)
- Product/Project Description - Digital Content
- Tri-fold Presentation Board (see specifications)
- Demonstration video of no more than 2.5 minutes (submitted via YouTube/SchoolTube)

A. Research and Development

Earlier in the course, students practiced various techniques for idea generation (ex. divergent and convergent tools). In the Maker Challenge, students will be asked to use these techniques to generate a proposal for their maker project. The prompt is specifically open-ended to allow for the expression of 21st century skills including creativity, collaboration, critical thinking, and communication. Based on their proposal, students will conduct research on feasibility, costs, history of the issue, contributing factors, urgency, current technologies in use (what is currently being done to address the issue), and explain how it connects to the principles of physics learned in the previous units.

The brainstorming activity will be an exercise applying divergent and convergent thinking. The improvisation step will be collecting five random items and encouraging the students to come up with several different uses for them. (Ex. a pen could become a warriors sword or a coffee cup could be a megaphone). The second step will be word association. In divergent thinking, students will write down words (Ex. nouns, verbs, adjectives, etc) and put them in different buckets. They will then pull one word from each bucket and create a sentence. The objective is quantity. In the convergent thinking, students will select the best ideas, check their objectives, and improve the ideas they selected. The objective is quality.

B. Design, Build, Test

Using the iterative design cycle developed in the course, student teams will design and build a working prototype that conforms to the parameters identified above. Students will test the functionality of the product against industry standards and based on the initial round of test results, student groups will redesign their devices. The final maker products will be assessed using a rubric for quality and innovation.

C. Final Presentation

Students will showcase their maker challenge products through a video pitch, a working physical prototype, and a three-sided technical display. This technical display includes four major components: 1) an introduction to the problem being addressed, 2) an explanation of the physics principles involved 3) design specifications and technical drawings (include 3-view and isometric representations preferably CAD-rendered) 4) testing results and justifications of changes made to device (based on initial testing)

Course Materials:

District Approved Physics Text
District Approved Engineering Text

Supplemental Instructional Material:

Physics Classroom
http://www.physicsclassroom.com/

PHET Interactive Simulations
http://phet.colorado.edu/en/simulations

Instructables
http://www.instructables.com/id/Geneva-Mechanisms

Robotpark Academy
http://blog.robotpark.com/specialized-mechanisms-geneva-wheel-mechanisms-51026/

Teach Engineering curriculum for K12 teachers
http://www.teachengineering.org/engrdesignprocess.php

Robotic Devices
http://www.vexrobotics.com/
http://curriculum.vexrobotics.com/curriculum

Optional 3D Design Software:

Sketchup
http://www.sketchup.com/

AutoCad
http://www.autodesk.com/

Solidworks
http://www.solidworks.com/