THE IMPACT OF INCLUDING A RENEWABLE ENERGY THEME ON PHYSICS EDUCATION AND PERCEPTION OF MEANING

by

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DEDICATION

This project is dedicated to my students, who have taught me far more than I them. May they go off and do great things.

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ABSTRACT

A renewable energy theme was incorporated into an AP Physics class. Renewable energy linked assignments, articles, videos, and discussion developed the theme. The Force Concept Inventory and class exams tracked progress in physics. Surveys and interviews gathered data on perception of meaning. The results suggest that the theme neither facilitated nor interfered with the learning of physics. Learning physics, however, improved their understanding of renewable energy topics. Overall students found the theme meaningful and relevant.

INTRODUCTION

Background

The impacts of human induced climate change have become increasingly apparent. Changes in extreme weather events and patterns have dramatically demonstrated this. Though specific effects of climate change are difficult to predict, they will certainly entail varying forms of ecological, economic, and social instability. As atmospheric CO_2 is at the heart of this issue, responses to climate change must involve changes in the roles of fossil fuels and renewable energy sources. Science teachers can play a crucial role in ensuring that students are prepared to make the best decisions possible in these circumstances and contribute productively to the public debate.

At present the high school science curriculum at Jay Pritzker Academy does not systematically address climate change. To target this deficit, this project explored the feasibility of incorporating a renewable energy theme into existing high school physics units. Class discussions, lab work and assignments supported the development of the theme such that the addition of new units into an already packed syllabus was not required. This project could be of interest to teachers in diverse content areas who share concern regarding climate change. It may also be of interest to teachers hoping to address NGSS standards tied to energy use and resources.

The inclusion of a renewable energy theme could not come at a cost to existing learning outcomes. The renewable energy theme needed to add depth to the material without hindering it with too much complexity or consume too much class time. Likewise, the renewable energy material could not be simplified to the degree that its inclusion provided mere surface level or contrived connections to physics content. The focus question below aimed to address these concerns.

Focus Question

My focus question was to what extent does the inclusion of a renewable energy theme enhance or detract from the learning of fundamental physics?

My sub-questions include the following:

1. To what extent can a renewable energy theme render physics class more meaningful?
2. How has the inclusion of a renewable energy theme in physics class impacted me as a teacher?

My support team provided guidance and feedback. My science advisor, Dr. Nicholas Childs has provided project ideas, notably in the use of Physport, a physics education website, to obtain and analyze assessments. Project advisor Walt Woolbaugh provided valuable guidance throughout the process. Colleagues at JPA such as Stephen Pollard, English teacher, and Adam Murray, biology teacher, provided feedback on the project.

CONCEPTUAL FRAMEWORK

The project is based on research literature in thematic education, climate change education, best practices in physics education, brain-based teaching research and literature pertaining to the perception of meaning in learning. The research base includes qualitative and quantitative work as well as perspectives rooted in science and philosophy.

Literature on Thematic Education

The first focus question addresses the impact of including a renewable energy theme on physics education. There is mostly qualitative evidence from a small research base that the inclusion of a theme can positively impact student learning (Tessier & Tessier, 2015). Potential benefits include an increased sense of connection with content, more positive attitudes to the subject and developing higher order thinking (Lung, 1999).

In Lung (1999,) a biology teacher describes the integration of biology content with the theme of a malaria outbreak in an African village. For the duration of the semester, biology topics were linked to solving the outbreak problem. The approach was combined with group presentations on key aspects of the theme. Though Lung offers no quantitative data he states that:

> I have used this program at college and high school levels for four years and have had enormous success…Student responses on questionnaires and evaluations are very positive and encouraging. They find it challenging and fun. (Lung, 1999, p. 21)

Lung describes how the theme is woven across several units. Teacher lectures and independent student research complement one another, culminating in presentations.

In Tessier and Tessier (2015) the inclusion of a theme in several university level courses is analyzed. A healthcare theme was used in an arts and health class, a beer theme in a biology class and a food theme in art appreciation class. The authors report moderate quantitative success measured using pre and post surveys on questions relating to personal connections to content, comfort in discussing class content and career links. Qualitative data indicates more positive student attitudes towards class content as well as increased levels of comfort with the material.

Barma and Bader (2006) detail a study involving ninth grade biology teachers incorporating the theme of health risks in using tanning salons. The effect on students learning was increased stimulation and the development of greater student autonomy.

In Lipson et al. (1993), thematic teaching is advocated to “promote a view of teaching and learning as a meaningful enterprise” (p. 253). The authors note that thematic teaching can provide a powerful context for why content is learned, provide additional time to cover more content and develop students’ higher order thinking skills. Thematic teaching is seen as a clear improvement over contextless abstract instruction that is often observed. The authors provide a cautionary note, however, stating that successful implementation of a theme is difficult. Poor implementation may lead to students inadequately learning content or may make only contrived connections between theme and course content. The authors advocate careful planning before implementing a theme (Lipson et al., 1993).

Literature on Teaching Climate Change

McNeal and Petcovic (2019) provide three suggestions for teachers intending to teach climate change. These are to connect students with local climate change related issues, have students collect their own data and to connect with climate change scientists. In doing so, students develop a view of climate change tied directly to their own experience and that of their communities.

Bardsley and Bardsely (2007) describe the use of a constructivist approach to climate change education. They too advocate introducing a problem-based approach. In their case students performed a kind of environmental impact assessment for a proposed development near a local beach. As McNeal and Petcovic (2019) suggest, the authors had students collect data from local ecological sites and assessed environmental impacts in their own communities. The authors believe that such training will increase students' resilience in the face of climatic uncertainty (Bardsley, 2007).

Seraphin et al. (2012) identify potential pitfalls in environmental education. The authors led a professional development conference that advocated the use of inquiry in teaching about climate change and renewable energy. Teachers then developed inquiry style units with their own students based on the conference. High levels of student engagement were reported by many. Nonetheless, teacher confidence in the subject was low, even after attending the conference. They found that the complexity of the topic, which involves several branches of science and social and economic considerations to be significantly challenging (Seraphin et al., 2012).

Rodgers (2014) outlined a short study in which business majors were taught about renewable technologies over seven weeks. They then made a "rocket pitch" a kind of brief business style sales pitch to encourage investment in a particular technology. Students in the study ranked traditional lecture, followed by class discussion, then videos as most effective in acquiring new information related to renewable technology. Though not highlighted by the students, the authors believe the rocket pitch activity itself was beneficial in learning about renewable energy (Rodgers, 2014).

Literature in this domain highlights the need for strong personal connections to local climate change, be it in the form of data collection, or for the business majors, making a sales pitch. The literature also highlights the difficulties stemming from the complexity of the issue.

Literature on Meaning in Education

The second research question addresses meaning in education. Meaningful can be defined as "serious, important or worthwhile" (Cambridge Dictionary, 2020). The question of meaning in education has been addressed by numerous theorists such as John Dewey, Carl Rogers, Jack Mezirow and others each offering a unique perspective. Though meaning is not easily quantified or defined certain trends emerge consistently in the literature. Meaningful learning has been tied to relevancy within the context of student experience, problem solving, and a sense of liberation or expansion of horizons (Burket & Wilson, 1989).

Dewey found that traditional education was often abstract and distant from students' lives. Dewey argued that learning experiences should be continuous, building on previous ones, and linked to future lessons. This, in conjunction with learning in a social context set the stage for growth (Burket & Wilson, 1989). He distinguishes between that which we have been taught to value versus what an individual, through personal experiences, determines to be worthwhile, the latter being much more significant (Dewey, 1916). Students must be led by a teacher though a series of educational experiences, such that the learners independently come to value that which is important. This emphasis on personal experience is supported by recent neurological studies. Learning only really takes place when an individual can relate content to their own personal metaphors and reference points. This has been tied to the importance of emotion in learning. Deeper emotions, tied to these metaphors, and other personal connections enhance learning (Jensen, 2008).

David Kolb and Peter Jarvis also tied meaningful learning to the experience of problem solving. Using knowledge to find solutions is what makes learning meaningful. Jarvis referred to a “disjuncture” whereby a learner sees a gap in their own knowledge in conjunction with a problem whose resolution requires this knowledge. When this condition is met meaningful learning can take place (Burket & Wilson, 1989).

Brain Based Best Practice

Eric Jensen (2008), a brain-based education researcher, cites three critical factors in making meaning. These are relevance, context, and emotion. Information perceived as relevant can be tied more easily to existing knowledge. Relying on existing physical connections between neurons and strengthening these connections, is what underlies learning. The context of learning is tied to pattern recognition. Learners need to be able to place new information into some relevant context, assimilating the information into a larger whole. Emotion is critical in labeling new information as important. Strong, and especially positive, emotion serves this function well (Jensen, 2008).

Education which has a greater likelihood of being perceived as meaningful should provide a series of experiences that are relevant to students' lives, linked to important problems to be solved.

Best Practice in Physics Education

One way to make physics relevant is through the deliberate and extensive use of illustrative examples (Futoran, 2018). By continually demonstrating the everyday application of concepts learned in class they become less abstract and more familiar.

The use of problem solving is a staple in physics teaching best practice. Research consistently relates positive student outcomes with problem solving. Students may be tasked with determining creative solutions to real world physics problems. This has been shown to have improve learning in a Ukrainian study (Korson, 2019). Students may be asked to explain a puzzling a phenomenon. Italian researchers have demonstrated that having students explain magic tricks tied to physics improves outcomes (Bagnoli et al., 2019). Turkish researchers have shown that the use of toys in solving physics problems can improve students' attitudes towards physics, which can in turn contribute to improving learning (Ince et al., 2015).

What unites these seemingly disparate approaches is the creation of disjuncture, using Jarvis' term, whose resolution requires the mastery of physics content. In my project climate change was the problem to be solved. Renewable energy technology is one part of the solutions to this problem. Understanding renewable energy necessitates understanding fundamental physics concepts such as motion and energy. By consistently referring to the theme across lessons; familiarity with the topic was enhanced and a sense of purpose in studying physics developed. This enhanced the sense of relevance in students' minds hopefully rendering class more meaningful.

METHODOLOGY

Demographics

Jay Pritzker Academy is in Tachet village, some fifteen kilometers outside of Siem Reap, Cambodia. We are a coeducational day school, providing both an American and Cambodian curriculum to about 460 students from prekindergarten through twelfth grade (JPA website n.d.). We aim to train talented and motivated students who would otherwise not have access to quality education. “Build a better future for ourselves, our families and our country” –a phrase taken from the school pledge encapsulates our mission. Preschool age children from the surrounding villages are invited to a yearly entrance test. Capable students earn a scholarship which must be renewed at the end of kindergarten, and again after first, third, sixth and ninth grade (Stephen McCambridge, personal communication Aug 12, 2019).

Pre-pandemic we provided three meals a day to our students as food insecurity exists within our community. Eligible students also receive free hygiene products and other forms assistance from the school. There is no tuition at JPA.

The curriculum is rigorous. English curriculum classes are equivalent to those American students of the same grade would take. We use American textbooks and take American standardized tests such as Aspire, SAT, ACT, and AP. Simultaneously students pursue all national curriculum classes needed to obtain a Cambodian high school diploma. Upper high schoolers usually juggle a full complement of AP classes while also preparing for Cambodian national exams.

JPA has little ethnic, but some economic diversity. All students are ethnic Cambodians, living within a roughly ten-kilometer radius around the school. Some students have mixed Chinese and Vietnamese heritage (Interview with admissions officer.).

Student homes range from traditional bamboo and wooden houses to larger three-story concrete and brick structures. Some are affluent enough to travel regionally with their families while others struggle to meet basic needs.

Despite challenging circumstances, graduates have been accepted to prestigious universities, regionally, in the United States and elsewhere. Students have also gained admission to highly competitive boarding schools across the globe. JPA only provides tuition to our own campus so high achievement, needed to earn full scholarships that include room and board is critical. Even those affluent by local standards generally cannot afford to study abroad, especially outside the region.

Sample

The treatment included a mixed 11th and 12th grade class consisting of 18 students, 16 of which were enrolled in Advanced Placement Physics 1 and two students in Conceptual Physics. These two students attended the same classes as the rest but completed different classroom tests and assignments as of mid-October. The class contained 12 juniors and six seniors. The seniors took Conceptual Physics in 11th grade and were generally stronger students given their previous year of physics. The class contained seven females, all juniors, and 11 males. Students were generally well motivated and capable. The juniors had a wider range of ability than the seniors. The two in Conceptual Physics struggled the most. The other ten ranged from struggling to very proficient.

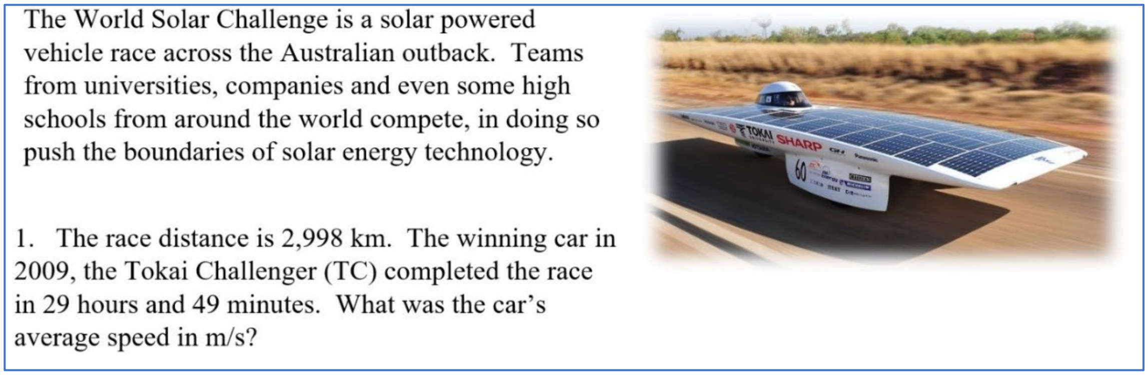
Online lessons during school closures provided a direct window into students' home lives. This revealed that many did not have access to quiet places to study. In many cases the audio from live online class competed with the sounds of livestock and other domestic noise. Many enjoyed semi-reliable cellular and internet connectivity, though some were not so fortunate. Frequent power cuts during the dry season in February and March provided an additional challenge. Most students do not have generators at home.

Another significant difference, especially for female students, was the presence and or requirement to care for younger siblings and cousins. Rural Cambodia is very traditional. In many families, daughters are still expected to contribute more significantly than sons to child rearing and other chores. At least one student had nearly full-time childcare responsibilities placed upon her while studying at home during the first semester.

Convincing parents that schooling could occur at home and that therefore their children should be burdened with fewer domestic obligations was often a challenge. This aspect, however, improved after January.

Treatment

The treatment plan consisted of three parts used in tandem. One was the development of assignments that tied renewable energy to physics concepts that are part of the curriculum. These assignments were planned to be administered weekly. As the semester progressed, and entropy increased, this stretched to approximately two to three weeks between these assignments, with larger gaps between assignments occurring after school holidays, or quarterly exam periods. Such assignments included analysis questions, and laboratory work. Complimentary to this was the development of the renewable energy theme. This was accomplished through the repeated use of references to renewable energy in class, discussion prompts, short videos, readings, and shorter physics problems that referred to renewable energy. These smaller tasks and references were included several times a week, especially at the start of the study period. Appendices B and H contain sample renewable assignments. The third component of the treatment included the measures of progress on the research questions. These consisted of a survey conducted in just before Christmas break, and interviews in March. Quarterly exams, practice AP tests and other assessments provided data. Appendix A reproduces the survey. Appendix B reproduces the questions used to guide the interviews.



The World Solar Challenge is a solar powered vehicle race across the Australian outback. Teams from universities, companies and even some high schools from around the world compete, in doing so push the boundaries of solar energy technology.

1. The race distance is 2,998 km. The winning car in 2009, the Tokai Challenger (TC) completed the race in 29 hours and 49 minutes. What was the car's average speed in m/s?

Figure 1. A sample short kinematics problem using a renewable energy theme.

The treatment was conducted both online and in class as between September and March campus opened and closed several times. Table 1 provides the matrix outlining the data collection methods for each question.

Table 1. Research Matrix.

Research Question	Force Concept Inventory	Class exams	Class Assignments and lab work	Survey	Group Interviews
Focus Question	X	X	X	X	X
Sub #1				X	X
Sub #2					Weekly teacher journal entries

Data Collection and Analysis Strategies

The focus question asks if the renewable energy theme enhances or detracts from the learning of physics. The Force Concept Inventory test was used as a pre and post-test of physics skills. The pretest was administered during the first week of class in September and the posttest was administered on March 31st. Between this period intermittent classroom assessments provided additional measurements. Scores on laboratory work and assignments provided additional data on the question. Appendix C provides a table of planned and administered assignments.

The FCI was designed by David Hestenes and others at the University of Arizona in the 1990s and is a well-respected measure of student physics achievement, used in high schools and universities alike (Hestenes, 1992). This measure was included to add validity to the study and simplify comparison with students outside JPA. The classroom tests and exams provided a mix of questions developed at JPA, College Board resources and those found in AP preparation books.

A midterm survey in December and interviews with each student in early March provided data on student perspectives. Students were asked to reflect on classwork and determine if the theme enhanced, detracted, or had no effect on learning physics concepts.

The first sub-question addressed the degree to which meaning was impacted by the inclusion of a renewable energy theme. This was tackled via the survey and interview. Questions from both measures overlapped, yielding a fuller snapshot of student views on the research questions.

The second sub question, addressing the impact of the study on me as a teacher was measured using journal entries.

An exemption to pursue formal approval from the Internal Review Board was obtained in October and permission to proceed was granted (Appendix D).

DATA AND ANALYSIS

Physics Achievement Results

The results of the Force Concept Inventory are shown in a box and whiskers plot below. Tables show individual results for the whole class and by subgroups in Appendix E.

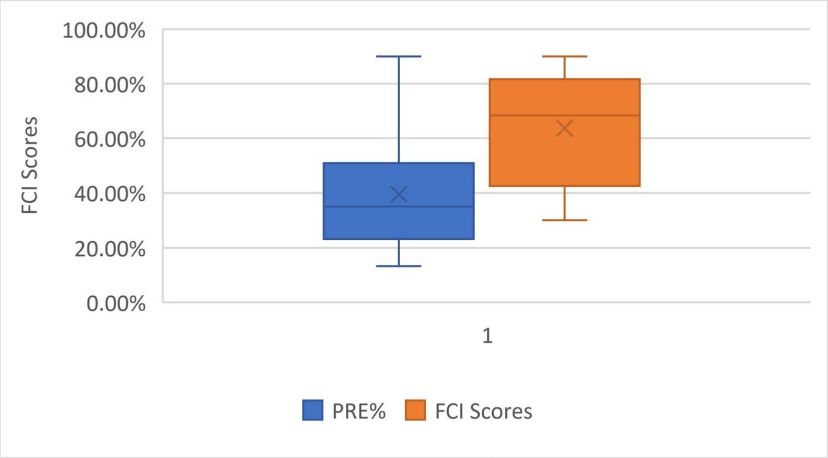


Figure 2. Force Concept Inventory pre and post test scores for all students, (*N*=18).

We see the median score on the pretest was 39% which rose to 68% in the post. This constitutes an average normalized gain for the class of 40% and an effect size using Cohen's D of 1.34. The range narrowed from about 73 to 60 from pre to post. The gains indicate that the treatment did not interfere with students' acquisition of physics content. Two students' scores dropped from pre to post. Student 18 achieved the anomalous 90% score on the pretest. His score dropped to 80% on the post. Eighty percent on the post matches the student's general ability and reasonably high scores on other assessments. The 90% on the pre was unusually high and is difficult to account for.

Student 13's score also dropped from 37% to 30%. Here the pretest score was in line with the class median and the student's abilities. The posttest was surprising. This student scored the highest in the class on the 3rd quarter exam, a full-length AP practice test. 30% on the post does not accurately reflect his abilities. Perhaps the student was distracted when completing the post or did not take it seriously as he knew the assignment was ungraded.

Students' Force Concept Inventory Data was uploaded into Physport's Data Explorer's database. Physport is a web-based resource developed by the American Association of Physics Teachers and Kansas University. The database contains achievement data from thousands of mostly university students who have taken the Force Concept Inventory facilitating comparison between one's own students and a baseline of American students (Physport Website, n.d.).

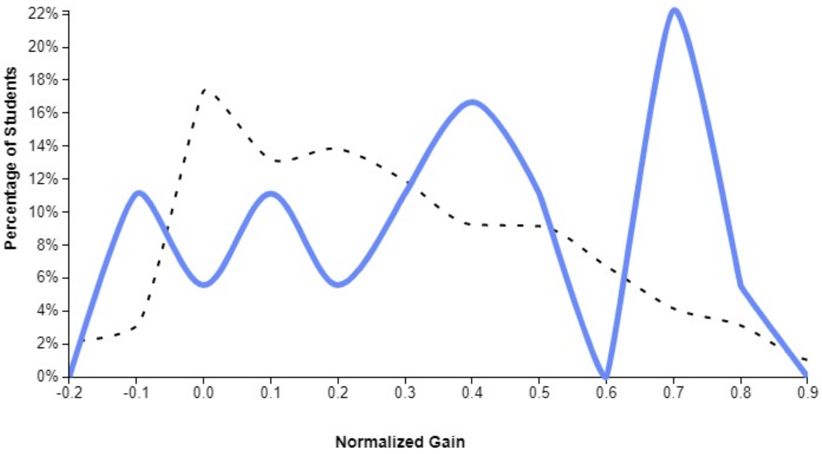


Figure 3. Percentage of students' normalized gains, (*N*=18).

The solid line shows JPA high school students, the dashed line represents all the students in the Physport database who took the FCI. The average gain seen in the dashed line is about 0.2 while that achieved by JPA students is about 0.4. Larger gains of about 0.7 were achieved by 22% of JPA students compared to the baseline of about five percent.

Below, the FCI results for the 11th and 12th grade AP students are shown separately. This data does not include the two students who switched from AP to Conceptual Physics in early November. For these two students one achieved a normalized gain of 19% and the other only 5%. These relatively small gains can perhaps be explained by the fact that they were in a mixed, but mostly AP class. Traditionally, Conceptual Physics is taught separately and is therefore paced slower. The two students found themselves in a hybrid environment that was less than ideal for them.

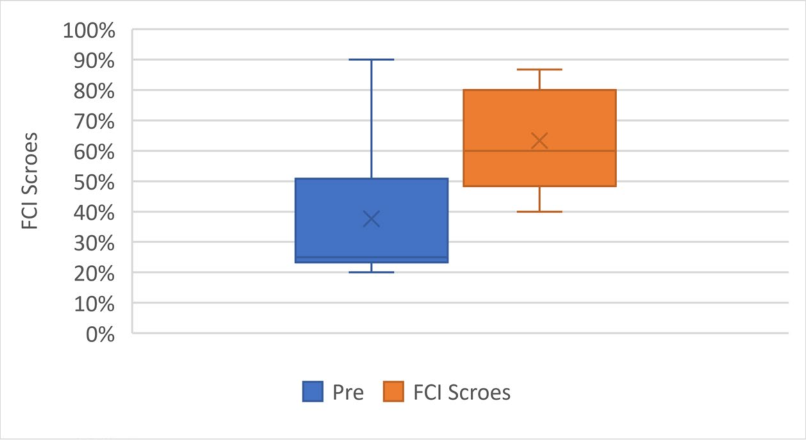


Figure 4. FCI pre and post test scores for 11th Grade AP Students, (*n*=12).

Here we see the range in the 11th grade shrank from 70 to 47. The median on the pretest was 39% which rose to 63% in the post. This constitutes average normalized gains of 41.8%. There is a slight drop in the highest score achieved due to Student 18.

The six 12th graders who tool Conceptual Physics last year generally scored higher than the juniors on the pre and post.

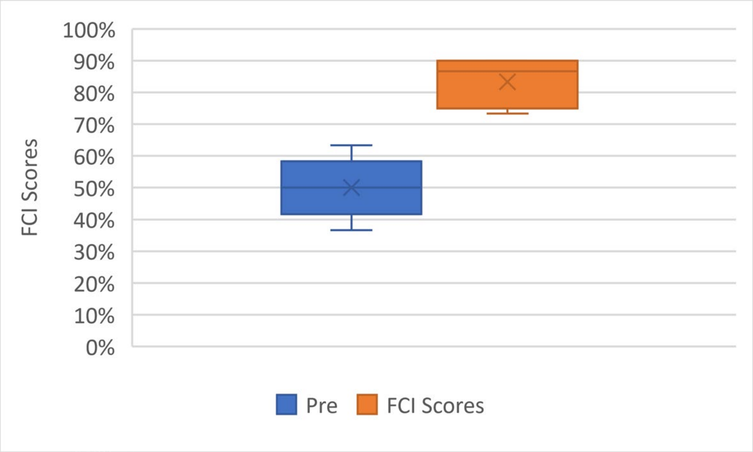


Figure 5. FCI pre and post test scores for 12th Grade AP Students, (*n*=6).

The 12th grade average rose from 50% to 83%. The range shrank from 27 to 17. The average gain was about 66%. This was their second time seeing many of the concepts. This explains why their pretest was higher and the fact that they were able to make greater gains, on average than the 11th graders. Much was review or deepening existing connections. In contrast, the 11th graders, had their first exposure to physics this year, and mostly online rather than on campus.

The graph below shows the average scores for major exams administered throughout the year. The assessments were meant to simulate AP level difficulty and scoring style. The graph shows raw unscaled class averages. Though the values are different for each administration of the AP exam, using typical scaling, raw scores of about 40% are usually considered an AP Physics 1 level 3. This is a passing score. Those of over 50% often equate to a 4. It is common for AP Physics teachers to scale results of AP Physics assessments to match the grade calculation typically used in student GPAs. A copy of the scaling table used can be found in Appendix F.

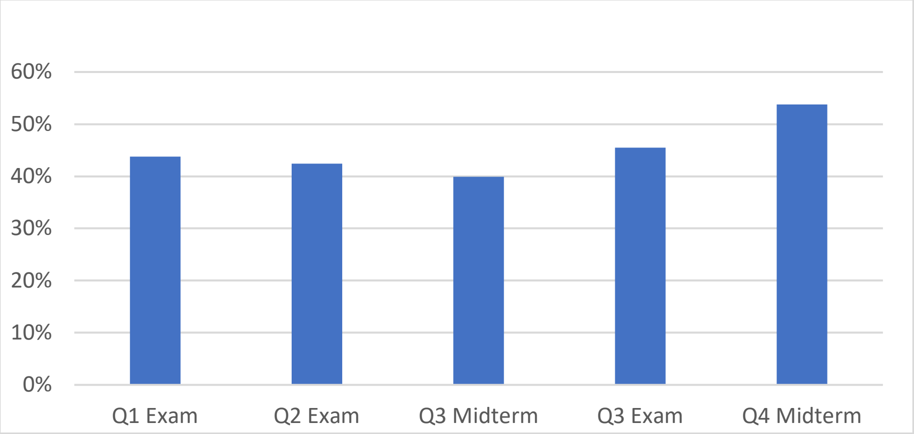


Figure 6. Several AP Physics classroom assessments, (*n*=16).

Across the major assessments the averages were generally passing AP Physics scores, though individual scores varied significantly. Several factors affected performance. Many students struggled with online learning. Virtually all students reported connectivity problems to varying degrees. Many reported reduced concentration and distractions at home. Many also reported feeling more disconnected, with fewer opportunities to connect and clarify misconceptions. Some reported significant frustration. Student 8 wrote:

> How do I not get overwhelmed when reading physics questions? My mind goes blank all the times after reading physics problems. I think it's just from the nervousness. I don't think physics and I are meant to be.

Student 10 wrote "I don't like completing long free response questions and when I do it, I get it all wrong, it feels terrible."

Lab work, essential for student understanding, was also greatly reduced during the periods online. Twenty-two percent of students cited in their survey that they missed labs. Indeed 50% indicated during interviews that lab work was their favorite part of physics class. Student Six reported that

> I think physics is a subject that requires labs and experiments to actually get the full concept [sic] so I think that having more labs is helpful. I understand that due to our current situation, we might not be able to do so.

The table below compares several measures of student achievement. All AP Students' ranking on the FCI posttest, the third quarter exam, and Albert practice are shown. Albert is a website that provides graded independent practice for students in a variety of subjects. As all three measures generate scores very differently, they could not be directly compared. Thus, the table compares class ranking in each. Note that students 14 and 17 are not included as they took Conceptual Physics.

Table 2. Class ranking in FCI Post Exam, Q3 Exam and Albert practice, (*n*=16).

Student	FCI Post	Q3 Exam	Albert	Student	FCI Post	Q3 Exam	Albert
S1	8th	9th	14th	S9	1st	6th	5th
S2	11th	7th	12th	S10	4th	4th	6th
S3	7th	6th	11th	S11	5th	3rd	7th
S4	6th	10th	8th	S12	9th	8th	10th
S5	2nd	2nd	4th	S13	13th	1st	2nd
S6	12th	13th	13th	S15	4th	12th	9th
S7	1st	11th	3rd	S16	10th	14th	12th
S8	3rd	14th	15th	S18	4th	5th	1st

100% of students were in the same quartile in at least two measures while 50% were in the same quartile in all three measures. This demonstrates student performance in physics was reasonably consistent

The graph below shows scores on selected renewable energy assignments. The assignments chosen combined physics and renewable energy concepts. The average scores shown include scores of all physics students.

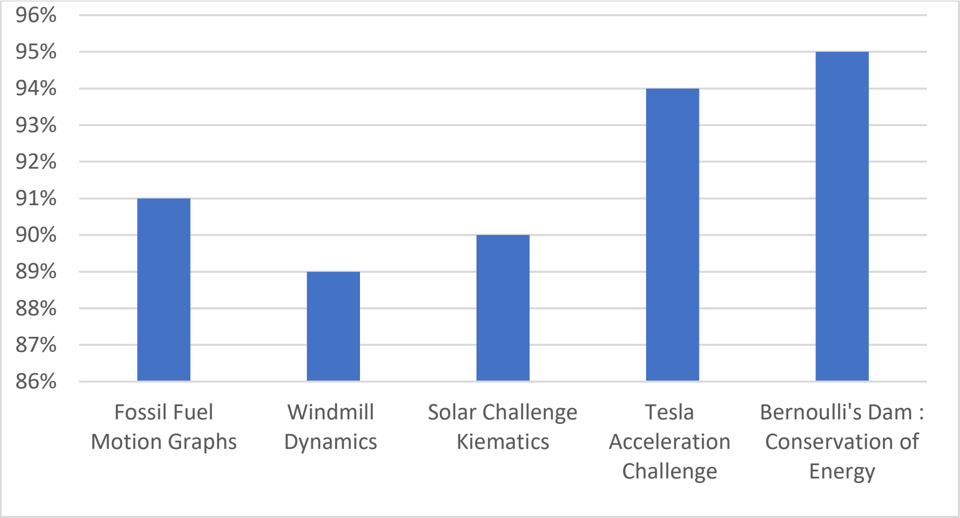


Figure 7. Scores on Selected Renewable Energy Assignments, (*N*=18).

The graph indicates generally high scores ranging from 89 to 95%. Generally, students performed well on these assignments. Enjoyment and a sense of meaning in completing these assignments varied. Student 6 reported the Solar Car Challenge was "fascinating." Students 4, 5, 9 all reported the Bernoulli assignment was particularly helpful. Many students reported frustration in building windmills at home. Others enjoyed the challenge. Student 14 reported that "I found it pretty fun to try to build our own windmill and so I think it would be fun to try more experiments and labs building our own models of renewable technologies."

Student Perception Results

In December a survey was administered asking questions on students' perception of learning physics through a renewable energy theme. The questions were grouped into three topics; renewable work is helpful in learning physics, physics is helpful in learning about renewables, and meaning and enjoyment. Students were directly asked how they felt about these questions as well as how meaning and or enjoyment related to particular assignments and task. (Appendix B).

The survey provided the following range of responses: “strongly disagree,” “disagree,” “neither agree nor disagree,” “agree,” and “strongly agree.” Two open ended questions at the end of the survey allowed students to write in additional comments. For analysis student responses were scored from negative two to positive two. A “strongly disagree” earned a score of negative two, a disagree negative one, “neither” a zero and so on. Student scores for each question within each topic were summed. If a student’s sum in that topic was a positive number, the student was considered to have an overall favorable response in that topic. If the sum was negative, generally unfavorable. The table below indicates the results of the class.

Table 3. Aggregated student perception data from survey, (*N*=18).

Renewable work is helpful in learning physics

Overall negative	4 students	22%
Overall neutral	1 student	6%
Overall positive	13 students	72%

Physics is helpful learning about renewables

Overall negative	1 student	6%
Overall neutral	1 student	9%
Overall positive	16 students	89%

Meaning and Enjoyment

Overall negative	1 student	6%
Overall neutral	6 student	33%
Overall positive	11 students	61%

The data shows that 72% of students found the renewable work helpful in learning physics and 89% found physics helpful in learning about renewables. Sixty one percent had an overall positive perception of meaning and enjoyment. At the time the survey was administered most students felt the renewable work enhanced their learning of physics in terms of achieving learning goals and developing a sense of meaning.

The individual results for the three questions included in the meaning and enjoyment topic are reproduced below.

Table 4. Results of all questions pertaining to meaning and enjoyment in survey, (*N*=18).

Overall, I have found that learning about renewable energy technologies has made physics class more meaningful?

Strongly disagree	Disagree	Neither	Agree	Strongly Agree
0	5.6	55.6	38.9	0

Overall, I find learning physics meaningful.

Strongly disagree	Disagree	Neither	Agree	Strongly Agree
5.6	0	38.9	50	5.6

Overall, I enjoy learning physics.

Strongly disagree	Disagree	Neither	Agree	Strongly Agree
5.6	11.1	66.7	16.7	0

Looking at the results of each question individually, we see 55.6%, 50%, and 66.7% chose “neither” in each question respectively. While the overall balance tipped in favor positive when summed together, it is worth noting that many students did not indicate a clear negative or positive result. Were these students finding a subtle way of saying “disagree?” Perhaps they really felt neutrally on the questions or found their meaning ambiguous.

In early March interviews were conducted. The questions used are reproduced in Appendix B. The questions provided the backbone of the interviews. Where appropriate, follow up questions were asked and digressions in the conversations were pursued as appropriate. In some cases, questions were omitted as students had already responded to them in previous discussion. Results from several of the most significant questions are displayed below as yes/no answers.

Table 5. Results from selected interview questions, (*N*=18).

Question	% Yes	% No
Do you find that learning about renewable energy helps you understand the physics concepts?	30	70
Do you find that learning physics helps you understand renewable energy topics?	77	23
Do you find learning physics meaningful?	94	6
Do you find learning about renewable energy topics meaningful?	77	23

During the interview, 30% indicated that the renewable energy work was helpful in learning physics. The figure is significantly less than calculated in the survey. This may result from the fact that more renewable assignments were conducted around the time the survey was given. Moreover, these were more closely directly tied to topics in AP Physics. The most recent renewable work completed at the time of the interviews was work on nuclear energy. This topic is not included in AP Physics 1.

Often during interviews when I asked if learning about renewables helped in learning physics I was told “No, Mr. Kahan it’s the other way around.” Indeed 77% indicated that learning physics elucidated renewable energy topics. This figure is consistent with the survey data which showed 89% of students had an overall positive view in this domain.

All but one student indicated that learning physics was meaningful. This shows an increase from 56% in the survey to 94% in the interviews three months later. Student 14, for example, despite having written a lot in her survey about frustration and stress said that physics is “without a doubt meaningful and important.” Forty four percent of students linked a sense of meaning in learning physics to professional, or academic goals. For those students considering jobs in STEM, especially engineering, the comments tended to be robust. For this group of students, the sense of meaning seemed obvious. Student 15 declared that learning physics was "meaningful for the moment…because of grades." The only student who stated that learning physics was not meaningful also tied her response to professional goals. She could not link the importance of physics to her chosen career.

Interviews were conducted on campus unlike the survey which was conducted during one of the school closures. This could explain why the data from the interview was more positive. It could also be the case that some students found it difficult to tell their teacher directly that class was not meaningful whereas choosing "neither" on a survey may have felt easier.

The overwhelming majority found learning about renewable energy meaningful. Student Six, when asked if learning about renewables was meaningful, stated "most certainly, we are approaching a stage where it might be too late, maybe we can still change." Student 12 echoed this sentiment saying that "we need to start learning about solutions." Student Five explained that learning about renewables in conjunction with the physics concepts was helpful. He stated that "it helps me see why we need renewables." He linked this to the Bernoulli-hydroelectric dam assignment.

Only four students indicated that learning about renewable energy was not meaningful. Of those four, all indicated that while they found the topic interesting, they could not say it was meaningful as they believed climate change simply cannot be stopped.

Teacher journal entries show a consistent pattern of positive remarks during periods where renewable assignments were used. This was especially true for those lessons that included discussion elements, either on or offline.

Difficulties noted in the journal rarely concerned student responses to assignments. Rather there were several references to times where I was the bottleneck, not producing renewable linked work fast enough to follow up on student progress.

CLAIM EVIDENCE AND REASONING

Claims From the Study

The data show three key findings. The renewable theme could be incorporated into the existing physics curriculum without necessitating the development of new units. The renewable theme neither improved nor interfered with the learning of fundamental physics concepts. Lastly the data suggest that the theme provided an additional layer of meaning and relevance to the class, potentially enhancing the student experience.

The theme was developed using assignments that tied renewable concepts to physics principles. Many of these were inspired by or borrowed directly from work completed in the PHSX 597, Physics of Renewable Energy class, taught by Dr. Nick Childs. Others were inspired by common physics problems found in standard curriculum materials. These assignments easily fit into the curriculum. From the perspective of the learner, these problems were like many others encountered in terms of the amount of reading required and the application of relevant skills. For instance, in the Fossil Fuel Motion Graphs, students plotted graphs using kinematic data. Unlike similar problems, however, students then calculated CO_2 emissions from the graph, and compared emissions from a car that was on the highway versus one idling in traffic. The second part of the assignment added depth and context. This provided a reason to study the physics but did not robustly enhance the acquisition of physics concepts. In reference to this assignment, Student Two stated “the topic was interesting but not helpful for AP Physics.” Other assignments such as the windmill construction or the hydroelectric dam analysis were similar in this regard.

Students completed renewable assignments quickly, usually scoring high marks as indicated in Figure 7. Students participated vigorously in online and offline renewable discussions. Students covered fossil fuel usage, wind, solar, hydroelectric, and nuclear power. None of this seemed to burden students. Indeed, the bottleneck for these assignments was on the teacher side rather than the students. I struggled to prepare enough of these assignments rapidly. This delay necessitated extending the study period, which likely reduced the efficacy of the treatment. A more immersive, shorter treatment would likely have proven more effective. As Jensen (2008) points out, emotion is the mind's way of flagging certain memories as important. It would have been easier to build up and maintain an emotional momentum in a shorter more intense treatment period. In preparation for next year, more renewable assignments will need to be prepared. This will entail reviewing many assignments currently used and then adding a renewable context to them where appropriate.

Overall, the results are encouraging. Despite the many pandemic related challenges for myself and students the theme worked. Students learned about a variety of renewable technologies and most were able to link these to the physics in the curriculum. The Force Concept Inventory and exam data demonstrate that students made satisfactory gains in their learning of fundamental physics.

It is worth noting that the *average* trend was one in which the theme did not enhance and did not interfere with the acquisition of physics concepts. Analysis of specific assignments and individual results paint a more nuanced picture. Some students struggled to make connections. Student One, referring to the windmill assignment, said "to this day, I don't see the point." Several others echoed this sentiment. Student 16 stated during the interview that “I can’t connect between physics and renewable energy,” then in the next question corrected herself stating “even though I don’t like it I can see the connection.” Additional student support was needed in preparing the windmills, especially the axles. Ensuring smoother operation would likely have lessened some of the affiliated stress which I believe underlies the students’ comments. The connections between the physics and the renewable technologies also need to be underscored. This can be accomplished by directly targeting the issue in classroom discussions and reflections.

For some, the opposite was true. Student Five spoke fondly about discovering in one of the assigned readings that carpooling had a lower carbon footprint than cycling. He appreciated seeing just how nuanced and complex the issue of renewable energy is. Student 18, of his own volition, made his windmill into generator using electrical equipment lying around his home. Student 13 in his notebook wrote that the “windmill lab shows us the practical side of learning about velocity and acceleration.” Presumably for this student, the real-life application of physics concepts added depth to the experience. Here we see a diversity of reasons why 77% of the class indicated in the interviews that they found learning about renewables meaningful.

The first sub question asked, “to what extent can a renewable energy theme render physics class more meaningful?” The survey data showed 61% had an overall positive sense of meaning and enjoyment. The interview data showed 94% of the class found physics meaningful and 77% found learning about renewable energy meaningful. I am cautiously optimistic about these findings as they do seem to indicate that the renewable theme does in fact render physics class more meaningful.

Still, I am mindful of the fact that on the survey, 55% chose “neither,” and 5% chose “disagree” in answering whether they found renewable energy made class more meaningful. To whether physics was meaningful, almost none disagreed, but 39% chose “neither,” and 67% chose “neither” in answering whether they enjoyed learning physics at all. These survey figures seemed to have improved dramatically by the time the interview was conducted but many potentially confounding variables are present.

The fact that the survey followed a period of school closure, the interview a period of on campus learning, could be a significant factor. Students generally missed coming to school. Students may have been confused about the term meaningful. During the survey there was no way to ask. During the interview, this term was explained, and students could ask questions. They also heard the responses of others. The presence of the teacher during the interview is an obvious confound that likely alters student responses, though it may be difficult to say how. Likewise, the grouping of students in interviews likely conditioned their responses. Students may have parroted, been inspired by or disagreed with one another as a result of their existing relationships rather than their genuine responses to the content.

Many student responses were likely tied to factors outside the research questions. Student One chose “neither” for every question on the survey. Student One struggled this year. Conceptual Physics would likely have been a better fit for her and may have colored her experience of the class. Student 15 chose “disagree” or “strongly disagree” for every question on the survey. One of the open-ended survey questions asked how physics class could be improved. She responded “I can't think of anything at the moment to enjoy learning physics. I just need to be born with the capacity to understand it, but that isn't possible." During the interview I pressed her on some of these points. Grade stress seemed to be the essential problem. AP Physics is not a high scoring class. It is difficult to earn an A in this subject. Student 15 is in 11th grade, mindful of university applications and found the grade related stress significantly diminished her enjoyment. She stated that at least for herself, feedback was helpful, but seeing grades was demoralizing. Student 8 commented that she enjoyed learning about renewables independently but found the pressure tied to grading stressful.

A source of meaning which emerged during the interviews was the difference in perception of renewable energy and physics that students had compared to their parents and other community members. Many related that they tried with varying degrees of success to work towards positive change in their communities. Student 14, orphaned, who lives in a Buddhist pagoda related how when talking to the monks "I try to tell them about burning trash… they don't listen." Students Eight and 17 also discussed having very different views from their parents regarding science and the need for environmentally friendly behaviors. Student 17 stated that "we will live differently than they did" meaning her generation would be more conscious of environmental issues such as littering and burning garbage than her parents' generation. Student Eight vented frustration about learning seemingly "useless" physics concepts, but then related with pride that she was often able to explain scientific phenomena to her family at home.

The perceived utility of concepts learned often emerged in conversations in students. As stated previously, the most enthusiastic students had direct professional or academic links to renewable energy or physics. Student 18, an aspiring environmental engineer had glowing comments in his survey. The aspiring engineers were also quite positive. Consider Student 4 who stated “yes, nearly everything is tied to physics, I want to be an engineer, physics is an important part of that.” In contrast Student One stated that “No, for me physics does not connect with what I want; to be a doctor.” Criticism flowed from students who perceived the course content to consist of complicated or obscure ideas distant from quotidian life. Though kinematics and dynamics are as fundamental in physics as can be, Student 15 stated that “you don’t need this stuff when you go to the market, it’s useless.” Contrast this with Student 13’s statement “when you ride a bike and start thinking physics, it’s really interesting…” Student perception of utility is clearly a critical factor. In the future I will have to work more deliberately to ensure that each student can make personal connections between their own academic and professional goals and the learning goals of the course. Futoran (2018) stresses the need for the repeated use and analysis of illustrative examples to connect students to content. This is an avenue for growth next year.

The findings are consistent with the existing body of research. Dewey wrote that a sense of meaning will result when teachers lead students to form their own value judgments from learning experiences (Dewey, 1916). Student quotes and corresponding survey and interview data corroborate this. Consider Students One and 15 who struggled to connect with the learning activities compared to Students 13 and 18 who did and consequently found the course more meaningful.

Kolb tied perception of meaning to problem solving (Burket & Wilson, 1989) as does brain-based research (Jensen, 2008.) The best practice in physics education literature cited earlier points to the importance of problem solving. The fourteen students who stated learning about renewable energy is meaningful believe climate change is a problem that can and must be tackled. They saw the inclusion of the theme as a small step towards a solution. The four who believe the problem to be intractable did not find learning about it as meaningful. The fatalism expressed by these students was concerning. It was not something I expected from those so young. This issue needs to be addressed in the coming years.

Literature on thematic teaching offers the potential benefit of increased engagement and positive student perception (Lung, 1999). That 94% of students said learning physics is meaningful, and the many positive student comments support this view. A theme which resonates with students can enhance the educational experience.

Value of the Study and Considerations for Future Research

The third research question asked, "How has the inclusion of a renewable energy theme in physics class impacted me as a teacher?" The impact of the project and this atypical academic year have been profound.

The project, as proof of concept for thematic teaching is significant. It offers the possibility of including more content without needing to rush through the existing curricula to add additional units. Including a theme can add depth and context to material that often seems abstract to students. Indeed, when I asked students if next year's class should learn about renewables, they all agreed that the theme should continue. While the project focused on renewable energy, many themes could work. Some suggested space science or health as possible choices. This opens doors for collaboration between subjects. For example, the course could follow a theme that matched one from a mathematics or humanities course. Having completed this project, the challenges and benefits of thematic teaching are now familiar. Further experimentation in this domain is no longer daunting.

It was encouraging to see students connecting to the renewable energy theme. Students find it interesting and meaningful and we do not yet have an adequate place for climate change in the curriculum. I feel a moral and professional imperative to correct this. While the project showed that the thematic approach is feasible much work remains. Better assessments of gains made in renewable energy are needed. An equivalent of the FCI for renewables needs development. Moreover, the renewable curriculum itself needs definition. More assignments and activities are needed, and the content standards need clarity. Promising tasks like the windmill assignment need improvements to render them more student friendly and useful. Many students, for example, had trouble creating a smooth axle for the windmills. Readings and discussions played an important role in setting the theme. Their selection should be less haphazard and more aligned with a renewable curriculum. Tied to this would be a renewable energy survey to be conducted before class begins. This would yield a baseline for measurement and provide useful feedback.

Student 15 stated that "yeah, its meaningful, (learning about renewables) but we don't live it." Ways for students to tackle climate change directly, in their own lives should be studied and where possible included. This is consistent with the findings in McNeal and Petcovic (2019) that stressed the importance of students collecting their own data, preferably within their own communities.

The renewable energy theme could also be included in middle school. I originally intended to include eighth grade physical science in the study. This class took a simplified FCI, and completed similar assignments including a survey. Until November, however, they only had online sessions once a week. This proved devastating to their learning and virtually all the fall semester's content needed to be retaught in the spring semester. As a result, I discontinued their participation in the study after December to allocate all time towards meeting basic content standards. Nonetheless initial data that was gathered was encouraging. Many of the same trends described in the high school group seemed prevalent. Next year, eighth grade will also include a renewable energy theme. Even if learning is online in the fall, they are expected to have five periods worth of live lessons.

Much was learned through the Force Concept Inventory and Physport. I had not used it previously and these are wonderful resources. Teaching in an American school in Cambodia can feel isolating. Determining what is normal or where students should be is sometimes difficult. The FCI and Physport database allow me to understand where my students fit globally.

Impact of Action Research on the Author

Data collection in the project has been very valuable. I now have much more experience with surveys, interviews, CATs and other techniques. More importantly I feel much more confident in knowing what to do with the information generated by these and other measures of perception and achievement.

The interviews took approximately five hours to complete. Analyzing the data from the interviews and the survey took more time. It was refreshing to be the one listening rather than talking for so long. Students provided mature and intelligent perspectives on our class. This information has rendered me more sensitive to the student experience of my own classes. It felt great to see successes highlighted, and I am very grateful for their having pointed out many areas where growth is needed. Some of these include reducing lecture and or making it more individualized. More guidance during lab work for some students, and more thorough processing of all work sent to students was also recommended. Student 18 stated that during lab work “you just let us go.” While I do value their developing their independence, especially in lab work more guidance in some cases may be called for. In the windmill assignment, for example, a more hands on approach might have led to better outcomes.

Another key finding was inadequate differentiation online. Student Nine stated in his survey that he wished there would be less review during online class. He expressed a desire to go faster and deeper. In contrast Students One and 17 asked that we slow down during these sessions. Student 16 complained that “the 12s always seem to know what’s going on and I don’t.” All of this points to inadequate differentiation. Group discussions often did not efficiently meet the needs of individual students.

Differentiation came much more naturally in class rather than online. It is much easier to see who is struggling in person. Students provide so much information in body language and facial expressions, in quick comments in class and in their interactions with each other. In class, responding to all this information is second nature and I was not aware of how much my practice relied on it. If some students struggle it is easy to set the rest on an independent task and take fifteen minutes of small group time to clarify something. In doing so other students eavesdrop and learn or ask to join such sessions. So much of the informal information provided by students is lost online. I need to be much more proactive in soliciting it, in mining it from assessment data and responding accordingly when teaching online. I need to develop better ways to differentiate and provide different content, practice and assessments based on where students are. More small group discussions should be organized so that advanced students can dive deeper and struggling students receive more support.

The focus on students' perceptions and experience of meaning has also been very valuable. Linking this to achievement data is important. This project provided a lot of practice in this regard. It has also made me more empathetic to students. Many students imagine physics is helpful because they think they will use it professionally. Conversely, if they suppose they will never again need to determine the acceleration of a block on a ramp then the subject becomes useless. The value in knowing how the world works and thus living a more examined life, to borrow Socrates' phrase, is self-evident to most teachers but rather opaque to most students. That physics sharpens the mind, making it more analytical, critical, and creative is a message that needs to be better disseminated. I will need to make this message more intelligible and resonant to my students.

In listening to students' perceptions on why and how they learn, my own sense of meaning in teaching has been invigorated. We spend most of our waking lives at work. Students spend about 180 hours a year in my class. If we assume an average of an hour of work completed at home for each period, this is 360 hours, or 6,480 hours for the whole class. Is all that time is being used in the most meaningful way? How many hours could be gained by reducing the friction caused by emotional stress, or more thoughtful planning. This project has compelled me to consider these questions and has instigated personal and professional reflection that I suspect will continue long into the future.

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APPENDICES

APPENDIX A

SUVEY QUESTIONS

Today we are going to fill out a survey regarding physics and renewable energy and what we have learned in class. This optional and you do not have to participate if you do not feel comfortable doing so or do not want to. Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way**.**

1. I found the examples related to renewable energy in warmups helpful in learning **physics.**
   Strongly disagree disagree neither agree nor disagree agree strongly agree

2. I found the examples related to renewable energy in practice problems helpful in learning **physics.**
   Strongly disagree disagree neither agree nor disagree agree strongly agree

3. I found the examples related to renewable energy in warmups helpful in learning about **renewable energy technologies.**
   Strongly disagree disagree neither agree nor disagree agree strongly agree

4. I found the examples related to renewable energy in practices helpful in learning about **renewable energy technologies.**
   Strongly disagree disagree neither agree nor disagree agree strongly agree

5. I found the Fossil Fuel Motion graphs activity helpful in learning **kinematics.**
   Strongly disagree disagree neither agree nor disagree agree strongly agree

6. I found the Fossil Fuel Motion graphs activity helpful in learning about the problem renewable energy technologies are trying to solve
   Strongly disagree disagree neither agree nor disagree agree strongly agree

7. I found the windmill labs helpful in learning about **kinematics.**
   Strongly disagree disagree neither agree nor disagree agree strongly agree

8. I found the windmill labs helpful in learning about **renewable energy technologies**

Strongly disagree disagree neither agree nor disagree agree strongly agree

9. Overall I have found that learning about renewable energy technology has helped me understand **physics concepts**
   Strongly disagree disagree neither agree nor disagree agree strongly agree

10. Overall, I have found that learning physics has helped me understand about **renewable energy technologies**?
   Strongly disagree disagree neither agree nor disagree agree strongly agree

11. Overall, I have found learning physics meaningful?
   Strongly disagree disagree neither agree nor disagree agree strongly agree

12. Overall, I have found that learning about renewable energy technologies has made physics class more **meaningful**?
   Strongly disagree disagree neither agree nor disagree agree strongly agree

13. Overall, I enjoy learning physics.

Strongly disagree disagree neither agree nor disagree agree strongly agree

APPENDIX B

INTERVIEW QUESTIONS

Today we are going to ask some questions regarding physics and renewable energy and what we have learned in class. This optional and you do not have to participate if you do not feel comfortable doing so or do not want to. Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1. What aspects of physics class do you enjoy the most?
    a. Can you tell me more about (variable cited in previous question)?
2. What aspects of physics class do you enjoy the least?
    a. Can you tell me more about (student variable cited in previous question)?
3. Did you find the home laboratory activities helpful in learning physics? Why or why not?
4. Did you find examples about renewable energy in practice problems practices and warm-ups helpful in learning physics?
5. Did you find the home laboratory activities helpful in learning about renewable energy? Why or why not?
6. Do you find that learning about renewable energy helps you understand the physics concepts?
7. Do you find that learning physics helps you understand the renewable energy topics?

We're going to define meaningful as "serious, important, or worthwhile."

8. Do you find learning physics meaningful?
9. Do you find learning about renewable energy topics meaningful?
10. Do you find the home laboratory exercises meaningful?
11. Is there anything else about the class, physics or renewable energy that you would like to share?

APPENDIX C

PLANNED AND ADMNISTERED RENEWABLE ASSIGNMENTS

Status	Unit	Renewable Energy Assignment
Administered	Kinematics	Kinematics Fossil Fuels and Motion Graphs
Administered	Kinematics	Solar Challenge: Kinematics
Administered	Dynamics	Windmill lab 1-linear kinematics
Administered	Dynamics	Windmill lab 2 acceleration
Planned Only	Dynamics	Green elevators
Planned Only	Circular Motion/Gravity	Windmill 3s-circular kinematics
Planned Only	Energy	Windmill 4 power measurement
Administered	Energy	Hydroelectric dam assignment (Bernoulli)
Administered	Rotation	Flywheel Reading
Administered	Rotation	Turbine analysis and presentation (Conceptual Physics only)
Planned Only	Rotation	Windmill 5 angular kinematics
Planned Only	Rotation	Pelton wheel analysis
Planned Only	Rotation	Fly wheel analysis
Administered	Nuclear Energy	Nuclear reading
Administered	Waves	Solar power reading

APPENDIX D

IRB EXEMPTION

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

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MEMORANDUM

TO: Adam Kahan and Walter Woolbaugh

FROM: Mark Quinn Mark Quinn CJ
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: October 19, 2020

RE: *"The Impact of Including a Renewable Energy Theme on Physics Education and Perception of Meaning" [AK101920-EX]*

The above research, described in your submission of October 18, 2020, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

X (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

X (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation; and (iii) the information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by section 16.111(a)(7).

____ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

____ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

____ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

____ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

APPENDIX E

INDIVIDUAL FCI SCORES AND GAINS

INDIVUAL FCI SCORES AND GAINS FOR 11th AND 12th GRADERS

	PRE 30pts	POST 30 pts	PRE%	POST%	Normalized Gains
Student 1	7	17	23%	57%	43.48%
Student 2	7	13	23%	43%	26.09%
Student 3	13	19	43%	63%	35.29%
Student 4	15	22	50%	73%	46.67%
Student 5	14	26	47%	87%	75.00%
Student 6	8	12	27%	40%	18.18%
Student 7	11	27	37%	90%	84.21%
Student 8	22	26	73%	87%	50.00%
Student 9	19	27	63%	90%	72.73%
Student 10	9	24	30%	80%	71.43%
Student 11	16	23	53%	77%	50.00%
Student 12	6	16	20%	53%	41.67%
Student 13	11	9	37%	30%	-10.53%
Student 14	10	11	33%	37%	5.00%
Student 15	7	24	23%	80%	73.91%
Student 16	7	15	23%	50%	34.78%
Student 17	4	9	13%	30%	19.23%
Student 18	27	24	90%	80%	-100.00%

Whole Class normalized gain: 40%

INDIVUAL FCI SCORES AND GAINS FOR 11th GRADERS

	PRE-RAW	POST RAW	PRE%	POST%	Normalized Gains
Student 1	7	17	23%	57%	43.48%
Student 2	7	13	23%	43%	26.09%
Student 3	13	19	43%	63%	35.29%
Student 6	8	12	27%	40%	18.18%
Student 8	22	26	73%	87%	50.00%
Student 10	9	24	30%	80%	71.43%
Student 12	6	16	20%	53%	41.67%
Student 15	7	24	23%	80%	73.91%
Student 16	7	15	23%	50%	34.78%
Student 18	27	24	90%	80%	-100.00%

11^{th} grade AP normalized gain: 41%

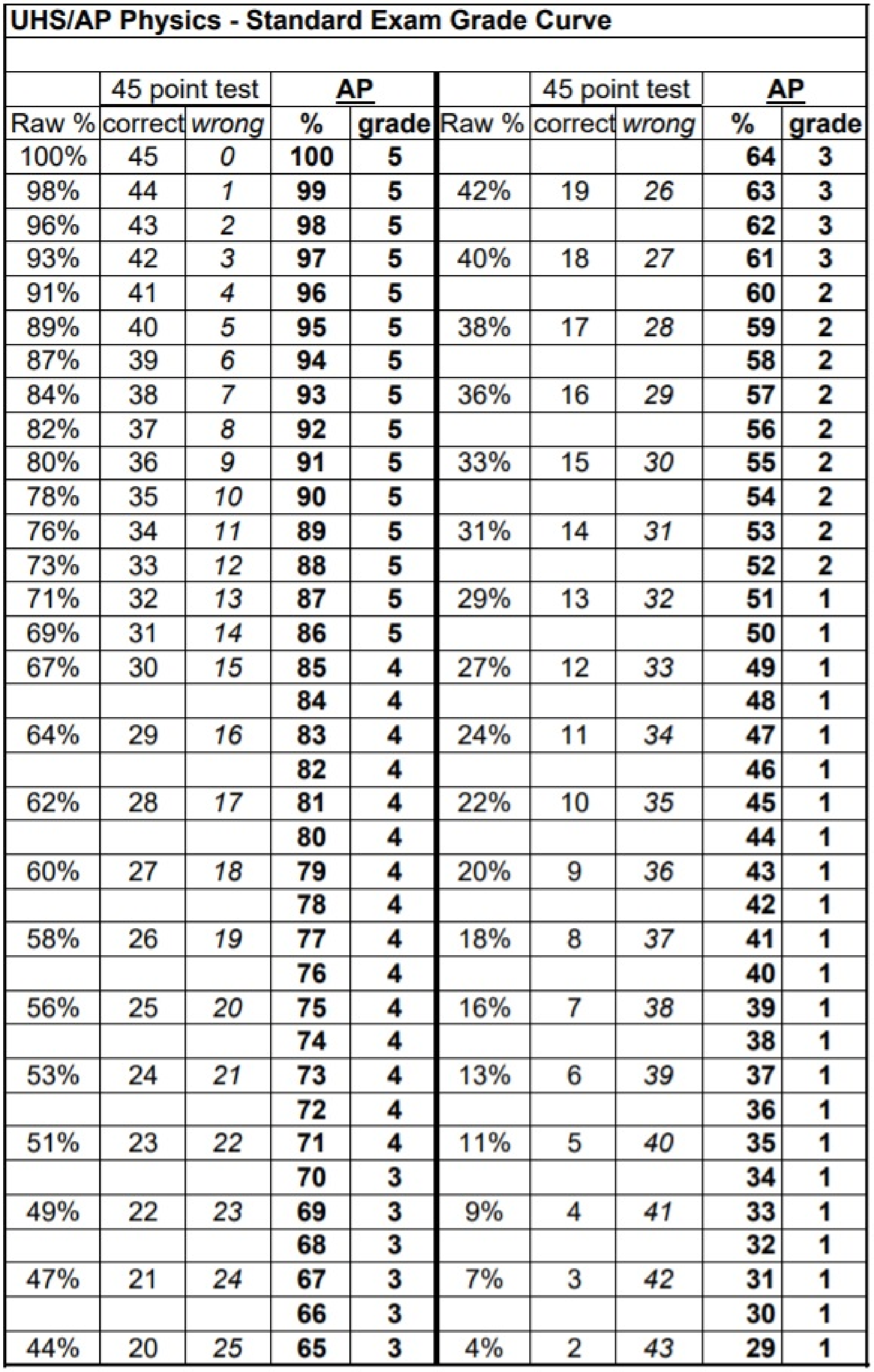
INDIVUAL FCI SCORES AND GAINS FOR 12^{th} GRADERS

G12 ONLY	PRE-RAW	POST RAW	PRE%	POST%	Normalized Gains
Student 4	15	22	50%	73%	46.67%
Student 5	14	26	47%	87%	75.00%
Student 7	11	27	37%	90%	84.21%
Student 9	19	27	63%	90%	72.73%
Student 11	16	23	53%	77%	50.00%
Student 13	11	9	37%	30%	-10.53%

12^{th} Grade normalized gains: 51%

APPENDIX F

AP GRADING SCALE



UHS/AP Physics - Standard Exam Grade Curve

	45 point test		**AP**			45 point test		**AP**	
Raw %	correct	*wrong*	**%**	**grade**	Raw %	correct	*wrong*	**%**	**grade**
100%	45	*0*	**100**	**5**				**64**	**3**
98%	44	*1*	**99**	**5**	42%	19	*26*	**63**	**3**
96%	43	*2*	**98**	**5**				**62**	**3**
93%	42	*3*	**97**	**5**	40%	18	*27*	**61**	**3**
91%	41	*4*	**96**	**5**				**60**	**2**
89%	40	*5*	**95**	**5**	38%	17	*28*	**59**	**2**
87%	39	*6*	**94**	**5**				**58**	**2**
84%	38	*7*	**93**	**5**	36%	16	*29*	**57**	**2**
82%	37	*8*	**92**	**5**				**56**	**2**
80%	36	*9*	**91**	**5**	33%	15	*30*	**55**	**2**
78%	35	*10*	**90**	**5**				**54**	**2**
76%	34	*11*	**89**	**5**	31%	14	*31*	**53**	**2**
73%	33	*12*	**88**	**5**				**52**	**2**
71%	32	*13*	**87**	**5**	29%	13	*32*	**51**	**1**
69%	31	*14*	**86**	**5**				**50**	**1**
67%	30	*15*	**85**	**4**	27%	12	*33*	**49**	**1**
			84	**4**				**48**	**1**
64%	29	*16*	**83**	**4**	24%	11	*34*	**47**	**1**
			82	**4**				**46**	**1**
62%	28	*17*	**81**	**4**	22%	10	*35*	**45**	**1**
			80	**4**				**44**	**1**
60%	27	*18*	**79**	**4**	20%	9	*36*	**43**	**1**
			78	**4**				**42**	**1**
58%	26	*19*	**77**	**4**	18%	8	*37*	**41**	**1**
			76	**4**				**40**	**1**
56%	25	*20*	**75**	**4**	16%	7	*38*	**39**	**1**
			74	**4**				**38**	**1**
53%	24	*21*	**73**	**4**	13%	6	*39*	**37**	**1**
			72	**4**				**36**	**1**
51%	23	*22*	**71**	**4**	11%	5	*40*	**35**	**1**
			70	**3**				**34**	**1**
49%	22	*23*	**69**	**3**	9%	4	*41*	**33**	**1**
			68	**3**				**32**	**1**
47%	21	*24*	**67**	**3**	7%	3	*42*	**31**	**1**
			66	**3**				**30**	**1**
44%	20	*25*	**65**	**3**	4%	2	*43*	**29**	**1**

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APPENDIX G

BERNOULLI’S THEOREM AND A HYDROELECTRIC DAM

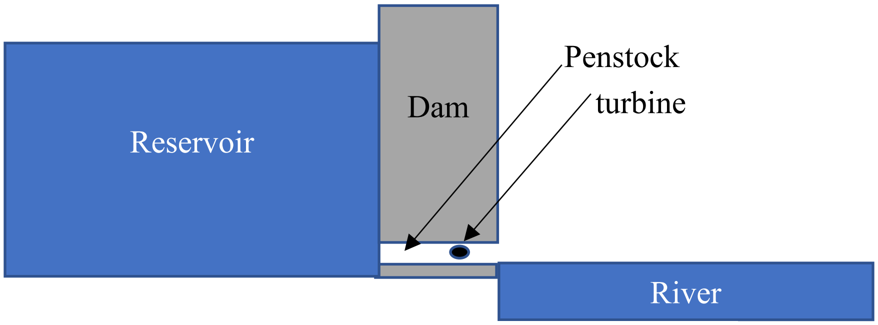


Figure 1: A schematic of a hydroelectric

Figure 1 shows a diagram of a hydroelectric dam. When electricity is needed, water is allowed to flow from the reservoir into the penstock. There the water will turn a turbine which is connected to a generator. The turbine blades have a radius up 5m and the depth of the reservoir is 200m.

Bernoulli's equation

$$P_1 + \rho g h_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g h_2 + \frac{1}{2}\rho v_2^2$$

1. What is the velocity of the water that hits the turbine?
2. Find the mass flow rate of the turbine. *(This is given by $\rho A v$ where A is the area of the turbine and v is the velocity of the water before it hits the turbine)*
3. Determine the power available to the turbine from the water. *(This is given by $1/2\rho A v^3$)*
4. The turbine extracts 90% of the power from the water. How much power remains in the water? Use this to determine the velocity of the water exiting the dam.

APPENDIX H

WINDMILL ASSIGNMENT

WINDMILL LIFT: A DEVICE FOR HOME PHYSICS INVESTIGATIONS

Objective:s

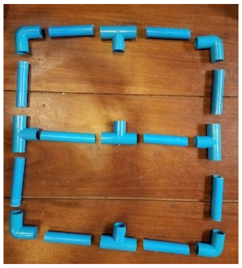
Build a windmill lift out of PVC pipe to explore a variety of introductory physics concepts. The purpose is to explore physics while simultaneously learning about renewable energy technologies.

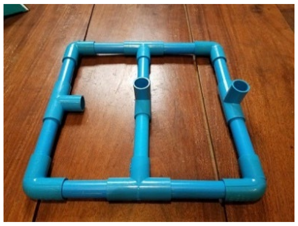
Materials:

- 2.5 meters of 18mm PVC cut into:
    - 11x 10cm pieces
    - 2x 50 cm pieces (extra PVC leaves margin for error)
- 6x 18mm T connectors
- 5x 18mm elbow connectors
- 1 round chopstick
- 1 plastic bottle *(liter size or larger is preferable. This item is not provided)*
- Masking tape
- String or fishing line
- Measuring tape or ruler
- Scissors
- A heavy nut or other small objects of known mass
- If cutting PVC a small saw
- Hot glue gun (optional)
- Sticky tack (optional)
- Skewer (optional)
- Plastic cup (optional)
- Two heavy textbooks

Base Instructions:

1. Layout 10, 10 cm pipe sections, 5 T connectors and 4 elbow pieces as shown in figure 1.
2. Connect them together so they form a square base with section of pipe running through the middle of the square.





3. Adjust the T connector in the center of the square such that the empty hole faces upwards. Do the same for one more T connector.
4. Insert the two longer PVC pipe into both T connectors.

5. Add and elbow connector to the pipe on the outside of the square. Add a T connector to the pipe coming out of the center of the square.

6. Use the last 10cm pipe to connect both long pipes.
7. Press on all connections so that the pipes all fit tightly together. Now the base is complete.

Windmill Blade and Axle Instructions:

1. Remove the spring mechanism and ink from the pen.
2. Tape the pen tube to the side of the T connector at the top of the base. This will hold the axle.

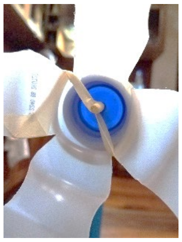
3. Rinse out and dry an empty plastic bottle.
4. Cut off the bottom of the bottle.

5. Cut the bottle lengthwise as shown.
6. Cut 3 more times such that you divide the bottle into 4 equal sections. These will be your blades. Press back on the blades to flatten them out.

7. Unscrew the bottle cap. Use the scissors or any sharp object to poke a small hole in the center of the cap.

8. Insert the chopstick into the hole. This is the axle for your blades.
9. Use tape to secure the axle to the cap. To do this wrap two piece of tape around the chopstick as shown.
10. Then stick the other side of the tape to the cap or blade.

11. Repeat this step with two other pieces of tape. *(The tape must pull tightly on all sides of the axle to keep it straight)*
12. Steps 9 through 11 can be completed with a hot glue gun instead of tape if you have one or even sticky tack.



13. Insert the chopstick into the pen tube.
14. Cut a 60 cm piece of string. Tie one end to the axle and the other to the nut. If you like, construct a baske t for the masses attach the other end of the string to the basket.

Cap with hot glue

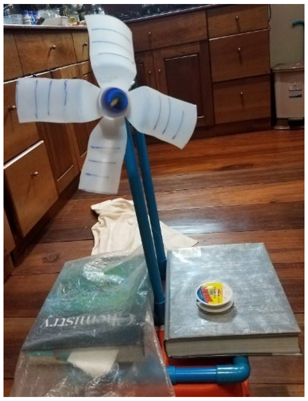
Optional Basket Instructions:

1. Poke a hole into a small plastic cup or container.
2. Then poke another hole directly opposite to it.
3. Insert a skewer into the holes.

Optional basket

Operation:
To operate the windmill place, it in front of a fan. You may need to adjust the height of the fan or place the windmill on a chair. The blades should spin when the fan is on. Note that:

- A light tap to the blades may be required to overcome static friction to get the blades going.
- Placing heavy textbooks on the base will reduce shake and improve performance



Textbooks holding the base down

Windmill Lab # 1.

Windmills are a great source of renewable energy with lots of potential for expansion in the more northern and southern latitudes as well as coastal regions. The global production of wind power was about 486 gigawatts as of 2016 and is increasing[1].

Materials:

- Assembled windmill
- stopwatch or some timekeeping device
- graph paper
- ruler
- fan

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[1] https://gwec.net/global-figures/wind-in-numbers/#:~:text=The%20record%20number%20of%2055.6,at%20the%20end%20of%202016.&text=In%202016%2C%20wind%20power%20avoided,tonnes%20of%20CO2%20emissions%20globally.

Directions

1. Set up the windmill in front of a fan. Be sure the nut is tied to the string on the windmill.

2. Place the windmill close enough to the fan such that the wind from the fan will spin the windmill blades slowly but with enough force to lift your washer. A slow lift will make data collection much easier. This will take some trial and error.

3. Determine the average speed of the washer as it is lifted.

4. Gather enough data to generate a position time graph modeling the motion of the washer as it is lifted.

5. Generate the position time graph.

6. Add a linear line of best fit to your graph. (your data may be quadratic). Find the slope of this line. Compare it with the velocity you found in step 3.

7. Post your answers from steps 3 to 6 in Google Classroom.

8. Reach out if you need help, are stuck or have any questions or comments.