Nexus Learning Grant Proposal:
Promoting Physical Intuition through Experiment-Based Learning

1. Abstract

This proposal seeks funding to overhaul the introductory physics course at Philadelphia University. The primary focus of this redesign will be to teach students physics, rather than math, by piquing their curiosity and guiding their intuition through experiment-based learning. The modern pedagogies adopted in this project will give ownership to the students, which has been clearly shown to increase student engagement in, aptitude for, and attitude toward physics [1, 2,3]. These approaches appeal to the Hallmarks goal of scientific understanding through curiosity and rigorous inquiry and also align with the basic principles of the Nexus Learning initiative. Two different but complementary approaches will be taken, with each approach using research-proven methods. Semester by semester, the developers will work together to assess which aspects of the two approaches work best, eventually convolving these successful approaches into one course which is best for Philadelphia University. We have a well defined rubric for quantifying student learning gains and the successes will be shared with scientists at the local and national levels.

2. Explanation of how the Project Advances NEXUS Learning

The first approach revolves around teaching physics through intuition-guided experiments conducted in-situ, thus removing the separation of theory and experiment. This will double as a lesson in the scientific method which will gain students' trust in the scientific process while (re)constructing proper physical intuition. The second approach uses a project-based delivery which enhances student learning by sparking their curiosity and supporting them to work autonomously. This gives students the freedom to explore the laws of physics through a system, product, or question which interests them. Both methods have been shown to enhance learning [1,2,3] by encouraging students to actively and collaboratively engage in the scientific process rather than learn a series of scientific facts. By accessing students' natural curiosity, this course will improve attitudes toward the subject and enhance comprehension of the material.

Intrinsic to our class design is the university's mantra of ``learning through doing.'' Students will learn to estimate possible solutions, ask appropriate questions, properly use the internet to research issues, apply their physics knowledge to a project, and seek professional advice when needed. This is a 21st-century education that lies at the heart of Nexus learning by encouraging future collaboration among students and scientists. Furthermore, the delivery of the proposed class resonates with the tenets of Nexus learning:

- Low-level learning (remembering, understanding, and applying) takes place individually, outside of the classroom. Higher-level learning (analyzing, evaluating, and creating), which requires collaborative discussion, takes place in the classroom.
- The combination of internet research, discussions, instructor-run demonstrations, student-run experiments, marker board problems, and applications of physics to the

real world will create a dynamic classroom in a dynamic space (Nexus Learning Hubs), which will resonate with all learning styles.

- In the Nexus Learning Hubs, instructors and students can perform tests and quickly share the results. This is key to a real-world physics education, as we can perform experiments and discuss their results at face-value, without waiting for a concocted scenario. The speed at which results can be shared and analyzed allows us to learn how the world really is, not how it ought to be. This establishes trust in ``what physicists do'' and fosters meaningful communication among scientists and non-scientists outside of the classroom.

3. Specific Project Goals and Learning Outcomes

Project Goals:

- We will improve our students' disposition towards physics and science in general.
- We will improve our students' scientific reasoning skills and understanding of basic mechanical phenomena.
- We will advance the Nexus initiative in the following ways.
    - We will teach the components of algebra-based physics that are relevant to other branches of science and medicine.
    - We will flip the classroom and encourage conversation and dissection of problems and real-world issues in the class.
    - We will teach the laws of physics by following the scientific method, in order to remove the assumed element of blind faith in the lecturer.
    - We will establish the students' trust in the scientific community by analyzing experiments rather than idealizations.

Learning Outcomes:

- We intend to learn the balance of experiment, discussion, problem solving, and project work that is most effective for teaching physics to PhilaU's mix of design and life-science students.
- We feel that a deep discussion of a few potent, profitable topics is more valuable than the shallow discussion of the slew of topics currently being taught. To this end, we intend to find the subset of topics we should use to most efficiently and productively teach basic physical reasoning.

4. Description of Activities and Time Frame

- Summer 2016: Develop studio-style experiments and student project solicitations which can be implemented in the Nexus Learning Hubs.
- Fall 2016: First-run of PHYS-101 with the new class format. Each day's activities will be documented in a studio log. Assessments will be administered (see section 5).
- Winter 2016-2017: Review studio logs to improve time management, experiments, and project solicitations. Assessment results will be analyzed. Discuss successes and struggles and begin converging toward one course format.

- Spring 2017: Second-run of new PHYS-101. This time, with the mentioned improvements. Assessments will be re-administered.
- Summer 2017: Review studio logs to further improve time management and in-class activities. Continue to compare assessments and evolve toward one course which capitalizes on the successes of the two formats. Ed Santilli will discuss preliminary results at the American Association of Physics Teachers (AAPT) meeting in Cincinnati, OH on July 22nd – 26th.
- Work will continue beyond the grant's time frame. Kasey Wagoner will present more complete results at the AAPT meeting in Washington, DC on July 28th - August 1st, 2018.

5. Project Assessment

There is great confidence that this project will have a positive impact on student learning. Our efficacy will be assessed with a series of nationally-recognized surveys. Work on this project has already commenced with the deployment of first-round of assessments.

- Students will be given the ``Colorado Learning Attitudes about Science Survey'' (CLASS) [4] to measure their disposition toward the subject. The attitudes of students taking the traditional course will be compared to the attitudes of students who take the new course, to see how those attitudes have evolved after the deployment of the modern pedagogies.
- Students will also take the ``Force Concept Inventory'' (FCI) [5] at the semester's beginning and end to assess their conceptual learning gains. The gains among different sections will be compared. Since the FCI had been administered to PhilaU students for several years, we will also be able to compare the new course with the traditional course.
- Since we cannot quantify our course's alignment with the principles of Nexus learning, we plan to be in contact with and observed by established Nexus advocates including Anne Bower and Jeff Ashley. Their advice will be used to modify the lesson delivery to be more in-line with the pedagogies supported by the Nexus learning initiative.

6. Documentation and Dissemination

We will document this project in a series of studio logs. Additionally, a student worker will video record our instructor-led demonstrations and mini-lectures. These recordings will be used to create Zaption videos which we can provide to students as supplementary material or as ``back-up material'' assigned during university closings.

We will present our methods and results at the 2017 and 2018 AAPT meetings (see section 4) and, through the Center for Teaching Excellence and Nexus Learning, we will lead a series of workshops showcasing our experiences to guide other science faculty wishing to adopt any of our methods. We will also publish one or more methods manuscripts in *The Physics Teacher* [6]. Finally, at the conclusion of the study, we will publish our findings in *Physical Review, Physics Education Research* [7].

7. Project Personnel

The project's PIs are Edward Santilli and Kasey Wagoner. Edward Santilli taught physics and mathematics at the high school and college levels for over twelve years, which includes several years in a studio setting. Kasey Wagoner taught physics labs for four years and active learning classes for three years. He completely revamped Washington University's introductory physics labs and has two papers under review for this work [8,9]. Additionally, he won multiple university-wide teaching awards and recently received the extremely competitive ``Vernier Technology Award'' from the National Science Teachers Association for his work in curriculum development. The PIs will hire two student workers who will test experiments and who will record in-class demos for documentation and dissemination purposes.

8. Budget Narrative and Worksheet

We have already implemented some of the ideas for the new class format, but more equipment is needed if the students are to conduct experiments themselves. We will therefore allocate most of the funds ($4226.72) to classroom equipment. This includes semi-frictionless tracks and carts, basic hardware and tools, voltage and current probes, etc. The student workers will be paid with the remaining funds ($1773.28).

References

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A *Energy* - Project Based Learning Example

The term *energy* frequently comes up in modern society (think of energy efficiency, renewable energy, nuclear energy, etc.). An investigation of these concepts begins with an understanding of energy itself and what it is, how it is conserved, and how it transforms. This understanding of the concept of energy is what we will develop during this project.

Background Resources

You will find these resources useful as you explore your project on energy. The background reading will give you an introduction to how the physics community thinks about energy and how energy is relevant to the modern world. The applets will allow you to play around with energy, exploring energy conservation and how this conservation leads to energy changing from one form to another. You are encouraged to explore these materials and more. If you find something that you feel is particularly useful, share it with your instructor!

Reading

- Open Stax - Chapters 7 & 8
- http://energyquest.ca.gov/story

Applets

- PhET: *Energy Skate Park: Basics*
- PhET: *Energy Forms and Changes*

Youtube Videos

- Bozeman Science: *Potential and Kinetic Energy*
- Doc Physics: *Work, Power, and Energy*

Your Project

You are tasked with developing a project that explores energy conservation and energy transformation. You will define and execute the project however, you should use your instructor as a resource. Your project could, *but is not required to,* take one of the forms below

- Experiment: Here you would be devising and executing a test of the aspects of energy that you wish to explore.
- Game: Here you would be developing a new game (it could be a video game or a sweet, 70s style board game, or something else) which teaches the players about the concept of energy.
- Product: Here you would be developing a new commercial product and/or analyzing an old commercial product. Your analysis would lead to an understanding of the forms of energy used/stored in the product in the hopes of making the product more energy efficient.

Your Report

At the end of this project you will submit a written report of the project. This should be well-written prose, not a list. The report should be concise, but complete and it should include the following.

- Objectives: This is an overview which should describe your project and how it explores the concept of energy.
- Projected Outcomes: This is a description of your goals for the project and should be completed before work has started on the project.
  - If your project is an experiment to test a specific quantity or set of quantities you should hypothesize an outcome for this experiment.
  - If your project is a game you should describe how the game is intended to teach players about energy
  - If your project is a product you should describe the product you intend to develop or how you intend to make an existing product more energy efficient.

- Implementation & Instructions: This section is about how your objectives are met. Detail how you built your apparatus. You will want to address questions including, but not limited to the following. What objects are in the project? What details about the objects are important? How do the components of your project move? How do they interact? Further, how does the user actually use the project? Your instructions should allow anyone with basic knowledge of energy to use and/or understand your project. You should detail any interaction required from the user. You should point out where the users should direct their attention.
  - If your project is an experiment to test a specific quantity or set of quantities you should describe the apparatus you have constructed to perform this test.
  - If your project is a game, make sure you include the rules here.
- Data: This section should include any data necessary for the completion of the project. All data should be organized in understandable data tables.
- Result and Summary: This is a concise, but complete, description of the outcome of your project.
  - If your project is an experiment to test a specific quantity or set of quantities you should detail what the results were and quantify the quality of those results.
  - If your project is a game you should describe how your game obeys the laws of physics and furthermore how your game teaches the player about these laws.
  - If your project pertains to a product you should describe the physics of the product you developed or give the results of the energy analysis of the product.
- Future Work: This section is a description of how you could improve or extend your project.
  - If your project is an experiment you could describe how the experiment might be improved to yield better results with less uncertainty, or how it might be extended to increase the number of quantities tested.
  - If your project is a game you should describe how your game might be extended to include more forms of energy.
  - If your project developed a product you should describe how the product could be improved to be more energy efficient. If your project was a product analysis you should describe how the product could be made more energy efficient.

Your Presentation

You will give a 10 minute presentation of the result of your project. Like the project itself, you are free to define the style of the presentation as long as it meets the requirements laid out in the Rubric. Each member of the group is expected to have an equal roll in the presentation.

Rubric	Possible	Score
Project & Report	**55**	
Begins with a well-written sentence or paragraph stating the objective(s) of the project (*i.e.* the role of energy). All topics mentioned are actually covered in the project.	15	
Clear statement of Projected Outcome of the project.	5	
Clear and complete description of the experimental process used in the project, or clear and complete instructions for using the project.	10	
Proper analysis of data and clear description of this analysis.	10	
Well-written conclusion that summarizes the results of the project. This should also include a statement of the way the project could be improved and/or extended in the future.	15	
Presentation	**25**	
The presenters are prepared and enthusiastic.	5	
The clearly states the goals and conclusions of the project.	5	
The presenters are able to answer questions about implementation of the simulation and/or the physics being investigated clearly and confidently.	10	
The presentation is completed in the allotted time.	5	
Creativity (Maximum of 20 points for creativity)	**20**	
The project uses an advanced understanding of energy (energy in electric fields, energy in magnetic fields, etc.) to meet the objectives of the project. (3 points per type of object, up to 6 points)	6	
Adjustments to material properties (density, mass, friction, restitution, attraction, etc) are made (or suggested) in order to meet the objectives (or improve the product). The importance of these choices must be explained in the report. (3 points per important modification up to 6 points)	6	
The report includes a focused, thorough, and clear discussion of modeling energy flow and/or interactions. (See the *Introduction to Modeling* on Blackboard.) This is especially interesting if an object or interaction is modeled in a clever way.	8	
The report includes a focused, thorough, and clear discussion of the limitations of a particular model or models. (See the *Introduction to Modeling* on Blackboard.)	8	
The user can interact with the project in a fun or interesting way.	6	

B *Discovering Potential Energy* – Experiment-Based Learning Example

In your reading, you learned how to calculate a moving object's energy. Throughout the next two classes, we are going to discover how and why energy is conserved in a simple system. You should work with your table to conduct the experiment and find answers together. Be sure to answer the questions in the order provided since this activity is designed to guide your intuition!

1. Review.

(a) What expression did we define as the energy of a single cart moving on a frictionless track?

(b) Use this definition to compute the total energy of a 2 kg cart moving to the right at 5 m/s and another moving to the left at 5 m/s. What do you notice (does direction matter)?

(c) If we were to remove all friction from the wheels, would the value of energy that you found in part b ever change? (Would energy be conserved?)

2. Thinking a bit.

(a) Use the same definition of energy (the formula from $1a$) to compute the energy of a 2 kg ball thrown at 10 m/s.

(b) Do you expect the direction of the throw to matter? (Big hint: Does E depend on direction?)

(c) Consider the same ball thrown directly upwards at +10 m/s. What do you expect the ball's velocity to be when it returns to your hand?

(d) Using this new velocity, compute the ball's energy. Was its energy conserved?

3. Some more scrutiny.

(a) Draw a velocity vs. time graph of the ball's motion. In words, where is the speed smallest? Where in the ball's flight does this happen?

(b) At this point in the ball's flight, compute its energy. Does its energy still look conserved?

4. Logically approaching our issues.

(a) What initial conditions and parameters could possibly effect the ball's maximum height, $h_{\max}$?

(b) Consider the units of each of these parameters. There is only one way they can all combine into a meaningful formula for $h_{\max}$. What is it and why?

5. Experimentation.

Some formulas contain unitless numbers. For example, the circumference of a circle is proportional to its diameter. The constant of proportionality, π, has no units and can only be determined experimentally[1]. We are currently in a similar situation. The relation that you found in $4b$ via unit analysis may have a 2, or a π, or a $\sqrt{3}$ that we need to figure out. It's time to conduct an experiment...

(a) To find the constant, you will drop a ball from a pre-measured height, h_{max} and use photogates to time the fall. Then, use the constant acceleration formula $a = \Delta v/\Delta t$ to determine v_{bottom}.

(b) Conduct the experiment several (at least 10) times for various values of h_{max}.

(c) In Excel, plot $y = gh_{\text{max}}$ vs. $x = v^2_{\text{bottom}}$ for each trial. If you create a trendline, what will its slope, s, represent and why? Do you think you should make the trendline pass through the origin?

(d) Compute the uncertainty in the trendline's slope, Δs.

(e) Report your final result, $s \pm \Delta s$.

(f) Does your result, $gh_{\text{max}} = sv^2_{\text{bottom}}$, suggest how can we recover a conservation of energy? How?

6. Conclusions.

So it seems that at the top of the flight, when $v = 0$, we have a way of computing what the energy *will be* when the ball reaches full speed. We call this calculated energy (you guessed it) the *potential energy*. In this case, the ball's potential energy is due to the gravitational field of the Earth pulling downwards. We know that a ball lifted above the ground has the potential to fall, so we say it has potential energy. Pretty sensible, eh?

We can recover a conservation law for energy if we include this potential energy into the calculation. With this in mind, we can redefine the energy of the ball to be $E_{\text{net}} = \frac{1}{2}mv^2 + \sum$(all potential sources of energy in the system). Energy is once again conserved, but transformed from kinetic energy, $\frac{1}{2}mv^2$, to gravitational potential energy, (mgh), and then back to kinetic energy. The idea that *energy can be transformed from one form to another* is crucial to the usefulness and validity of the law of conservation of energy.

And now, I have a final question for each of you. Can we absolutely prove the Law of Conservation of Energy? If so, how? If not, what good is it?

[1]...or maybe with mucho mathematics.