Making Chemistry and Physics Fun For Everyone
Designing High School Courses to Engage ALL Learners

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Engineering Design Process

1. Identify the problem
2. Brainstorm solutions
3. Select a design
4. Build a model or prototype
5. Test and evaluate
6. Optimize the design
7. Share the solution
Identify The Problem

Oak Harbor High School needed new science curricula that would be aligned to standards and meet needs of ALL students.

Demographics:

- Rural/suburban
- Naval air station
- High student attrition
- 17% ELL
- SpEd/504: 20%
- 40% Low Income
Constraints

- Core 24 - 3 years of Science to graduate
- NGSS - must align to all 3 dimensions in all 4 domains
- 11th Grade Comprehensive Science Test
- Mandatory adoption timeline
- No existing curriculum
- Cannot cost more than average curriculum adoption
- Must include Pre-AP track as well as modifications for SpEd and ELL
Criteria

● Successful completion of courses
● Must be RELEVANT and ENGAGING for ALL students
● Passing scores on the WCAS
  ○ OHHS Scores have exceeded state average for past two years
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Brainstorm Ideas

● Develop a two-year REQUIRED sequence based on the NGSS Modified Domains Course Progression Model (Bundles Standards):
  ○ 9th - Biology
  ○ 10th - Chemistry and/or Physics
  ○ Earth/Space AND Engineering integrated into all three courses
● Project-based learning
  ○ End of unit summative engineering design project
● Engaging for ALL learners
  ○ Frequent hands-on, relevant, activities, investigations and assessments
Engineering Design Process

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Select a Design

1. Select a **learning model** and **pedagogical approach** with proven track records for engaging diverse learners
2. Use **NGSS Storylines** process & tools and selected phenomenon.
3. Divide each Trimester into units based on PEs
4. Use WA **Test Design & Item Specs** to develop assessments
   ○ develop Engineering Challenges as summative assessments using to build rubrics
   ○ develop “written” final test for each unit
5. Find or create highly engaging, relevant, modern lessons and activities.
The Design

1. The selected learning model and pedagogical approach

**5E Instructional Model**

- **Explain**
- **Explore**
- **Engage**
- **Evaluate**
- **Elaborate**

**Ambitious Science Teaching**

1. Planning for engagement with important science ideas
2. Eliciting students’ ideas
3. Supporting ongoing changes in thinking
4. Pressing for evidence-based explanations
The Design

Use **NGSS Storylines** process & tools and selected phenomenon

### Step 2: Unpacking

2. What are the sub-ideas & implicit understandings of each of the DCI(s) and CCC(s)?

   Repeat steps 2A and 2B for each part of the Framework text relevant to your unit.
   (Copy and paste this section as a separate table for each phrase you unpack)

| 2A: Paste a sentence from the Framework text here. Bold a phrase that is important to unpack. |
| DCI & Framework: Newton’s second law accurately predicts **changes in the motion** of macroscopic objects. |

| 2B: Clarify what that specific phrase above means in your own words. Include not just the “what” but also the “how” and “why.” Do not simply restate the language of the Framework. Identify the concepts that students must understand that are not written on the page, but are needed in order to get to the key punchlines of the science. |
| Speed vs velocity |
| velocity measure of how fast something moves in a particular direction |
| acceleration $a=(\Delta \nu)/\Delta t$ how much velocity changes over a period of time. changing speed OR changing direction results in an acceleration. |
| Force something that causes a push or pull |
| net force (force diagrams?) the push or pull that wins |
| $F=ma$ how we calculate force. force = mass times acceleration |
The Design

Divide each Trimester (67 minutes classes) into units based on bundled PEs. Each unit...

- Starts with students making **initial models** to explain an engaging phenomenon
- Builds student understanding via progression through 5E framework, via **hands-on investigations** of phenomena, and continuously **revising** initial models
- Culminates with a **final task, project or challenge** (engineering-based when suitable)
Trimester 1: Where do all the different elements come from?
- Unit 1: Structure and Properties of Matter
- Unit 2: Nuclear Processes
- Unit 3: Life Cycle of Stars
- Unit 4: Bonding and Bond Energy
- Unit 5: Mass Conservation

Trimester 2: Where does matter go? How does it change forms?
- Unit 1: Mass Conservation
- Unit 2: Reaction Rate
- Unit 3: Equilibrium
- Unit 4: Properties of Water
Chemistry A:
Elements are formed through nuclear processes.
Key Question: Where do all the different elements come from?

<table>
<thead>
<tr>
<th>Unit 1: Structure and Properties of Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit 2: Nuclear Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit 3: Life Cycle of Stars</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS-ESS1-1. Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun’s core to release energy that eventually reaches Earth in the form of radiation.</td>
</tr>
<tr>
<td>HS-ESS1-3. Communicate scientific ideas about the way stars, over their life cycle, produce elements.</td>
</tr>
</tbody>
</table>
How the properties of an element determine the way it’s atoms will react with other atoms.
Key Question: Where did the energy come from?

<table>
<thead>
<tr>
<th>Unit 4: Bonding and Bond Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HS-PS1-2</strong> Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.</td>
</tr>
<tr>
<td><strong>HS-PS1-4</strong> Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit 5: Mass Conservation</th>
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</thead>
<tbody>
<tr>
<td><strong>HS-PS1-7</strong> Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.</td>
</tr>
</tbody>
</table>
Chemistry B:
How the properties of an element determine the way it’s atoms will react with other atoms.
Key Question: Where did the matter go?

Unit 1: Mass Conservation
HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

Chemical systems and effects.
Key Question: How does matter change forms?

Unit 2: Reaction Rate
HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

Unit 3: Equilibrium
HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

Unit 4: Properties of Water
HS-ESS2-5. Plan and conduct an investigation of the properties of water and its and use the results to explain why the value of water as a natural resource and/or source of energy.
Physics:

Trimester 1: Physics of Transportation
- Unit 1: Balloon Car Challenge
- Unit 2: Car Crash Cushion Challenge
- Unit 3: Self-powered Car Challenge

Trimester 2: Physics of Space Exploration
- Unit 1: Water Rocket Challenge
- Unit 2: Wind Tube Hovercraft Challenge
- Unit 3: Electromagnetic Wave Project
# Trimester 1: Transportation

## Unit 1: Motion and Forces

**MS-PS2-1**: Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects.

**MS-PS2-2**: Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.

**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.

## Unit 2: Momentum and Impulse

**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.

**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.

**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.

**HS-PS2-6**: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
Unit 3: Energy

HS-PS3-1: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy

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.

HS-PS3-5: Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.
### Unit 4: Rocket Science

**HS-ETS1-1:** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

**HS-ETS1-2:** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

**HS-ETS1-3:** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

**HS-ETS1-4:** Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

### Unit 5: Gravity and Orbits

**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.

**HS-ESS1-4:** Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
Unit 6: Big Bang, Light and Waves

**HS-ESS1-2:** Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.

**HS-PS4-1:** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

**HS-PS4-3:** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

**HS-PS4-4:** Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

**HS-PS4-5:** Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
The Design

Use WA Test Design & Item Specs to develop assessments
<table>
<thead>
<tr>
<th>Code</th>
<th>Alignment</th>
<th>Item Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS-PS2-1.1</td>
<td>SEP-DCI-CCC</td>
<td>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/or its acceleration.</td>
</tr>
<tr>
<td>HS-PS2-1.2</td>
<td>SEP-DCI</td>
<td>Analyze data to support a claim about the net force on a macroscopic object, its mass, and/or its acceleration.</td>
</tr>
<tr>
<td>HS-PS2-1.3</td>
<td>DCI-CCC</td>
<td>Use Newton's second law of motion to describe the mathematical relationship among the net force on a macroscopic object, its mass, and/or its acceleration.</td>
</tr>
<tr>
<td>HS-PS2-1.4</td>
<td>SEP-CCC</td>
<td>Analyze data to support a claim about cause and effect relationships in a system.</td>
</tr>
</tbody>
</table>

**Details and Clarifications**

- Analyze data is expanded to include:
  - organizing and/or interpreting data using tables, graphs, and/or statistical analysis
  - identifying relationships in data using tables and/or graphs
  - identifying limitations (e.g., measurement error, sample selection) in data
  - comparing the consistency in measurements and/or observations in sets of data
  - using analyzed data to support a claim and/or an explanation

- Examples of Newton's second law describing mathematical relationships among net force, mass, and/or acceleration may include, but are NOT limited to:
  - a force causing a smaller acceleration on a more massive object than on a less massive object
  - an increase in the net force on an object causing an increase in the acceleration of the object
  - a net force that is not zero causing a change in motion of a given object
  - objects of different mass with the same acceleration experiencing different net forces

Note: The equation F=ma is not provided on the WCAS.
Engineering Design Process

- identify the problem
- brainstorm solutions
- select a design
- build a model or prototype
- test and evaluate
- optimize the design
- share the solution
The Prototype

Find or create highly engaging, relevant, modern lessons.

- Select high quality OER lesson plans when possible
- Fill in with non-OER resources when necessary
- Create extremely high quality lesson plans when the above cannot be found
The Prototype (Example)

Assemble lessons into 5E model scope and sequence

- **Sample Scope and Sequence**
- Engage: Phenomena with **Model** (Ambitious Science Teaching)
- Explore: hands-on activities (Kesler Stations, POGIL, ADI, Escape Rooms)
- Explain: ck-12, notes/graphic organizers
- Elaborate: labs, revise models
- Evaluate: task and test
Trinitite from Trinity bomb site first US bomb test July 16, 1945
The Prototype

Organization and dissemination of materials

- **Notebooking**
- **Google Classroom**
- **Daily Work Tracking Sheet**

<table>
<thead>
<tr>
<th>Name</th>
<th>Model</th>
<th>POGIL</th>
<th>Isotope Practice Questions</th>
<th>Nuclear Quest</th>
<th>edpuzzle: Radioactive Isotopes</th>
<th>Nuclear Decay Process Practice Questions</th>
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<tbody>
<tr>
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</table>
The Prototype

Assemble lessons into 5E model scope and sequence

- **Engage**: Phenomena with Model (Ambitious Science Teaching)
- **Explore**: hands-on activities (**PocketLab**, **Gadgets & Gizmos**)
- **Explain**: ck-12 and **Physics Classroom Concept Builders**
- **Elaborate**: investigations, revisit models
- **Evaluate**: unit test/engineering challenge/escape rooms

- **Sample Scope and Sequence**
The Prototype

<table>
<thead>
<tr>
<th>Anchoring Phenomena: Car vs Motorcycle vs Jet</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test - 0.5 days</td>
<td></td>
</tr>
<tr>
<td>- Engage</td>
<td></td>
</tr>
<tr>
<td>a. Model - 0.5 days</td>
<td></td>
</tr>
<tr>
<td>i. Objective: I can create a model to demonstrate my thinking about scientific phenomena</td>
<td></td>
</tr>
<tr>
<td>1. Explore - 12 days</td>
<td>cell phones video app time</td>
</tr>
<tr>
<td>a. Pressure and Force Gizmos Questions, Materials List - 1 day</td>
<td></td>
</tr>
<tr>
<td>(dozens of covers of Under Pressure by Bowie &amp; Mercury)</td>
<td></td>
</tr>
<tr>
<td>i. Pressure Power</td>
<td></td>
</tr>
<tr>
<td>ii. It's a Hold Up!</td>
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<tr>
<td>iii. Losing Weight</td>
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<tr>
<td>iv. Candle Vacuum</td>
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<tr>
<td>b. Pressure Globe DEMO</td>
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<tr>
<td>c. Can Crush DEMO</td>
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<tr>
<td>d. Investigations - 12 days</td>
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<tr>
<td>i. Investigating Constant Motion with Video Analysis (OHHS) - 2 days</td>
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<tr>
<td>2. Engage</td>
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<tr>
<td>a. Spreadsheet</td>
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<tr>
<td>i. Objectives:</td>
<td></td>
</tr>
<tr>
<td>a. I can collect, organize and analyze data about average velocity</td>
<td></td>
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<tr>
<td>b. I can create a position vs. time graphs and use them to describe the motion of an object</td>
<td></td>
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<tr>
<td>c. I can define the meaning of velocity, with respect to an object's change in position over time.</td>
<td></td>
</tr>
<tr>
<td>ii. Investigating Changing Motion with Video Analysis (OHHS) - 2 days</td>
<td></td>
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<tr>
<td>3. Engage</td>
<td></td>
</tr>
<tr>
<td>a. Spreadsheet</td>
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</table>
The Prototype

- Explain Part 1: cK-12 Homework - 5 days
  a. Motion and Acceleration
     1. Position and Displacement Questions Form ✓
     2. Average Velocity Questions Form ✓
     3. Instantaneous Velocity Questions Form ✓
     4. Average Acceleration Questions Form ✓
     5. Uniform Acceleration - remove questions with calculations Questions Form ✓
     6. Acceleration due to Gravity Questions Form ✓
     7. Position vs. Time Graphs Questions Form ✓
     8. Velocity vs. Time Graphs Questions Form ✓
  b. Forces and Newton's Laws of Motion
     9. Force Questions Form ✓
     10. Types of Force Questions Form ✓
     11. Weight Questions Form ✓
     12. Inertia Questions Form ✓
     13. Friction Questions Form ✓
     14. Connecting Newton's First and Second Laws Questions Form ✓
     15. Newton's Third Law Questions Form ✓
- Explain Part 2 - Physics Classroom Concept Builders Homework - 4 days
  a. Displacement, Velocity and Acceleration
     1. Distance vs. Displacement To analyze a multi-stage motion and to determine the distance and displacement for that motion.
     2. Position-Time Graphs - Conceptual Analysis (Assign Apprentice level only, Master for advanced students) To analyze a position-time graph and associate the graph features with motion characteristics of a moving object.
     3. Words and Graphs (Assign Apprentice level only) To identify the velocity-time graph that
# The Prototype

**Extend/Elaborate - 1 day**
- CER: Would it be better to reduce the mass of the car or increase the force of the engine to win a drag race? *(On back of model)*
  - Objective: I can make a claim about scientific evidence that is supported by scientific principles.

**Evaluate - 2 days**
- Escape Room: [Race Against the Clock Reflection Questions - 1 day](#)
  - Objective: I can apply content from the unit to solve a problem.
- Assessment: Pre/Post Test MC
  - ME 1 Motion and Forces [Google Form question bank](#)
  - ME 1 Motion and Forces Form A - 1 day
  - ME 1 Motion and Forces Form B

**Engineering Challenge: Balloon Car Race Google Doc with Rubric - 3 days**
- Objectives:
  - I can apply Newton’s 3 Laws to the design and build of a balloon powered car
  - I can discuss how the engineering process is a series of problems and evaluate solutions to the problems.
Prototype Examples

- Momentum Gizmos
- Balloon Powered Car Challenge
- Car Crash Cushion Challenge
- Water Rockets
Engineering Design Process

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Test and Evaluate

First implementations:

- Chemistry in 2017-18 and Physics in 2019-20
  - Tracking in-class and state assessment scores
  - Looking at both effectiveness and engagement
  - Keeping notes of each activity and component
Revise the Design

What has changed since first developed?

- Covid required moving all classes online
  - Virtual labs and simulations replaced all hands-on activities
- Now that we’re back to in-person, we continue to integrate the new digital resources with the in-class, hands-on lessons
  - Quizlet, Kahoot, digital escape rooms, Edpuzzle, Gizmos, Physics Classroom
- Shifting to CK-12 FlexBook® 2.0
Engineering Design Process

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Optimize the Design

How do we improve from here?

- Based on feedback, modify, improve or replace components as needed
- Refine and customize lessons that were used as-is
- Modify assessments to make them more robust and more 3D
- Address engagement/accessibility of math-heavy content
Engineering Design Process

- Identify the problem
- Brainstorm solutions
- Select a design
- Build a model or prototype
- Optimize the design
- Test and evaluate
- Share the solution
Access to the Curricula

The slides for this presentation and the scope and sequence documents for all 6 units are available now on the NSTA conference site.

Both Chemistry and Physics curricula are available on the OER Commons site.

Thank you so much for attending our presentation today and wanting to learn about our courses!

Please email Jonathan Frostad if you have any questions.