1. Significance.

1.1 Need, Current Practice, and Proposed Intervention. America needs new ideas regarding sustainable energy sources and citizens need to make informed choices about energy use. The ability to think clearly about energy is defined as essential knowledge in the Department of Energy document, *Energy Literacy: Essential Principles and Fundamental Concepts for Energy Education* (2012). “Energy and matter: Flows, cycles, and conservation” is one of the targeted seven concepts that cross science disciplinary boundaries within *A Framework for K-12 Science Education* (NRC, 2012). Because the new Next Generation Science Standards (NGSS) were based on that framework, energy standards are found within all science content domains in the NGSS (NGSS Lead States, 2013). However, analysis of a specific instance of energy transfer depends greatly upon which components are included in the system. For example, when evaluating the energy efficiency of an electric car, is one considering only the fully charged car or is one including the burning of coal at the power plant, along with all the energy transformations that produced the electricity that charged the car? Therefore, a second cross-cutting concept within the *K-12 Science Education Framework* and the NGSS is “Systems and System Models.”

The NGSS signal a turning point in education policy making. These standards recognize that energy provides a “unifying interpretation” of the changes occurring in physical systems, whether in biology, chemistry or physics (Papadouris and Constantinou, 2013, p. 215.) Thus, creation of fully developed curricula to address NGSS science standards is a high priority, including by this solicitation (IES, Education Research Program 84.305A, 2014). Traditionally, teaching about energy has been largely declarative (something teachers call “hand-waving”) with presentation of a plethora of largely unrelated technical terms (Papdouris and Constantinou, 2013). Experiential encounters focus on discipline-specific energy transfers without reference to energy across disciplines. This lack of cohesion thwarts student understanding as they move from one discipline to the next (Cooper and Klymkowsky, 2013).

We are failing our students in not making explicit connections among the way energy is treated in physics, chemistry and biology. We cannot hope to make energy a cross-cutting idea or a unifying theme until substantive changes are made to all our curricula. (Cooper and Klymkowsky, 2013, p. 209, italics added.)

For example, biologists often refer to carbon compounds as storing energy, when specifying the system of reactants in which that fuel is combusted is crucial in defining the energy available. (Cooper and Klymkowsky, 2013). Stanford particle physicist Helen Quinn, one of the leaders of the K-12 framework, lists words used by various disciplines to refer to energy: food, biomass, kinetic and potential energy, bond energy, enthalpy, energy flows and energy resources (Quinn, 2013). When terms are in common usage, misconceptions concerning the scientific consensus can result, as has been documented for energy terms (Erickson, 1979 and Duit 1981, cited in Wang et al., 2013). But even if these are used in a scientifically precise way, how are they all related? A long history of research has detailed student and teacher confusion about energy (Driver, 1994; Liu and McKeough, 2005). In particular, there has been difficulty in understanding energy conservation and the fact that with each transfer, some energy is no longer available to do work (Liu and Park, 2012, cited in Duit, 2013).

At the high school level, there has been a call since 1993 in the *Benchmarks for Science Literacy* (AAAS,1993) to provide an interdisciplinary approach to instruction regarding what
powers life. Because teachers lack an understanding of energy, their approaches are often simplistic and not interdisciplinary (Duit, 2013.) Similarly, without an understanding of the cross-cutting nature of energy, students cannot realize that physical processes underlie chemical reactions (Duit, 2013) and life! The IES-funded SUN Project (Batiza et al., 2013) responded to that call by using a hydrogen fuel cell as a precursor to physical manipulatives to scaffold understanding of the impact of potential difference in driving energy transfer in both abiotic and biological systems. In a series of Harvard lectures, the pioneering microbiologist A. J. Kluyver, shortly before his death said,

*The most fundamental character of the living state is the occurrence in parts of the cell of a continuous and directed movement of electrons.* (Kluyver and van Niel, 1956, p. 71, italics added).

The energy transfer that results from this electron movement in cellular respiration and the photoelectric effect that initiates this process in photosynthesis seem, at first glance, abstract and difficult to understand. However, our work in a randomized, controlled trial has shown that teachers grasp these fundamental ideas with rich conceptual understanding of the biological processes involved, even one year after instruction (Batiza et al., 2013). Our initial analyses of student effects in a cluster, randomized, controlled trial indicated increased student understanding with moderate to large significant effects (Please see Section 1.4.) This work suggests to us the importance of an understanding of fundamental particle interactions, even if at an elementary level in biology, as the basis for energy transfers in all disciplines. As Helen Quinn states “...we cannot clearly understand many of the commonly used terms for forms of energy until we break them down again and into the underlying particles and their interactions (2013).” In fact, it is only through an understanding of biological energy transfer mechanisms that students are convinced that life itself is driven by physical forces (Barak et al., 1997; 1999). The SUN curriculum allows us to be uniquely positioned to provide this perspective in biology.

During our previous work at the high school level regarding biological energy transfer and in our current NSF-funded work with undergraduates in cell biology, bio-molecular engineering, and physics, we have wrestled with ways to apply fundamental understandings of energy transfer across disciplines. Throughout we have asked, “What concepts make it apparent that energy in one discipline means the same thing as energy in another?” Interacting with others who had a similar passion broadened our understanding of the difficulties encountered, a narrowing consensus on such concepts (DOE, 2012, NRC, 2012; Quinn, 2013), and ways to bring coherence to student lessons (Quinn, 2013; Nordine et al., 2011; AAAS 2014; Eisenkraft, 2014; Chen et al., 2013). From these foundations we have developed Four Curricular Guides that correspond to four unifying Concepts (Table 1). We have elaborated the Curricular Guides into a Coherent Energy Framework (Table 2) for creating energy lessons across the high school science disciplines and in alignment with the NGSS. This framework is based upon four unifying concepts with *Common Concepts, Common Visualizations, and Common Practices* for each (Table 2). We believe that repeated application of these consistent elements will result in transfer of student understanding of energy within and across disciplines (Bransford, 2000; Nordine et al., 2011). We will apply these guides as we develop complete NGSS-based energy curricula for each science discipline during this project.

Each of these curricular guides is based upon an engagement at the beginning of the lesson/unit through a real world experience of an energy transfer phenomenon, a strategy that has
shown promise in helping learners analyze energy systems (See Nordine et al., 2011) and transfer understanding to an unknown system by analogy (Batiza et al., 2013). In all cases, care must be exercised to avoid language traps that generate misconceptions as students progress from one science discipline to the next (Cooper and Klymkowsky, 2013 and Lancor et al., 2012).

These four Curricular Guides are briefly summarized below in Table 1, with references to researchers who have discussed or demonstrated their importance. The theoretical/empirical rationale for each is discussed more fully in Section 1.3.

<table>
<thead>
<tr>
<th>Common Concept</th>
<th>Curricular Guide</th>
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<tr>
<td>1. Definition of the system, surroundings and interactions</td>
<td>Use a real world experience of energy transfer to identify the series of energy transfers. Then elicit clear definitions of the system and surroundings one will consider. Use explicit language and common visualizations (Nordine et al, 2011; Brewe et al., 2011; Eisenkraft, 2012; 2013; 2014).</td>
</tr>
<tr>
<td>2. 1st and 2nd Laws of Thermodynamics (conservation of energy) and (energy degradation to an unusable form with each transfer)</td>
<td>Teachers and students should repeatedly and explicitly apply the 1st and 2nd laws of thermodynamics (Eisenkraft, 2012; 2014; NRC, 2012). This can be accomplished when used as constraints within visualizations of energy transfer (Brewe et al., 2011).</td>
</tr>
<tr>
<td>3. Fundamental particle interactions that drive energy transfer</td>
<td>Students need interactive experiences with explicit representations of fundamental, invisible mechanisms of energy transfer (Nordine et al., 2011; Cooper et al., 2013; Quinn, 2013; Perkins, 2014) This should follow and be explicitly linked to real world experiences of such mechanisms (Nordine et al., 2011; Batiza et al., 2013).</td>
</tr>
<tr>
<td>4. “Joule” is a universal unit of energy</td>
<td>Students need to understand that energy quantities in any form can be represented with the unit “joules.” Therefore discipline-specific energy units should be regularly converted to the universal unit “joules.” Use of a common joule number line can make this commonality apparent. (Robert Chen presenting at Eisenkraft, 2012)</td>
</tr>
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Therefore, this project will directly address the need for coherent energy curricula aligned with all of the NGSS energy-related standards by first creating and validating such curricula. Then their promise will be determined in three simultaneous cluster, randomized controlled trials with high school students in regular biology, chemistry and physics classes in Wisconsin.

1.2 Major Goals and Hypotheses.

Goals
1. Our primary goal is development and validation of coherent, feasible and effective NGSS-based energy curricula for high school biology, chemistry and physics.
2. Secondarily, we are interested in the impact of this coherent energy curriculum on student belief that biological energy transfer is driven by physical laws.
3. We will also determine the impact of discipline-specific workshops (that nonetheless provide an interdisciplinary perspective toward energy) on teacher knowledge and self-efficacy.
Informal Hypotheses (See Appendix B, HLM Analyses, for more details.)

1. Students taught with the newly developed curricula will have significantly greater domain-specific knowledge about energy than controls.
2. Biology students taught with this new curriculum will have a significantly greater belief that life is powered by physical processes than controls.
3. Teachers who attend the Energy across Disciplines Workshop will have greater domain-specific knowledge about energy than controls.
4. Teachers who attend the workshop will have a greater self-efficacy with regards to teaching about energy than controls.

This project will result in validation of curricula and assessments required for a later project focused on development of learning progressions across disciplines through scientist support of site-specific interdisciplinary professional learning communities.

1.3 Key Components of the Proposed Intervention. The most important component of the proposed intervention is the Coherent Energy Framework we have developed that is summarized above in Table 1 and described in detail below and in Table 2. The experts in this field seem to agree that exploration of energy transfers should begin with real world experiences that learners can then characterize and begin to explore (Quinn, 2013; Nordine et al., 2011). Experts also agree that clarity is important when discussing energy. But as described above there is disagreement regarding what is important to teach and how this should be done. We have distilled our research into this topic into four Common Concepts upon which our Coherent Framework for curricular development is based (Table 2). In order to provide consistency across disciplines, we suggest common ways to visualize these concepts and common practices to engage students.

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<tbody>
<tr>
<td>1. Definition of the system, surroundings and interactions</td>
<td>Real world experience of energy transfer</td>
<td>Students create energy transfer process diagrams to define visible energy transfers that occur and come to a consensus model. “Indicators” and “factors” that influence that transfer can be identified.</td>
<td>Student ability to define the system/surroundings</td>
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<td>Drawings such as those by Brewe et al. (2011) that indicate components within a dotted line system boundary and use lines between components and across the boundary to indicate interactions.</td>
<td>Students define the components of the system, surroundings and interactions for a specified transfer process.</td>
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<tr>
<td>2. 1st and 2nd Laws of thermodynamics</td>
<td>Real world experience of energy transfer</td>
<td>Students create energy transfer process diagrams to define energy transfers that occur.</td>
<td>Student ability to account for the transfer of energy within the constraints of the 1st and 2nd laws</td>
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<td></td>
<td>Interactive animations showing conservation with energy lost to an unusable form.</td>
<td>Students explain how the animation illustrates the 1st and 2nd laws.</td>
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<td></td>
<td>Energy transfer diagrams that account for the 1st and 2nd laws (process diagrams like those in Nordine et al.(2011) and pie shapes like those in</td>
<td>Students create a snapshot of energy storage at the beginning, middle and end of energy transfer accounting for the 1st and 2nd laws.</td>
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1.3A Common Concept 1. Definition of the system, surroundings and interactions using proper terms for energy transfer (Table 2). Across the science disciplines, learners should understand that energy is not a “stand alone” entity. It does not exist outside of the motions and interactions of matter (in the forms of substances or light) that can result in energy transfers within one form of energy storage (as in a chemical transformation) or from one form to another (as when moving current induces a magnetic field). As Helen Quinn stated, “Students tend to conceptualize energy as a thing. Physicists conceptualize it as a quantity that can be associated with things, and transferred from one thing to another, but which itself is not as a substance.” Therefore all discussions of energy depend upon a careful description of the system under consideration as described above for the true energy costs of an electric car. How does the characterization of the system change when examining the energy of a book at a certain height above the ground, vs. when that book is being held in place by a human arm? An accurate description of the system under consideration will help make this difference self-evident.

In each discipline students should use Common Visualizations and Common Practices to model the system within which energy is conserved, specifying the components and interactions within and across the boundaries of the system under consideration. After first experiencing a macro-level energy transfer, students can begin to explore what has occurred through process diagrams, such as those used by middle school students to great effect (Nordine et al., 2011).

Nordine and colleagues had middle school students repeatedly create process maps of the energy transfer with drawings that make energy transfers explicit, such as those in the book, “The Way Things Work” by David Macaulay. Interactive visualizations of invisible fundamental particle interactions that are freely available, for example at energy.gov/videos. (See, for example, “10 Ways to ‘See’ the Electric Field.” PhETs at the University of Colorado, etc. Such visualizations will be chosen for simplicity in terms of the particle interaction conveyed.

Students manipulate interactive visualizations to discover interaction laws and make predictions regarding outcomes. Students are guided to link the fundamental particle interaction explored to the real world experience encountered. Students provide arguments to explain results using the interactive visualization or laboratory/experiment or demonstrations. Teachers describe an application of that same particle interaction that drives energy transfer in another discipline.

Students calculate work done in joules. Students use the number line to position particular energy expenditure. Teachers/students convert common units to joules in other disciplines. Teachers/students refer to comparable energy expenditure in another discipline.

3. Fundamental particle interactions that drive energy transfer

4. “Joule” is a universal unit of energy

Brewe et al. (2011). Pie shapes can be used to account for all initial energy (1st law), to account for some conversion to an unusable form (2nd law) or for energy inputs when the size of the pie increases.

The teacher draws explicit attention to the 1st and 2nd laws.
conversions occurring within everyday objects, such as chemical glow sticks and solar powered calculators. Importantly, students tracked “indicators” of energy transfer such as light. The indicator’s magnitude could be affected by “factors” which were also tracked. Their short and long-term data provide evidence that identifying the energy transfers within real world experiences promoted an ability to discuss energy transfers in a more scientifically accurate way.

When clarifying the precise system under discussion, we will encourage use of a strategy described by Eric Brewe, et al. (2011) in which students model the system components within a dotted line boundary that separates the system from its surroundings. When students use lines to indicate interactions within and across the system boundary, this simplification of the energy question under discussion can help them define the problem and eliminate extraneous details. With such models, students can discuss whether the system is "open" to both matter and energy exchanges between the system and the surroundings, "isolated" so that there are neither matter nor energy exchanges between the system and the surroundings or "closed" so that energy exchanges as heat or work are allowed, but no matter enters or exits the system. We feel that consistent application of such strategies will increase student ability to clarify any energy transfer problem under consideration. In another study one might be able to ask whether describing the system promotes a conceptual vs. an algorithmic approach to problem solving.

1.3B Common Concept 2. 1st and 2nd Laws of thermodynamics (Table 2). An understanding of the 1st and 2nd laws of thermodynamics and awareness of the application of these principles across disciplines is needed. The 2012 Framework for K-12 Science Education and the Energy Literacy Framework produced by the Department of Energy emphasize the importance of students understanding of the 1st and 2nd laws of thermodynamics (See Principles 1.3 and 1.4 within the Energy Literacy Framework and Principles PS3.B and PS3.D within the K-12 Framework.) In his 2012 NSTA workshop that introduced the Energy Literacy Framework, Arthur Eisenkraft stressed the importance of explicit reference to the 1st and 2nd laws with each student experiment regarding energy transfer (also see Eisenkraft, 2014). The 1st law of thermodynamics is conservation of energy. The universe has a set amount of energy, which will not change at all over time. Often this law is expressed as the conservation of matter and energy. In reality, matter is energy as revealed by Einstein’s famous equation of matter at rest \((E_0 = mc^2)\) and matter is converted to energy, noticeably with nuclear events, but even undetectably in chemical reactions (as described by Quinn, 2013). The 2nd law states that with each irreversible energy transfer, some energy must be converted to an unusable form, while total energy is nonetheless conserved. Therefore this endless conversion of energy to an unusable form marks the progress of time, with the inevitable end of no possible energy transfer. This is important to keep in mind as we consider the real cost of energy transfers and the futility of a perpetual motion machine.

Students need to be explicitly aware that some energy must be converted to an unusable form with each transfer (the 2nd law), even while energy is conserved. Student drawings of energy transfers can capture these ideas as described by Brewe et al. (2011). A series of pie charts divided into wedges can indicate the relative storage of energy as it moves from one storage mode to another while reminding students that with each transfer, a wedge of the pie must indicate energy converted to an unusable form, but nonetheless conserved. The pie charts also allow one to indicate an influx of energy into the system as the pie gets bigger. This kind of explicit reference is needed given the conflicting metaphors for energy transfer used in different disciplines. For example, in biology, teachers often refer to energy as being “lost” (in conflict with the 1st law) as energy is transferred from one trophic level to the next (Lancor, 2012).
The University of Colorado PhETs already provide interactive simulations that describe the 1st and 2nd laws for certain physical interactions at the macro and subatomic scales. For example, the “Energy Skate Park: Basics” simulation shows the complete inter-conversion of potential and kinetic energy in a dynamic bar graph until friction is added. As the skateboarder swishes back and forth in an ever-decreasing arc, more and more energy is converted to “Thermal energy” (an unusable form). The board comes to a stop when all of the original available energy has been completely converted to thermal energy (as indicated on the dynamic bar graph). Students could be asked to explain how the animation illustrates the 1st and 2nd laws. Similarly they could create pie charts that provide a snapshot of energy storage at the beginning, middle and end of energy transfer of that skateboard/boarder system, from its launch until it comes to a stop, accounting for the 1st and 2nd laws. We will add curricular supports for such freely available interactive visualizations so as to highlight the 1st and 2nd laws or create similar visualizations to interactively conceptualize application of these laws as needed across disciplines. For example, Michalek and Hanson (2006) developed a classroom simulation about entropy. We feel that consistent application of such representations will increase student ability to account for the transfer of energy within the constraints of the 1st and 2nd laws.

1.3C Common Concept 3. Fundamental interactions that drive energy transfer (Table 2).

Fundamental interactions power energy transfers when matter interacts with electromagnetic, gravitational and nuclear force fields. The emergent manifestations of these interactions are all around us in 21st century communication devices as well as in 19th and 20th century advances, such as the telegraph, steam engine, cars, and the refrigerator. A true understanding of energy depends upon some knowledge of the kinds of exchanges that are possible.

An important component of their program was physical demonstrations of invisible energy transfer mechanisms, such as the heat expended when a large metal ball hit an obstacle and caused a burned ring on a paper wedged between the ball and the obstacle. Therefore, explorations of fundamental interactions that drive energy transfer will be explicitly tied to such real world experiences.

Other macro experiences of invisible energy transfers are available as freely available dynamic simulations, again such as those from the University of Colorado’s PhET site (http://phet.colorado.edu/), headed by physicist Kathy Perkins or at any number of Web sites, including at energy.gov/videos. See, for example, “10 Ways to ‘See’ the Electric Field.” For example, one PhET allows students to manipulate the frequency of light to see its effect on single molecules of CO2 and O3, a critical concept with regards to global warming. Another shows the impact of light in causing electrons to be ejected from materials, the basis for energy conversion in photosynthesis. Such emissions are also the basis for the lives of photosynthetic organisms that live off the black body radiation from hot deep ocean vents.
We will look for the most simple but accurate freely available Common Visualizations to enhance understanding of critical invisible interactions that allow for energy transfer. Drawings such as those in the book, *The Way Things Work* by David Macaulay, can also provide a template for Common Visualizations (Table 2) we can create to discuss the series of invisible energy transfers inherent in everyday engineering marvels, such as refrigerators. (We used such a strategy at the undergraduate level.) If none are freely available we will create our own, given the abilities of our lead designer, Mark Hoelzer, MFA and his apprentice. Such visualizations can be used at varying degrees of sophistication to support particular energy-dependent NGSS. Table 2 suggests a variety of ways in which students can interact through Common Practices with such visualizations after having already experienced a relevant real world energy transfer. Such practices include exploring the laws of conservation and energy degradation, making predictions, planning an experiment or providing scientifically sound arguments that explain a phenomenon. The *Framework for K-12 Science Education* suggests eight scientific practices which are embedded within the relevant NGSS. We think that consistent interactive encounters with Common Visualizations of the invisible forces that drive energy transfer after an initial experience with a real world manifestation of that mechanism will enhance student conceptual understanding of particle interactions that drive energy transfer. Given that teachers will be encouraged to provide examples of the same underlying process in another discipline, we think that students will begin to understand that all energy transfers are driven by physical laws (Barak et al., 1997; 1999)

1. **3D Common Concept 4. “Joule” is a universal unit of energy.** In order to provide evidence that the units of energy can be represented as joules no matter the discipline, disparate energy units should be converted to joules (Chen, personal communication, 2012). This Common Practice reinforces the idea that “energy is a physical quantity that follows precise natural laws,” (Principle #1 of the seven energy principles within the Energy Literacy Framework). For example, when students encounter food Calories in their work or textbook in biology (kilocalories in chemistry and physics), or kilowatt hours in physics, they should be encouraged to convert that number to the corresponding number of joules. Consistent use of a Common Visualization of a joules number line should help students to develop a sense for the relative quantification of energy expenditures while reinforcing energy as a universal concept that has the same meaning across disciplines. Such number lines should include everyday reference expenditures across disciplines, such as the energy consumed by an incandescent 60W light bulb left on for two hours or by a person who walks 5 miles on a treadmill while expending 130 kilocalories per mile. This type of coherence has been leveraged in the use of a number line to support conceptual understanding of the measureable quantity represented by a fraction. (Fuchs et al., 2013; Siegler et al., 2013).

At the same time, the teacher should provide examples of the same energy expenditure in joules from another discipline. For example, how might one consider the energy available from a hamburger completely combusted in the presence of oxygen (imagine it burned to ash and all the matter and heat trapped within an isolated system). The 920 Calories (920,000 calories which = ~3,900,000 joules) from a bacon cheeseburger (see: http://www.fiveguys.com/menu/nutritional-information.aspx) are not immediately available to do work. Note that 3,900,000 joules = ~2,900,000 foot-pounds. If all joules were used to do work within a short amount of time with 100% efficiency in the requisite muscles, one could immediately lift a 4000 pound car 725 feet! Obviously, this does not happen. First, all of the energy available to do work from the hamburger is not converted to a form that muscles can use.
On average, conversion to ATP (a molecule that influences the reactivity of other molecules in living things) is only about 27% efficient and that conversion is not instantaneous. In addition, that conversion takes place all over the body, not just in the muscles used to lift a load, and maintenance of body systems (i.e. burning calories while you sleep!) uses much of that ATP. Also there is energy converted to an unusable form during the several steps by which ATP powers the muscles. Your body releases heat to the surroundings, thus it is not a closed system. For all of these reasons, consuming a bacon cheeseburger does not allow one to lift a car over 700 feet. Discussions of comparable energy expenditures across disciplines using common joule units should promote student understanding that energy expenditures can be discussed in equivalent ways, regardless of the discipline.

Besides making it a habit to convert energy across disciplines to joules, the curricula will make teachers aware of the energy traps to avoid and will provide them with scientifically precise terms. For example, a fuel (such as food, biomass and fossil fuels) is merely an assumed reactant in a reaction with oxygen. Because oxygen is ubiquitous, we make this assumption. These do not reflect the reality of incomplete combustion or the actual conditions under which energy is harvested from these reactions. However, we have tables describing the joules released or required for chemical reactions under very specific conditions. These tables are valuable, not only for energy released from common fuels in the presence of oxygen, but they also can indicate the energy available from batteries (not dependent on oxygen) and even whether or not certain chemicals will react!

These ideas can be applied to energy transfers within any discipline. In each case, the coherence of this approach will allow for integration of concepts learned (Bransford et al., 2000; Nordine et al., 2011) Besides making these ideas easier to grasp and use by providing reinforcement of fundamental ideas and relieving cognitive load through the use of Common Concepts, Common Visualizations and Common Practices, it is hoped that students will begin to understand that these particle interactions underlie energy transfers within all disciplines, including life itself.

Given that many teachers do not have the prior knowledge required to implement this curriculum, the workshop for teachers will be based on the Coherent Energy Framework as well. The key components of this framework - Common Concepts, Common Visualizations and Common Practices - will guide development of model lessons by this research team. This project will also provide the tools for teachers to implement the relevant energy-related Next Generation Science Standards (NGSS Lead States, 2013). But perhaps most importantly, this framework will guide modifications of existing lessons by teachers. Doing so within the context of this framework will establish coherence in the treatment of energy across disciplines and provide a usable template for sustainable change. Although this question is beyond the scope of this developmental proposal, perhaps consistency in the way energy is discussed and presented as students progress from one science discipline to the next will have an even greater impact on student learning. These curricula are a necessary prerequisite.

1.4 How our previous work impacts this project. Our unique approach to biological energy transfer works as validated by our previous research. We have demonstrated significant effects on teachers in a randomized, controlled trial (Batiza et al., 2013) and significant effects on students in a cluster, randomized controlled trial (Batiza et al., manuscript in preparation). SUN research shows that highlighting the real driving force for energy transfer through real world experiences with hydrogen fuel cells and proper scaffolding of the biological mechanisms
with physical and digital manipulatives significantly impacts conceptual understanding of the mechanism by which energy is transferred in cellular respiration in teachers (Batiza et al., 2013).

### Pre Workshop

### Post Workshop

### One Year Later

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Figure 2. Teacher conceptual growth. The impact of the SUN Workshop is evident in this teacher’s drawings with written explanation of the process of cellular respiration. Here is a high average example of the teacher’s understanding as a result of the workshop and continued rich and accurate conceptual understanding even one year later. Notice that a high level of confidence in her answer (4 on a scale of 1 to 5) was achieved even “without studying.” (Image from Batiza et al., 2013)

In a randomized, controlled trial teachers demonstrated their understanding with concept-rich drawings with explanations of the process of cellular respiration that reflected very large effect size 3.38 (p<0.001) and significant gains were maintained when measured one year later. (Batiza et al., 2013). Student results with ANOVA comparison indicated the SUN group (N=334) scored significantly higher than controls (N=319) on a multiple choice test with a moderate effect size of 0.43 (p<0.001) when measured on average at least two months after instruction. Without the SUN treatment, control students made no gains at all and scored significantly lower than a small AP comparison group. However, the gains of the SUN group were not significantly different from those of AP students taught with traditional materials. Therefore it appears that proper scaffolding can significantly enhance learning. Initial HLM analyses confirm these results (Batiza et al, manuscript in preparation). In drawings which demonstrated a large effect size, students mentioned ATP as a product of this process in response to a similar open-ended drawing question significantly more (27% vs 10%) than did cluster, randomized controls. (Batiza et al. manuscript in preparation). Because we focus on the mechanism and driving force for energy transfer from food and oxygen to production of ATP, and we scaffold understanding with fuel cells and physical and digital manipulatives that make these invisible transfer processes and their rationales accessible, we are uniquely positioned to provide greater coherence in the treatment of energy transfer across disciplines.

The workshop for teachers began with the real world experience of the net energy release when electrons move in a video of a hydrogen plus oxygen explosion, induced with the addition of some energy in the form of a blow torch. This was followed by discussions of their experience in other systems, such as lightning, where the system allowed for spontaneous movement of electrons. Finally, the teachers set up and operated a hydrogen fuel cell that powered a motor-driven propeller to experience the movement of electrons from hydrogen to oxygen. Notably this movement occurs without any inducement other than the
presence of a catalytic membrane that allows for incoming hydrogen to be automatically split into hydrogen and oxygen. The main purpose of this activity was to show that electrons from one chemical substance can move along a specified path to another substance without any additional input of energy. They are driven by Coulombic force, the same force that drives electron movement in lightning and in batteries. One can see evidence of the net energy released and work done in the movement of the propeller put in their path. This parallels what happens in the mitochondria of living things as electrons move spontaneously from broken down food to oxygen along a specified path. The invisible sequence of events that allows for movement of electrons from hydrogen to oxygen in a fuel cell is made visible in our animation of this process, available on YouTube https://www.youtube.com/watch?v=hi6RYtg08so. In addition, learners can move laminated materials to see that matter is conserved as water is formed during this process. At the same time, a meaningful context for a discussion of the relative energy storage of reactants and products is made visible as learners see the sequence of energy transfer steps involved. The chemical hydrogen donates electrons that move in an electric current to power a motor (that has hidden conversions) attached to a mechanical propeller on their path to oxygen gas encountered at the end of this process. Protons take a separate path to also join with the oxygen plus electrons to make water. With each energy transfer, some energy must have been converted to an unusable form, including heat. Finally some energy is stored in the chemical product water made. Therefore this experience provides a context for discussing energy transfer constrained by the 1st and 2nd laws of thermodynamics.

This sequence of events that occurs in the mitochondrion as electrons move from broken-down food to oxygen is supported with digital materials that animate the simplified overall path of electron movement. In addition learners move physical components in nested cafeteria trays that represent the salient membrane-bound compartments of the mitochondrion. The physical manipulatives allow learners to experience a simplified path of electron movement as they move electrons (small magnets) from food to oxygen across the pumps. The movement of negatively charge electrons causes the pumps to pump positively charged protons (ball bearings) into the confined space between the trays (an example of Coulomb’s Law). This confinement moves positively charged protons close together. This repulsion and concentration difference between the two compartments is the driving force for these protons to passively enter the only outlet available. [Such membrane potentials, which are a major biological energy transfer mechanism are mentioned but rarely modeled.] That single outlet is the entrance to the ATP synthase, a protein machine that makes ATP. Students can insert ball-bearing protons into a mechanical ATP synthase model. As they turn the central shaft they see the binding site for the raw materials from which ATP is made become accessible. Students can insert schematic models of
those materials to produce ATP. Hence the rationale for production of the life currency ATP from food we must eat and oxygen we must breathe becomes accessible.

The production of water and carbon dioxide from food (glucose) and oxygen is also made visible. As learners strip electrons from food, carbon dioxide is released. As electrons reach oxygen, protons are added and water is made. Thus matter is conserved. Large cell mats allow students to position these components so as to track the flow of matter and energy through photosynthesis and cellular respiration.

These manipulatives make the series of energy transfers in living things visible. Energy is transferred from the chemical reactants to the electrical energy of moving electrons, to the concentrated protons, to the mechanical turning of the ATP synthase and finally to some energy stored in the chemical ATP and the other products of this reaction, carbon dioxide and water.

Therefore learners can discuss these processes in groups, relieving cognitive load as they point to various steps without having had to keep a mental model of the entire process in short-term memory. Applying the 2nd law, they will know that as a result of this series of energy transfers, the chemical energy of the products, carbon dioxide and water and ATP made must be lower than the chemical energy of the reactants.

Thus these materials can be used to model the process of cellular respiration as described by NGSS HS-LS1-7. This standard states, “Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy.” We disagree with the clarification statement that “Emphasis is on conceptual understanding of the inputs and outputs of the process of cellular respiration.” This statement refers to conservation of matter. There is nothing in the standard about energy transfer except the declarative statement that there is a net transfer of energy.

**1.5 Theory of Change.** The Intervention developed and tested will be energy-coherent
but nonetheless discipline-based, NGSS-aligned curricula. Each discipline-specific, but energy coherent curriculum will be tested in a separate, but simultaneous cluster, randomized controlled trial. The target population is Wisconsin high school students in regular classes of biology, chemistry and physics. Because we will recruit such classes within one teacher team per school, randomization within discipline (biology, chemistry or physics) will occur by school after matching for school freshman-class size and ethnicity distribution. (This data is freely available from the Wisconsin Department of Public Instruction Website). Since there will be only one team per school, and each trial of the effects on students will be discipline-specific, this will amount to randomization at the teacher level with students clustered within each teacher. After exposure to instruction applied for every energy-based NGSS standard over the 2018-19 school year, we anticipate that students will increase their discipline-specific knowledge of energy transfer and confidence in their responses (Figure 5).

Similarly we hypothesize that biology students will increase their belief that life is powered by physical laws. These outcomes will be determined both regarding pre/delayed post assessments and most importantly relative to cluster, randomized controls. Although the level of exposure to this curriculum in the classroom will vary by discipline, we anticipate that each student will have experienced this curriculum for at a minimum of 50 classes during the school
year. We will collect data regarding key moderators, such as previous GPA and gender and examine the impact of these moderators on student measurements. Wisconsin no longer allows collection of data regarding participation in the national lunch program.

In order to help teachers become proficient in using this curriculum in a discipline-specific way, teachers will attend an in-service workshop on Energy across Disciplines with break-out sessions that provide discipline-specific content. Teachers will be provided with classroom materials required to implement this curriculum and continuing support in the form of semi-annual regional meetings (Figure 5). The immediate downstream effects of this intervention include better teacher understanding of the key concepts listed in the Coherent Energy Framework (Table 2 and Figure 5). In addition, the teacher will learn how to apply this framework to other lessons already within their current curriculum. As a result of these impacts, the teacher will change their classroom practices and increase their confidence in their ability to teach energy-related material and their belief that life is driven by physical laws. Then students will be affected in terms of their abilities to comprehend the four key concepts listed in the Coherent Energy Framework (Table 2 and Figure 1), which will impact student knowledge, confidence in their responses and sense that life is powered by physical laws. We expect that the greatest impact will be shown by biology students.

While this workshop will expand teacher knowledge beyond that typically required to teach current textbook curricula, we agree with Helen Quinn (2013) that teachers need to have a broader view of energy in order to teach this topic coherently. We adopted that approach with regards to the SUN Project and found that teachers rated the workshop on each of all four items regarding its usefulness at or above 4.6 on a scale from “1-not at all useful” to 5- extremely useful (Batiza et al., 2013). So as to provide a proper test of the three curricula, teachers need to be instructed both with regards to new knowledge, to gain confidence in their use of the new materials and in order to make substantive changes to their current curricula so that these changes are implemented. Given the letters of agreement from the Advisory Board Teacher teams who will help develop this curriculum, from the Wisconsin Department of Public Instruction who will help us to recruit schools and from Milwaukee Public Schools, who have pledged 8 or the 40 participating teams, there is broad support in Wisconsin, both for the caliber of our work, based on the SUN Project and for the expected positive outcomes for students in this proposed work.

The resources provided by this project will include the new curricula on a USB flash drive and as paper copies within a Workshop manual for each teacher. In addition, each school will receive tools for implementation of the curriculum up to $2800. Depending upon what the school already has and needs, tools will include 10 sets of SUN materials (made at MSOE for cost at $100 per set) and hydrogen fuel cells we used for SUN along with photovoltaic cells (available together from fuelcellstore.com as the Solar Hydrogen Education kit for $87 per set).

In order to reduce cognitive load, while allowing students to explore certain technologies...
in greater and greater depth, common manipulatives first encountered in one course will be used across disciplines. For example, while the hydrogen fuel cell can be used in biology to provide a rationale for the movement of electrons in the electron transport chain of cellular respiration, it can also be used in chemistry to describe electrolysis (running on battery power in reverse) and supporting NGSS standard (HS-PS1-4) regarding energy release vs. absorption based on total bond energy. (*See Appendix B for a list of all standards addressed by this project.*) Similarly, its proper use will reinforce the stoichiometry of the hydrogen and oxygen gases produced when matter is conserved (HS-PS1-7). Supported by an animation already developed for the SUN Project (Batiza et al., 2013; [http://www.youtube.com/watch?v=hi6RYtg08so](http://www.youtube.com/watch?v=hi6RYtg08so)), the hydrogen fuel cell also provides a segue to understanding what powers batteries in chemical half-cell reactions and how the same driving force determines which chemicals will react in oxidation-reduction reactions (HS-PS1-2). The fuel cell and the photovoltaic cell can again be used as an introductory real world experience in physics before students explore the induction of a magnetic field, the process by which current turns the motor attached to the propeller (HS-PS3-5).

Similarly, the photovoltaic cell provides evidence that an interaction between light and matter gets electrons moving (HS-PS3-3, HS-PS4-4 and HS-PS4-5). SUN Project resources for educating teachers include the SUN Chloroplast E-book, which highlights this interaction as a driving force for photosynthesis. (SUN Chloroplast E-book and YouTube Video, 2013a; 2013b).

### Table 3. Project Work Plan.

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
</tr>
</thead>
</table>

1) Development of Initial Lessons and Assessments

2) Iterative Validation of Lessons and Assessments and Development of Workshop

3) Discipline-specific, Cluster RCT

4) Formative and Summative Data Analysis

5) Dissemination

1) Initial lessons and assessments, developed during the first year will be 2) iteratively validated and tested so as to be ready for the 3) three discipline specific cluster RCTs. 4) Formative analysis, including analysis of feasibility of implementation will occur throughout the development process. Summative analysis will include ANOVA analysis of the short and long-term impacts on teachers and HLM analysis of the impacts on students. 5) Dissemination will occur throughout this project via members of the Scientist/Educator Advisory Board and findings will be communicated at national meetings.

### 2. Research Plan
This research will result in the development of validated curricula in biology, chemistry and physics aligned for each of the energy-related NGSS and cluster, randomized, controlled trials of their effectiveness. All of the materials and assessments to conduct this trial, including assessments for the fidelity of implementation at different stages will be developed, based on existing assessments, or created anew for this work. All assessments will be validated prior to the discipline-specific, cluster, randomized, controlled trials in Year 3.  

2.1 Overall Project Work Plan (Table 3 and Project Timeline in Appendix B). The major work foci by year is indicated in Table 3 and discussed below. Details regarding the development of lessons and assessments are discussed further below. Table 4 provides a yearly list of these foci.

2.1A Year 1. The lesson and assessment prototypes will be developed by the Core Group of Co-PI Scientists, Master Teachers and Evaluators over the entire first year (See Personnel). They will meet monthly for four hours with prior work, especially initial lessons development by the master teachers, shared on Google Docs and by email. In addition, they will develop new measures for providing feedback from the Advisory Board Teacher Teams, for later classroom observations and interview scripts for students having difficulty. Beginning in December of Year 1, the Advisory Board Teacher Inter-disciplinary Teams (Lists of teams and their functions are provided under the Personnel Section; Letters of agreement are in Appendix D.) will work as professional learning communities in monthly meetings at their schools to validate those lessons and assessments. Project staff will attend these meetings to provide a lesson overview, answer questions and observe. The teacher teams will validate the lessons regarding their domain content, alignment with the NGSS and feasibility of implementation. Formative assessment will be provided from each Teacher Team meeting so that the Core Group can generate the next iteration in their monthly meetings and provide these back to the teacher teams.

Quarterly meetings of the teacher teams will allow them to share information with their disciplinary peers from other schools and to further discuss cross-disciplinary connections with the entire group. The full Scientist/Educator Advisory Board will gather at two of these meetings to provide additional input. Because the full board will include Scientists and Educators (See letters in Appendix D), the Coherent Energy Framework will be disseminated.

2.1B Year 2. The Core Group will continue to meet monthly for four hours to discuss lesson and assessment iterations and to develop related curricula and assessments for the Energy across Disciplines Workshop. Ann Batiza or Marisa Roberts will introduce the lessons to the Advisory Board Teacher Teams at their monthly meetings. The teams will test the lessons in their classrooms and continue to meet monthly at their schools to suggest revisions with staff present. Staff will also record observations during classroom lessons to determine the level of implementation with regards to the Coherent Energy Framework. Students having difficulty will be interviewed and videotaped by project staff at the end of the school day, so as to further address deficiencies in the lesson designs. During this year, the teacher teams will also begin to examine ways that connections across disciplines can be made, based on their local curriculum. This feedback will provide information for further development of the lessons and the curricula for the Energy across Disciplines Workshop. The Scientist/Educator Advisory Boards will provide oversight and help to disseminate this effort. By the end of Project Year 2, final versions of all assessments will have been created so that they can be validated during the third year.

Throughout the year, Co-PIs Batiza and Roberts will visit schools to recruit teachers for the discipline-specific cluster, randomized, controlled trials. The Wisconsin Department of Public Instruction has indicated they will publicize this effort and Milwaukee Public Schools has indicated they will provide 8 teacher teams for the RTCs. (Please see letters in Appendix D). At
the end of Year 2, recruited teams of teachers will be randomly assigned to Treatment or Control Group.  (*Please see Section 2.2CTrials for more details.*)

2.1C Year 3. The third year of the project will be devoted to finalizing all curricular materials, the validation of finalized assessments and initiation of the RCTs with delivery of the Energy Across Disciplines Workshop. The Core Group’s monthly meetings will be concerned with responding to the Advisory Board Team data and finalizing all preparations for the workshop. The Advisory Board Teams will again iteratively implement the revised lessons with the finalized assessments so that the final versions of both can be validated. Some model lessons presented by the Advisory Board Teacher Teams and Master Teachers Roberts and Hendriks will be videotaped for use during the Energy Across Disciplines Workshop. Again Ann Batiza and Marisa Roberts will attend the teacher team meetings to record observations and answer domain content questions. Throughout all the teacher team meetings, project staff will collect observations regarding the barriers and supports needed for proper functioning of the professional learning communities in anticipation of a future proposal.

Co-PIs Batiza and Roberts will oversee development of all workshop materials during the academic year and summer. Two days prior to the workshop, the Core Group will assemble to go over all presentations. In June, the 7-day workshop and initial half-day meeting will be delivered. Only the Treatment Group will attend the workshop, but all teachers participating in the RCTs will attend for the first half day to provide baseline data and learn about administration of assessments to treatment and control group students. Data collected from teachers during the workshop will be coded and analyzed. (*Please see Section 2.2C for more details.*)

2.1D Year 4. The fourth year of the project will be concerned primarily with the three discipline-specific cluster randomized controlled trials, the HLM analysis of those trials and summative analysis of the project. During this school year, data will be collected from one class of students of all teachers participating in the cluster, RCTs. Treatment Group teachers will use the Coherent Energy Curricula aligned to the NGSS. Control Group teachers will teach according to “business as usual.” All teachers will attend semi-annual regional meetings led by Co-PIs Batiza or Roberts to share information within their cohort. In addition, PI Batiza and will visit a randomly selected group of classrooms in order to collect implementation data. At the end of the RCT trials, as an added incentive for their participation, all waitlist control teachers will attend the Energy Across Disciplines Workshop and receive materials for their schools. Again all teachers will attend the first half-day to provide data; this will serve as a year-later assessment of knowledge and self-efficacy for the treatment teachers. Co-PIs and evaluators will disseminate the results of this work at meetings such as NARST and the appropriate discipline-based professional meetings.

The key events during each year are summarized in the *Project Timeline in Appendix B.*

2.2 Evaluation Plan

Collecting high-quality evaluative data and promptly feeding them into the process are vital to the successful development of effective NGSS-based energy curricula. To that end, our experience with the SUN project will be greatly beneficial to the new project. Overall the evaluation can roughly be viewed as two phases: the measurement phrase and the statistical analysis phrase. The measurement phrase generally precedes statistical analysis, but in a few occasions, they will be intertwined. Table 5 summarizes the major work in the data collection and program evaluation for this project. The first major evaluation task is to ensure that the newly developed curriculum and corresponding lesson plans have high validity evidence. The following steps will be taken in this endeavor. First, the development process will be well
documented and culminated in a curricular development blueprint, as exemplified in Table 6. The main goal of such as blueprint is to indicate how the Common Concepts and the NGSS standards will be represented by the newly developed lesson plans and assessment tasks. This table will be used by the CORE group in the developing process. It will also be used by the Advisory Board Team Teachers to provide feedback to the development team. More specifically, teachers will evaluate the match between each lesson plan and assessment with the intended standard(s) and concept(s). Their evaluation will be fed into the next round of development.

2.2A Development and Validation of Lessons for Students and Workshop Manual for Teachers. In Year 1, as described above in Section 2 Research Plan, the scientist experts and master teacher experts will develop initial curricula and related assessment items for each energy-related NGSS based on the Coherent Energy Framework during monthly meetings. Development of any new animations and simulations, beyond those freely accessible will be produced during this time by designer Mark Hoelzer and his ¼ time apprentice. The curricula will be validated with regards to domain knowledge and alignment to the NGSS by Scientist/Educator Advisory Board, starting in in December of Year 1 and continuing through June of Year 3. As individual teachers try out lessons, feedback from the monthly meetings of the Teacher Teams will allow the Core Group to develop the next iteration of a lesson in their monthly meetings. That iteration will be implemented by teachers in the Teacher Teams who have not yet used it. In this way formative pre/post student data, data regarding validity of the assessments and iterative feasibility of implementation data will be collected. Data regarding sources of confusion will be collected on site and video of those interviews will be transcribed and analyzed. Besides focusing on the curricular lessons being tested, the teacher teams will meet to discuss ways to further apply the Coherent Energy Framework to other lessons at their schools and ways to reinforce these ideas as students move from one discipline to the next.

During Year 3, finalized lessons and assessments will be tested this year in the classes of the members of the Teacher Teams as they continue to meet monthly and provide data. The Core Group meetings will be concerned with ensuring that all domain-specific content is validated and prepared for the upcoming workshop and RTC. In addition, the master teachers and volunteers from the Teacher Teams will tape example lessons that will be used during the Energy Across Disciplines Workshops. The Teacher Teams will continue to revise their local curriculum across disciplines, which they will finalize and submit. Because Ann Batiza and Marisa Roberts will record observations as they attend each meeting, these communities will provide a model for the functioning of such groups, which may be relevant in a later proposal.

Because teachers will have been assigned to groups, the Treatment group will be assessed in advance for their need for SUN materials and fuel cells. Each school will have a $3500 budget for needed supplies. The needed materials in addition to these requests will be readied for in anticipation of the workshop and future implementation by the Treatment group. The Workshop Manual will be readied as both paper copies and e-files. The NGSS-based Coherent Energy Curriculum will allow for reproduction of classroom lessons.

2.2B Development of Measures and Data Collection Procedures including those for Evidence of Feasibility and Fidelity of Implementation. Development of assessments is summarized in Table 4. These include assessments to address all of the student and teacher outcomes specified in the Hypotheses. Assessments already validated within the SUN Project will be modified to assess teacher self-efficacy, conceptual development during the workshop and fidelity of implementation. The validated SUN Energy Transfer Teaching Efficacy Belief Instrument will be used to measure self-efficacy with regards to teaching energy transfer. It was
modified from the STEBI-A by Enochs and Riggs (1990). We determined the reliability coefficient (Cronbach’s alpha) to be 0.88, based on teacher pretest scores and .79 based on teacher posttest scores (Batiza et al., 2013). Any score above 0.7 is considered to indicate a reliable measure. We will revise the SUN Conceptual Connections Record Assessment, used during the SUN Workshop to capture day –to-day domain-specific connections conceptual connections related to the Common Concepts (See Appendix C for the SUN version.).

Although we used an implementation instrument with the SUN Project, new i assessments will be developed to assess implementation of the Common Concepts from the Coherent Energy Framework and alignment to the NGSS as described in Tables 4 and 5 below. These will be used by the Advisory Teacher Teams, classroom observers during development and during the RCT and teachers participating in the RCTs. During Year 3, the finalized student assessments will be validated. From this year’s data, we will perform an item analysis.

<table>
<thead>
<tr>
<th>Table 4 Summary of Data Collection Measures and Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objectives</strong></td>
</tr>
<tr>
<td>1. The newly developed lesson plans and assessments have high content validity.</td>
</tr>
<tr>
<td>2. Teachers master the Common Concepts and Common Visualizations under the new curriculum.</td>
</tr>
<tr>
<td>3. a. Students master the Common Concepts and Common Visualizations under the new curriculum. b. Students believe that life is powered by physical forces.</td>
</tr>
<tr>
<td>4. Teachers improve self-efficacy to teach about energy transfer.</td>
</tr>
<tr>
<td>5. Teachers implement the new curriculum with high fidelity.</td>
</tr>
</tbody>
</table>
To assess the effect of the new curriculum on teachers, statistical procedures such as ANOVA and ANCOVA analyses (controlling for pre-knowledge or prior condition) will be conducted on teacher outcome variables, which are content knowledge, confidence, and self-efficacy. The relevant data will be the pre and post assessments of teachers attending the workshop in Year 3. As an interdisciplinary approach, it may also be interesting to compare teachers from different subject areas on the above measures.

To assess the effect of the new curriculum on students, HLM analyses will be conducted on the RCT data. In this case, students will be nested within teachers. Meanwhile, covariates such as an implementation fidelity index can also be modeled to examine their effects on student learning outcome. Due to the nested structure of the data (i.e., students nested within teachers), we will use hierarchical linear models (HLM) to test the effect of the treatment on student outcomes. Student background variables such as pretest scores, GPA, and gender are used as control variables. In addition, the time interval since the end of instruction will also be controlled for in the analyses. After testing the main effects of treatment, we will then test whether the treatment effects are moderated by pretest scores, gender and GPA. The specific models are shown in the table "HLM Analyses in Appendix B."

According to the theory of change, it is hypothesized that the intervention changes teacher knowledge and practices which in turn lead to changes in student outcomes. To test such mediation effect, we will use Multilevel Structural Equation Modeling (Preacher, Zyphur, & Zhang, 2010). Figure 7 in HLM Analyses, Appendix B, shows the specification of the model. The proposed model is fully saturated and therefore have perfect model fit. We will use the Mplus software version 6.11 (Muthén, & Muthén, 1998-2011) to estimate the model. The 95% confidence intervals of the indirect effects (i.e., a*b) will be computed using the parametric bootstrapping method. This method has the advantage of not assuming the symmetric distribution of the indirect effect and can be implemented using the computer program PRODCLIN developed by MacKinnon et al. (2007). (For details please see HLM Analyses, Appendix B).

Finally, we will examine the impact of fidelity of implementation on student outcomes in the Treatment Group only using HLM (see the specific model in HLM Analyses, Appendix B).

To promptly analyze the data and deliver evaluation results, a centralized data system will be set up by Bo Zhang, a Co-PI from the Educational Statistics and Measurement Program from UW-Milwaukee. This system will store the data in their original formats as well as link them together.

<table>
<thead>
<tr>
<th>Common Concepts</th>
<th>Lesson Plan Alignment with NGSS Standards and the Common Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NGSS Standard 1</td>
</tr>
<tr>
<td>1. Definition of the system, surroundings and interactions</td>
<td>Lesson Plan 1</td>
</tr>
<tr>
<td>2. 1st and 2nd Laws of thermodynamics</td>
<td>……</td>
</tr>
<tr>
<td>3. Fundamental particle Interactions that drive energy transfer</td>
<td>……</td>
</tr>
<tr>
<td>4. “Joule” a universal unit of energy</td>
<td>……</td>
</tr>
</tbody>
</table>
for data analysis. Various statistical packages (e.g., SPSS, SAS, HLM, NVIVO and BILOG for item response theory analysis) will be utilized. A doctoral student trained with statistics and measurement will be hired to manage the data system daily under the supervision of the Co-PI.

2.2C Cluster, Randomized Controlled Trials of Effectiveness of Each Curriculum.

During Year 2 of the study, with the help of the Wisconsin Department of Public Instruction (please see letter in Appendix D), we will obtain commitments from teacher teams made up of biology, chemistry and physics teachers from 40 schools to take part in discipline-specific, cluster, randomized controlled trials of the effectiveness of each curriculum. Because of expected attrition, initially 70 schools will be recruited; we will obtain commitments from 50, and expect that this will provide approximately 40 teachers from each discipline who will actually participate. (We already have a commitment from the urban district, Milwaukee Public Schools, for 8 such teams. Please see the letter in Appendix D.) Teachers of biology, chemistry and physics from schools matched for freshman class size and school ethnicity will be randomly assigned as by the toss of a virtual coin at www.random.org at least one year in advance to either the treatment group or corresponding control group. (Our previous experience suggests that early recruitment will enhance participation by allowing teachers to plan their summer activities at least one year in advance.) This means the entire team will be assigned to attend a Workshop either in the summer of 2018 (Treatment Group) or in the summer of 2019, as compensation for having been the Control Group during that previous academic year. Because we understand that even with prior agreement, not all teachers will be able to attend, any Treatment Group teacher not able to participate in the 2018 workshop will be dropped from the study. However, the rest of the team will be allowed to attend the workshop. We are not specifically testing the establishment of professional learning communities at schools; rather we are testing the promise of the individual curricula under typical conditions. Therefore consistency in the makeup of teams is not integral to the research design. We anticipate that we will end up with approximately 40 schools actually participating, which on average will supply 120 teachers and one class of ~20 of their students, divided into discipline-specific Treatment and Control Groups.

During Year 3, all preparations for the Workshop, including for room use at MSOE to accommodate teachers in disciplinary or inter-disciplinary groups will be completed. Similarly, all preparations for housing and food to accommodate experimental group teachers during the workshop and to accommodate all teachers during the initial half-day meeting will be completed. (See Appendix C for a preliminary workshop Curriculum.)

During the summer of Year 3, all 120 project teachers will attend the first half-day of the workshop in order to provide baseline data and become familiar with the assessment schedule. However, only the 60 teachers who comprise the discipline-specific Treatment Groups will attend the remaining 4.5 days of the workshop (See the Workshop Calendar in Appendix C.) Here they will gain the knowledge and confidence to implement the newly-developed NGSS-based Coherent Energy Curriculum for their discipline and become grounded in the four Common Concepts targeted by this intervention (Table 2). Introductions to invisible interactions that drive energy transfer will be delivered to the entire group in the morning. Much of the rest of the day will be devoted to discipline-specific NGSS-aligned lessons enacted by participants within break-out groups. Each day teachers will have time for conversations across disciplines with teachers from their school team. Time during the workshop will be set aside to for teachers to integrate these lessons into their current curricula, a workshop practice required to change classroom practice. Given the common baseline data regarding knowledge and self-efficacy already collected at the beginning of the workshop, teachers will also be assessed regarding these
outcomes at the end of the workshop. In addition, they will complete a daily Conceptual Connections Record, which will be modified as described above in Table 4 (See Appendix C for the SUN version.)

The design of the three simultaneous cluster, randomized controlled trials will parallel what we did during the successful SUN trial. During the 2018-19 school year, we will collect pre/post data from one class of students of each participating teacher. Each Treatment Group teacher will implement the new NGSS-based Energy Coherent Curriculum for his or her discipline in at least one class, chosen prior to the beginning of school. Informed consent will be gathered from each participating student prior to implementation. Therefore for 20 treatment and 20 control teachers for each of 3 science disciplines, assuming 20 participating students in each class, there will be about 400 treatment students and 400 control students within each disciplinary trial for a total of about 800 x 3 or 2400 students affected across disciplines. Because we are interested in the long-term effects of these curricula, we will assess students at the beginning and end of the school year, taking into account the interval since the end of instruction in the HLM analysis. Students will be assessed for pre/post knowledge and confidence in their answers. Implementation data will be deposited online by teachers per NGSS standard taught. Staff will visit half of the classes to observe using the implementation rubric described in Table 4, which will provide a motivation for fidelity and check on self-reporting.

During Year 4, participating Experimental and Control teachers will gather at regional half-day meetings to discuss implementation of their curriculum (whether treatment or control.) Also, during Year 4, materials for the compensatory Energy across Disciplines Workshop (and subsequent implementation outside of the study by the waitlist controls) will be prepared as described above. In the summer, near the end of Year 4, the Control Group will attend the Energy across Disciplines Workshop AFTER they have contributed control data during the previous school year. The Experimental Group teachers will attend only the first half-day of this workshop. While the Control Group Teachers will provide year-later pre-assessment teacher data, the Experimental Group Teachers will provide data regarding teacher year-later long-term knowledge retention and self-efficacy. Data collection during this workshop regarding teacher outcomes for the Waitlist Control Group will proceed as before.

2.3 Dissemination of Results and Conclusions. Several stakeholders will be interested in the outcome of this work. These include teachers, school and district-level administrators, the state Departments of Public Instruction, those who teach teachers, education researchers and the general public. These stakeholders will become aware of the results of this study in the following ways: All of the Wisconsin teachers (135), administrators (45) and students (at least 2025) who participate in this project, either in its development or during the cluster randomized controlled trials of each disciplinary curriculum will be directly affected. Twenty percent of the teachers in the RCT (24) will be from Milwaukee Public Schools. The advisory board includes the Director of Education and Outreach for the Great Lakes Bioenergy Research Center, a representative from the Wisconsin Department of Public Instruction, the Director of the Milwaukee Area Collaborative Science and Mathematics Teacher Education Program for pre-service teachers at UWM and a representative from the administration of Milwaukee Public Schools. In addition, the Co-PIs will publicize these results during years 3 and 4 by submitting this work to appropriate state and national meetings such as the Wisconsin Society of Science Teachers, The Wisconsin Association of Physics Teachers, the Biennial Conference on Chemical Education, the National Association of Biology Teachers, the AAAS and NARST. Co-PIs Carol Hirschmugl and Ann Batiza will give a presentation on Energy across Disciplines for about 1000
members of the public at the long-running UWM Science Bag as they did before about biological energy transfer. The project will also be discussed at the Gordon Conference on Visualization in Science and Education for which Ann Batiza is the co-chair in 2017.

3. Personnel

<table>
<thead>
<tr>
<th>School/Institution</th>
<th>Name</th>
<th>Position</th>
<th>Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whitefish Bay High School</td>
<td>Bill Henkle</td>
<td>Principal</td>
<td></td>
</tr>
<tr>
<td>Whitefish Bay School District</td>
<td>Judy Weiss</td>
<td>Coordinator, biology, engineering teacher and former engineer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paula Krukar</td>
<td>Physics and chemistry teacher</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Katie Brown</td>
<td>Biology, chemistry and biotechnical engineering teacher</td>
<td></td>
</tr>
<tr>
<td>South Milwaukee High School South Milwaukee School District</td>
<td>Beth Kaminski</td>
<td>Principal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jeff Kubel</td>
<td>Physics teacher</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Joel Shilling</td>
<td>Chemistry teacher</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kelly Farris-Renner</td>
<td>AP Biology teacher and K-12 Science Coordinator</td>
<td></td>
</tr>
<tr>
<td>Oostburg High School Oostburg School District</td>
<td>Scott Greupink</td>
<td>Principal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Terry Hendrikse</td>
<td>Physics and chemistry teacher (formerly biology teacher)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Colette Veldhorst</td>
<td>Chemistry teacher</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ted Schanen</td>
<td>Biology teacher</td>
<td></td>
</tr>
<tr>
<td>Greendale High School Greendale School District</td>
<td>Steve Lodes</td>
<td>Principal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Melissa Senn</td>
<td>Chemistry and AP Chemistry teacher</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amy Zientek</td>
<td>Biology and AP biology teacher</td>
<td></td>
</tr>
<tr>
<td>Harvey Philip HS (alternative school) Waukesha Public School District</td>
<td>Sharon Thiede</td>
<td>Director of Student Services</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sabrina Massy</td>
<td>Chemistry and physics teacher (formerly biology teacher)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lori Hughes</td>
<td>Chemistry and physics teacher</td>
<td></td>
</tr>
<tr>
<td>Rufus King HS Milwaukee Public School District</td>
<td>Jennifer Smith</td>
<td>Principal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vivienne Weber</td>
<td>Biology, Chemistry and Environmental Science teacher</td>
<td></td>
</tr>
<tr>
<td></td>
<td>John Kish</td>
<td>Chemistry, Biology and Environmental Science teacher</td>
<td></td>
</tr>
</tbody>
</table>

This project will be led by Dr. Ann Batiza, who trained as a molecular biologist at UW-Madison after years of teaching, and who was the PI of both the IES and NSF-funded SUN projects that developed an interdisciplinary approach to biological energy transfer. She will oversee all aspects of this project except evaluation. She is also the author of the NSTA-recommended trade textbook, *Bioinformatics, Genomics and Proteomics: Getting the Big Picture*. Co-PI Carol Hirschmugl is a physics professor at UW-Milwaukee whose novel way to
study the chemical composition of live tissue using a synchrotron has been reported in *Nature Methods*. She worked with Ann Batiza using the SUN Project approach in the physics Energy and the Environment course at UWM for non-majors. Co-PI Professor Bo Zhang of UW-Milwaukee is the long-time lead evaluator of the SUN Project and psychometrics expert. Co-PI Marisa Roberts, M.Ed. is also a SUN co-author who teaches biology and chemistry at Whitefish Bay High School, and who teaches pre-service teachers at Concordia University of Wisconsin. Key personnel Professor Robert Hanson of St. Olaf College is a co-author of *Molecular Thermodynamics*, an introductory chemistry textbook now used at Harvard.

The Co-PIs and key personnel for this proposal make up the Core Group of scientists, master teachers and evaluators who will develop the initial curricular lessons and assessments and be involved in all phases of this project. The scientists are: PI, Dr. Ann Batiza-molecular biology; Co-PI, Professor Carol Hirschmugl-physics; and Professor Robert Hanson-chemistry. The master teachers are Co-PI Marisa Roberts – biology and chemistry, Mr. Jonathan Knopp – chemistry and Mr. Terry Hendrikse – physics. The lead evaluator is Co-PI Professor Bo Zhang. Associate Professor Wen Luo of Texas A & M University is the HLM expert for this project. Emeritus Professor David Nelson of UW-Madison, who is the co-author of *Lehninger Principles of Biochemistry*, has kindly volunteered his services during all phases of this project. (Please see letters of agreement in Appendix D and their CVs.). After correspondence by email and Google Docs, this core group will meet for four hours every month during the first year to develop the initial lessons and assessments. They will also meet monthly during the remaining two years during iterative development and validation of the lessons, assessments and workshop. They will also assemble for two full days each summer to finalize curricula and assessments prior to the next year’s iteration and to prepare presentations for the workshops. In the summer of the third year and the fourth year they will present the workshop. The lead designer for this project is Mark Hoelzer, MFA in Web design. As the lead designer for the Center for Biomolecular Modeling at MSOE as well as for the SUN Project, he is an expert in interactive web design.

The Advisory Board Teacher Teams will participate during the first two and a half years as they work with the Core Group to iteratively validate and revise lessons and assessments. (Please see Table 6 and their letters of agreement in Appendix D). A member of the Wisconsin Dept. of Public Instruction, a member of Milwaukee Public Schools and a teacher educator from UW-Milwaukee along with additional scientists will attend 4-hour semi-annual Scientist/Advisory Board meetings, either remotely or in person (Table 7 and Appendix D). These meetings will partially overlap with two of the Advisory Board Team meetings.

<table>
<thead>
<tr>
<th>School/Institution</th>
<th>Name</th>
<th>Position</th>
<th>Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Wisconsin-Madison</td>
<td>Richard Amasino</td>
<td>Professor of Biochemistry, Director of Education and Outreach for the Great Lakes Bioenergy Research Center</td>
<td>√</td>
</tr>
<tr>
<td>University of Wisconsin-Milwaukee</td>
<td>Paul Lyman</td>
<td>Professor of Physics</td>
<td>√</td>
</tr>
<tr>
<td>MSOE</td>
<td>Gul Afsan</td>
<td>Director of Biomolecular Engineering Program</td>
<td>√</td>
</tr>
<tr>
<td>MSOE</td>
<td>Cynthia Barnicki</td>
<td>Metallurgical Engineer and Professor of Mechanical Engineering</td>
<td>√</td>
</tr>
<tr>
<td>MSOE</td>
<td>Jim Mallmann</td>
<td>Professor of Physics and R. D. Peters Professor of Materials Science</td>
<td>√</td>
</tr>
<tr>
<td>MSOE</td>
<td>Eryn Hassemer</td>
<td>Molecular Biologist and Professor in the Biomolecular Engineering Program</td>
<td>√</td>
</tr>
</tbody>
</table>
The PI will collect all formative feedback and provide summaries in advance of the monthly meetings during the first year and will make all revisions suggested for the monthly iterative changes. She or Marisa Roberts, will attend each of the monthly meetings of the Advisory Board Teacher Teams in order to provide an overview of new lessons, answer questions and make observations. Ann Batiza will also oversee collection of all primary data and its organization for retrieval, undergraduate production of school sets of materials, and work with Marisa Roberts to recruit schools for the RCTs. She will write the Energy Across Disciplines Workshop Manual and make all preparations for the two workshops with Marisa Roberts. During the cluster RCTs, she and Marisa Roberts will visit all of the schools (Treatment and Control) in order to collect data regarding the materials used and level of implementation of the Coherent Energy Framework. She will provide teachers with needed assessments, correspond about timely deposition of implementation data and also store primary data from the RCTs at MSOE. In addition, Ann Batiza and Marisa Roberts will lead 8 semi-annual regional meetings of the treatment and control teachers. Although each teacher will attend two meetings, they will be held in different areas in the state. Wen Luo will conduct the HLM analysis as soon as data is available in Year 4. Bo Zhang will analyze formative data as it becomes available, teacher outcome data from the two workshops, and oversee the summative evaluation in the summer of Year 4. All members of the Core Group will contribute to papers prepared by this work and all Co-PIs will attend meetings to disseminate findings in years 3 - 4.

4. Resources

MSOE is fully equipped to produce the necessary SUN materials as they have in the past. The SUN Project has a 36-inch inch Canon iPF720 plotter and large laminator. Ann Batiza shares the resources of the MSOE Center for BioMolecular Modeling (CBM) which is equipped with ZCorp printers for rapid prototyping of any needed models. It has two PC and one Silicon Graphics workstations with software packages (RP-RasMol, RP-Magics and SolidWorks) required for this project and well as Adobe software for illustration, graphics, and video editing. It provides 700 square feet laboratory space for assembling all necessary materials and an auditorium which can be used for gatherings of all participants during the workshop. Media-rich classrooms can easily handle the disciplinary sub-groupings of 20 teachers and meetings of the Advisory Board Teacher teams with remote access available by Webex. Because of our experience with the SUN Project, we are well equipped to handle collection of informed consent, primary data collection, coding of formative data in SPSS and development of online surveys needed to collect data regarding adherence to the Coherent Energy Framework while the treatment group teachers implement the new energy-based NGSS-aligned curricula. We will continue to use Ioxphere software for which data MSOE has a secure server. At UWM, Professor Bo Zhang has all needed analysis resources as stated above. We feel that application of the Coherent Energy Framework, which answers the question, “What concepts make it apparent that the meaning of energy is equivalent across disciplines?” has the potential to significantly increase student knowledge about energy and belief that fundamental interactions power all energy transfer. We are eager to begin this work.
Appendix A

On January 10, 2014, we submitted a proposal to NSF-REAL called: *Energy Across Disciplines: Research on Curricular and Teacher Change through a Scientist/Educator Partnership and Iterative Design by Professional Learning Communities*. While both that proposal, which was not funded, and our current proposal share a focus on energy across disciplines, the earlier proposal’s hypotheses were directed at teacher outcomes, not at student outcomes. Also, we had not yet developed the Coherent Energy Framework and therefore the conceptual basis for the research was poorly specified.

This proposal targets student outcomes after having validated and established the feasibility of use of curricula for the three main science disciplines. While the previous proposal was focused on supporting the working of teacher teams as they developed an energy learning progression at their schools, this proposal has a clear plan regarding how information will flow. Lessons will be developed by a Core Group of scientists and master teachers with a definite plan for monthly feedback from the teacher teams. Also, development during the earlier proposal would have lasted only two years, not three. While the NSF proposal outcomes included case studies of the establishment of professional learning communities at different high schools, this work will conduct three simultaneous cluster, randomized controlled trials regarding the impact of three discipline-based science curricular on student knowledge. These curricula all answer the question, “What concepts make it apparent that the meaning of energy is equivalent across disciplines?” We are fortunate that our earlier proposal was not funded as it has given us time to wrestle with this question and to arrive at the four Common Concepts with their Common Visualizations and Common Practices that can guide a coherent approach to energy across disciplines.
Based on our analysis, there are 28 energy-related NGSS standards that we feel will strengthen conceptual understanding of the link between external manifestations and the fundamental interactions that drive energy transfers. These include standards listed in Next Generation Science Standards:  For States, By States (NGSS Lead States, 2013) under the headings Chemical Reactions, Structure and Properties of Matter, Forces and Interactions, Energy, Waves and Electromagnetic Radiation and Matter and Energy in Organisms and Ecosystems. We have designated 13 standards that will be addressed in the Physics Energy Curriculum, 8 standards that will be addressed in the Chemistry Energy Curriculum, and 6 that will be addressed in the Biology Curriculum. The standards addressed are indicated in the Table below.

<table>
<thead>
<tr>
<th>Standards that will be addressed in each energy curriculum. Note that the focus of each standard has been summarized to more readily convey the topic. The wording is not exact.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physics</strong></td>
</tr>
<tr>
<td>HS-PS2-1 Analyzing data regarding relationship between force, mass and acceleration of an object</td>
</tr>
<tr>
<td>HS-PS2-2 Using math to show total momentum conserved when no net force on system</td>
</tr>
<tr>
<td>HS-PS2-4 Using Newton’s Law of Gravitation and Coulomb’s law to predict the gravitational and electrostatic forces between objects.</td>
</tr>
<tr>
<td>HS-PS2-5 Planning an experiment to provide evidence regarding induction of magnetic and electric fields</td>
</tr>
<tr>
<td>HS-PS3-1 Mathematically modeling the change in energy of system components</td>
</tr>
<tr>
<td>HS-PS3-2 Developing and using models to show that macro level energy can be accounted for as a combination of the energy associated with the motion of particles and their relative positions.</td>
</tr>
<tr>
<td>HS-PS3-3 Designing, building and refining a device with constraints that converts one form of energy into another.</td>
</tr>
<tr>
<td>HS-PS3-4 Providing evidence from a student-designed experiment of the transfer of</td>
</tr>
<tr>
<td>Thermal energy in a closed system to show a more uniform distribution of energy</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>HS-PS3-5</strong> Developing and using a model of two objects interacting through electrical or magnetic fields to illustrate the forces and changes in energy of the objects due to the interaction.</td>
</tr>
<tr>
<td><strong>HS-PS4-1</strong> Using math to support a claim about relationship among frequency, wavelength and speed of waves in various media.</td>
</tr>
<tr>
<td><strong>HS-PS4-3</strong> Evaluating claims and evidence of electromagnetic radiation as a particle or wave, and usefulness of each model</td>
</tr>
<tr>
<td><strong>HS-PS4-4</strong> Evaluating validity and reliability of claims of effects of different radiation frequencies when absorbed by matter</td>
</tr>
<tr>
<td><strong>HS-PS4-5</strong> Communicating how some devices use the principles of wave behavior and interactions with matter to transmit and capture information and energy</td>
</tr>
<tr>
<td>Year</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td><strong>Year 1</strong></td>
</tr>
<tr>
<td>September</td>
</tr>
<tr>
<td>2015 – August 2016</td>
</tr>
<tr>
<td><strong>Year 2</strong></td>
</tr>
<tr>
<td>September</td>
</tr>
<tr>
<td>2016 – August 2017</td>
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<tr>
<td><strong>Year 3</strong></td>
</tr>
<tr>
<td>September</td>
</tr>
<tr>
<td>2017 – August 2018</td>
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<tr>
<td><strong>Year 4</strong></td>
</tr>
<tr>
<td>September</td>
</tr>
<tr>
<td>2018 – August 2019</td>
</tr>
<tr>
<td><strong>Year 4</strong></td>
</tr>
<tr>
<td>September</td>
</tr>
<tr>
<td>2018 – August 2019</td>
</tr>
<tr>
<td><strong>Year 4</strong></td>
</tr>
<tr>
<td>September</td>
</tr>
<tr>
<td>2018 – August 2019</td>
</tr>
<tr>
<td><strong>Year 4</strong></td>
</tr>
<tr>
<td>September</td>
</tr>
<tr>
<td>2018 – August 2019</td>
</tr>
</tbody>
</table>
## Appendix B

### Models in the HLM and ML-SEM analysis

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Statistical Model</th>
</tr>
</thead>
</table>
| Are there differences between the control and treatment groups in student outcomes controlling for pretest, gender, GPA, and time interval since instruction? | Level 1: $Y_{ij} = \beta_0 + \beta_1 \text{Pretest}_{ij} + \beta_2 \text{Gender}_{ij} + \beta_3 \text{GPA}_{ij} + e_{ij}$  
Level 2: $\beta_0 = \gamma_{00} + \gamma_{01} \text{Time\_Interval}_j + \gamma_{02} \text{Treatment}_j + u_{0j}$  
$\beta_1 = \gamma_{10} + u_{1j}$  
$\beta_2 = \gamma_{20} + u_{2j}$  
$\beta_3 = \gamma_{30} + u_{3j}$  
where $i$ indexes students within teachers and $j$ indexes teachers. The coefficient $\gamma_{03}$ represents the difference between the control vs. the treatment group controlling for all the covariates. |
| Are the treatment effects moderated by pretest, gender, and GPA?                     | Level 1: $Y_{ij} = \beta_0 + \beta_1 \text{Pretest}_{ij} + \beta_2 \text{Gender}_{ij} + \beta_3 \text{GPA}_{ij} + e_{ij}$  
Level 2: $\beta_0 = \gamma_{00} + \gamma_{01} \text{Time\_Interval}_j + \gamma_{02} \text{Treatment}_j + u_{0j}$  
$\beta_1 = \gamma_{10} + \gamma_{11} \text{Treatment}_j + u_{1j}$  
$\beta_2 = \gamma_{20} + \gamma_{21} \text{Treatment}_j + u_{2j}$  
$\beta_3 = \gamma_{30} + \gamma_{31} \text{Treatment}_j + u_{3j}$  
where $\gamma_{11}$, $\gamma_{21}$, and $\gamma_{31}$ represent the interaction effect between treatment and pretest, gender, and GPA, respectively. |
| Are the treatment effects mediated by teacher knowledge, teacher-self efficacy, and teacher practice? | See the Multilevel SEM model depicted in Figure 7. |
| What are the effects of teachers’ fidelity of implementation on students’ outcomes in the treatment condition? | Level 1: $Y_{ij} = \beta_0 + \beta_1 \text{Pretest}_{ij} + \beta_2 \text{Gender}_{ij} + \beta_3 \text{GPA}_{ij} + e_{ij}$  
Level 2: $\beta_0 = \gamma_{00} + \gamma_{01} \text{Time\_Interval}_j + \gamma_{02} \text{Fidelity}_j + u_{0j}$  
$\beta_1 = \gamma_{10} + u_{1j}$  
$\beta_2 = \gamma_{20} + u_{2j}$  
$\beta_3 = \gamma_{30} + u_{3j}$  |
Figure 7. Multilevel SEM for mediation analysis.
Energy Transfer Teaching Efficacy Belief Instrument

Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate letters to the right of each statement.

SA = Strongly Agree
A = Agree
UN = Uncertain
D = Disagree
SD = Strongly Disagree

1. When a student does better than usual in energy transfer, it is often because the teacher exerted a little extra effort. SA A UN D SD
2. I am continually finding better ways to teach energy transfer. SA A UN D SD
3. Even when I try very hard, I don’t teach energy transfer as well as I do most subjects. SA A UN D SD
4. When the energy transfer grades of students improve, it is most often due to their teacher having found a more effective teaching approach. SA A UN D SD
5. I know the steps necessary to teach energy transfer concepts effectively. SA A UN D SD
6. I am not very effective in monitoring energy transfer experiments. SA A UN D SD
7. If students are underachieving in energy transfer, it is most likely due to ineffective energy transfer teaching. SA A UN D SD
8. I generally teach energy transfer ineffectively. SA A UN D SD
9. The inadequacy of a student's energy transfer background can be overcome by good teaching. SA A UN D SD
10. The low energy transfer achievement of some students cannot generally be blamed on their teachers. SA A UN D SD
11. When a low achieving child progresses in energy transfer, it is usually due to extra attention given by the teacher. SA A UN D SD
12. I understand energy transfer concepts well enough to be effective in teaching elementary energy transfer. SA A UN D SD
13. Increased effort in energy transfer teaching produces little change in some students' energy transfer achievement. SA A UN D SD
14. The teacher is generally responsible for the achievement of students in energy transfer. SA A UN D SD
15. Students' achievement in energy transfer is directly related to their teacher's effectiveness in energy transfer teaching. SA A UN D SD
16. If parents comment that their child is showing more interest in energy transfer at school, it is probably due to the performance of the child's teacher. SA A UN D SD
17. I find it difficult to explain to students why energy transfer experiments work. SA A UN D SD
18. I am typically able to answer students' energy transfer questions. SA A UN D SD
19. I wonder if I have the necessary skills to teach energy transfer. SA A UN D SD
20. Effectiveness in energy transfer teaching has little influence on the achievement of students with low motivation. SA A UN D SD
21. Given a choice, I would not invite the principal to evaluate my energy transfer teaching. SA A UN D SD
22. When a student has difficulty understanding a energy transfer concept, I am usually at a loss as to how to help the student understand it better. SA A UN D SD
23. When teaching energy transfer, I usually welcome student questions. SA A UN D SD
24. I don’t know what to do to turn students on to energy transfer. SA A UN D SD
25. Even teachers with good energy transfer teaching abilities cannot help some kids learn energy transfer. SA A UN D SD
STEBI FORM B SCORING INSTRUCTIONS  (Inservice)

Step 1. Item Scoring: Items must be scored as follows: Strongly Agree = 5; Agree = 4; Uncertain = 3; Disagree = 2; and Strongly Disagree = 1.

Step 2. The following items must be reverse scored in order to produce consistent values between positively and negatively worded items. Reversing these items will produce high scores for those high and low scores for those low in efficacy and outcome expectancy beliefs.

<table>
<thead>
<tr>
<th>Item 3</th>
<th>Item 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 6</td>
<td>Item 19</td>
</tr>
<tr>
<td>Item 8</td>
<td>Item 21</td>
</tr>
<tr>
<td>Item 10</td>
<td>Item 22</td>
</tr>
<tr>
<td>Item 13</td>
<td>Item 24</td>
</tr>
<tr>
<td>Item 15</td>
<td>Item 25</td>
</tr>
</tbody>
</table>

In SPSSx, this reverse scoring can be accomplished by using the RECODE command. For example, recode ITEM3 with the following command:

```
RECODE ITEM3 (5=1) (4=2) (2=4) (1=5)
```

Step 3. Items for the two scales are scattered randomly throughout the STEBI B. The items designed to measure Personal Science Teaching Efficacy Belief are as follows:

<table>
<thead>
<tr>
<th>Item 2</th>
<th>Item 12</th>
<th>Item 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 3</td>
<td>Item 17</td>
<td>Item 23</td>
</tr>
<tr>
<td>Item 5</td>
<td>Item 18</td>
<td>Item 24</td>
</tr>
<tr>
<td>Item 6</td>
<td>Item 19</td>
<td></td>
</tr>
<tr>
<td>Item 8</td>
<td>Item 21</td>
<td></td>
</tr>
</tbody>
</table>

Items designed to measure Outcome Expectancy are as follows:

<table>
<thead>
<tr>
<th>Item 1</th>
<th>Item 10</th>
<th>Item 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 4</td>
<td>Item 11</td>
<td>Item 16</td>
</tr>
<tr>
<td>Item 7</td>
<td>Item 13</td>
<td>Item 20</td>
</tr>
<tr>
<td>Item 9</td>
<td>Item 14</td>
<td>Item 25</td>
</tr>
</tbody>
</table>

Note: In the computer program, DO NOT sum scale scores before the RECODE procedures have been completed. In SPSSx, this summation may be accomplished by the following COMPUTE command:

```
COMPUTE ESCALE = ITEM2 + ITEM3 + ITEM5 + ITEM6 + ITEM8 + ITEM12 + ITEM17 + ITEM18 + ITEM19 + ITEM21 + ITEM22 + ITEM23 + ITEM24

COMPUTE OESCALE = ITEM1 + ITEM4 + ITEM7 + ITEM9 + ITEM10 + ITEM11 + ITEM13 + ITEM14 + ITEM15 + ITEM16 + ITEM20 + ITEM25
```

SUN Workshop 2010 Conceptual Connections Record

Today, you will record your previous knowledge and baseline understanding of cellular respiration and photosynthesis. This exercise will provide you with a record of your growth in understanding of both key processes during the workshop.

Later you may use this “Conceptual Connections Record” to review what you have learned during this course.

Directions

At the beginning of class today...

1. **Draw a line for each connection you can make** between “Cellular Respiration” and each of the surrounding concepts. Do the same between “Photosynthesis” and each of the surrounding concepts.

2. **Number each line** you draw sequentially within that category as (X.X). The numbers will reflect the category (the first X) and the sequential number of connections drawn (the second X).

3. On the Daily Conceptual Connections Record, for each line drawn, **record the number (X.X) and a statement** that shows a relationship between the outlying concept to which the line was drawn and Cellular Respiration or Photosynthesis. Use as many sheets as you need.

For example:

<table>
<thead>
<tr>
<th>No. (X.X)</th>
<th>Between X and Cellular Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Describe a relationship between “fuel cell” and “cellular respiration.”</td>
</tr>
<tr>
<td>1.2</td>
<td>Describe a second connection between “fuel cell” and “cellular respiration.”</td>
</tr>
<tr>
<td>5.1</td>
<td>Describe a relationship between ATP and cellular respiration.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No. (X.X)</th>
<th>Between X and Photosynthesis (not shown)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Describe a relationship between fuel cell and photosynthesis.</td>
</tr>
<tr>
<td>Day</td>
<td>Time</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Sunday</td>
<td>Noon-1:00</td>
</tr>
<tr>
<td>PM</td>
<td>1:00-3:00</td>
</tr>
<tr>
<td></td>
<td>3:00-4:00</td>
</tr>
<tr>
<td></td>
<td>4:00-5:00</td>
</tr>
<tr>
<td></td>
<td>5:00-6:00</td>
</tr>
<tr>
<td></td>
<td>6:00-8:00</td>
</tr>
<tr>
<td>Monday</td>
<td>9:00-9:30</td>
</tr>
<tr>
<td>AM</td>
<td>9:30-9:50</td>
</tr>
<tr>
<td></td>
<td>9:50-10:15</td>
</tr>
<tr>
<td></td>
<td>10:15-10:30</td>
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<tr>
<td></td>
<td>10:30-12:00</td>
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<td></td>
<td>12:00-1:00</td>
</tr>
<tr>
<td>Monday</td>
<td>1:00-2:45</td>
</tr>
<tr>
<td>PM</td>
<td>2:45-3:00</td>
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<tr>
<td></td>
<td>3:00-4:15</td>
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<tr>
<td></td>
<td>4:15-4:45</td>
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<td></td>
<td>4:45-5:00</td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuesday</td>
<td>9:00-10:30</td>
</tr>
<tr>
<td>AM</td>
<td>10:30-10:45</td>
</tr>
<tr>
<td></td>
<td>10:45-12:00</td>
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<tr>
<td></td>
<td>12:00-1:00</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Activities</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Tuesday PM</strong></td>
<td>Lesson work in discipline teams (1:45)</td>
</tr>
<tr>
<td></td>
<td>o Physics (Magnetic/electrical field interaction using DC motor kits)</td>
</tr>
<tr>
<td></td>
<td>o Chemistry (chemical reactions based on outermost electron arrangement of</td>
</tr>
<tr>
<td></td>
<td>atoms)</td>
</tr>
<tr>
<td></td>
<td>o Biology (cellular respiration)</td>
</tr>
<tr>
<td></td>
<td>Break (15 min)</td>
</tr>
<tr>
<td></td>
<td>Continue with Lesson work (1:15)</td>
</tr>
<tr>
<td></td>
<td>School-based teacher teams discuss what they have learned (0:30)</td>
</tr>
<tr>
<td></td>
<td>Conceptual Connections Record (CCR) (0:15)</td>
</tr>
<tr>
<td><strong>Wednesday AM</strong></td>
<td>3rd fundamental interaction - Photoelectric effect (1:30)</td>
</tr>
<tr>
<td></td>
<td>Break (15 min)</td>
</tr>
<tr>
<td></td>
<td>Lesson work in discipline teams (1:15)</td>
</tr>
<tr>
<td></td>
<td>o Physics (transmitting and capturing information and energy through waves)</td>
</tr>
<tr>
<td></td>
<td>o Chemistry (energy changes in chemical reactions based on changes in bond</td>
</tr>
<tr>
<td></td>
<td>energy between atoms)</td>
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<tr>
<td></td>
<td>o Biology (photosynthesis)</td>
</tr>
<tr>
<td></td>
<td>Lunch (1:00)</td>
</tr>
<tr>
<td><strong>Wednesday PM</strong></td>
<td>Lesson work in discipline teams (1:45)</td>
</tr>
<tr>
<td></td>
<td>o Physics (transmitting and capturing information and energy through waves)</td>
</tr>
<tr>
<td></td>
<td>o Chemistry (energy changes in nuclear reactions based on transformations</td>
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<td></td>
<td>within atoms)</td>
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<tr>
<td></td>
<td>o Biology (photosynthesis)</td>
</tr>
<tr>
<td></td>
<td>Break (0:15)</td>
</tr>
<tr>
<td></td>
<td>Continue with Lesson work (1:15)</td>
</tr>
<tr>
<td></td>
<td>School-based teacher teams discuss what they have learned (0:30)</td>
</tr>
<tr>
<td></td>
<td>Conceptual Connections Record (CCR) (0:15)</td>
</tr>
<tr>
<td><strong>Thursday AM</strong></td>
<td>4th fundamental interaction - quantum levels (1:30)</td>
</tr>
<tr>
<td></td>
<td>Break (0:15)</td>
</tr>
<tr>
<td></td>
<td>Lesson work in discipline teams (1:15)</td>
</tr>
<tr>
<td></td>
<td>o Physics (particle motion and energy on the macroscopic and microscopic</td>
</tr>
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<td></td>
<td>levels)</td>
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<tr>
<td></td>
<td>o Chemistry (reaction rate and kinetic molecular theory)</td>
</tr>
<tr>
<td></td>
<td>o Biology (cycling related to PS and CR)</td>
</tr>
<tr>
<td></td>
<td>Lunch</td>
</tr>
<tr>
<td>Time</td>
<td>Activity</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1:00-2:45</td>
<td>Lesson work in discipline teams (1:45)</td>
</tr>
<tr>
<td></td>
<td>- Physics (particle motion and energy on the macroscopic and microscopic levels)</td>
</tr>
<tr>
<td></td>
<td>- Chemistry (conservation of mass and equilibrium in reactions)</td>
</tr>
<tr>
<td></td>
<td>- Biology (cycling related to PS and CR)</td>
</tr>
<tr>
<td>2:45-3:00</td>
<td>Break (0:15)</td>
</tr>
<tr>
<td>3:00-4:15</td>
<td>Continue with Lesson work (1:15)</td>
</tr>
<tr>
<td>4:15-4:45</td>
<td>School-based teacher teams discuss what they have learned (0:30)</td>
</tr>
<tr>
<td>4:45-5:00</td>
<td>Conceptual Connections Record (CCR) (0:15)</td>
</tr>
<tr>
<td>1:00-2:00</td>
<td>Lesson work in discipline teams (2:00)</td>
</tr>
<tr>
<td>2:00-3:00</td>
<td>Break (0:15)</td>
</tr>
<tr>
<td>3:00-3:15</td>
<td>School-based teacher teams – meet to begin adjustments to curriculum (1:15)</td>
</tr>
<tr>
<td>3:15-4:45</td>
<td>Lunch (1:00)</td>
</tr>
<tr>
<td>4:45-5:00</td>
<td>Large group session - guidelines for adjusting curriculum (0:30)</td>
</tr>
<tr>
<td>1:00-2:00</td>
<td>School-based teacher teams - meet again to finalize adjustments (1:00)</td>
</tr>
<tr>
<td>2:00-3:00</td>
<td>Discipline teams – meet to continue adjustments (1:00)</td>
</tr>
<tr>
<td>3:00-3:15</td>
<td>Break (0:15)</td>
</tr>
<tr>
<td>3:15-4:45</td>
<td>Continue with discipline team discussions (1:30)</td>
</tr>
<tr>
<td>4:45-5:00</td>
<td>Conceptual Connections Record (CCR) (0:15)</td>
</tr>
<tr>
<td>9:00-9:30</td>
<td>Large group session - look at goals achieved (0:30)</td>
</tr>
<tr>
<td>9:30-10:30</td>
<td>Discuss online data implementation recording and schedule for assessments (1:00)</td>
</tr>
<tr>
<td>10:30-10:45</td>
<td>Break (0:15)</td>
</tr>
<tr>
<td>10:45-12:00</td>
<td>Administration of post assessments (1:15)</td>
</tr>
<tr>
<td>12:00-1:00</td>
<td>Lunch (1:00)</td>
</tr>
<tr>
<td>1:00-2:00</td>
<td>Discipline teams meet to go over adjustments made and answer questions (1:00)</td>
</tr>
<tr>
<td>2:00-3:00</td>
<td>School-based teacher teams – to review any changes made (1:00)</td>
</tr>
<tr>
<td>3:00-3:15</td>
<td>Break (0:15)</td>
</tr>
<tr>
<td>3:15-4:15</td>
<td>Entire group meets to go over adjustments made (1:00)</td>
</tr>
<tr>
<td>4:15-4:45</td>
<td>Conceptual Connections Record (CCR) (0:15)</td>
</tr>
<tr>
<td>4:45-5:00</td>
<td>Farewells (0:15)</td>
</tr>
</tbody>
</table>
### Example of the Coherent Energy Framework Components Aligned to an NGSS Standard

This is an example of how components of the framework and the NGSS standard can guide curricular development. This example has not been validated by the process for curricular validation described in this proposal. But it shows a way in which the components of the framework can be mapped to domain-specific and NGSS-aligned content. This would follow a previous real world exploration of this phenomenon that is more complex.

**Course and Grade** 11th/12th Grade Physics

**Lesson Topic:** Energy relationships within Newton’s Law of Gravity and Coulomb’s Law of electrostatic force. (This part addresses only Coulomb’s Law and occurs over several days.)

The fully developed lesson plan will give an optimized sequence of events.

**NGSS Standard:** HS-PS2-4. Use mathematical representations of Newton’s Law of Gravitation and Coulomb’s Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [Assessment Boundary: Assessment is limited to systems with two objects.]

<table>
<thead>
<tr>
<th>Lesson Components</th>
<th>By Teacher</th>
<th>By Student</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Definition of the system, surroundings and interactions</strong></td>
<td>1.1 and 1.2 Engagement - Coulomb’s Law of Electrostatic forces: Previous day’s use hydrogen fuel cells allowed students to experience charge movement and plot the energy transfers. Today’s lesson focuses on a more isolated system. 1.1 Pith ball demonstration. (We will film a demonstration similar to that at <a href="http://www.ap.smu.ca/demonstrations/index.php?option=com_content&amp;view=article&amp;id=106:pithballs">http://www.ap.smu.ca/demonstrations/index.php?option=com_content&amp;view=article&amp;id=106:pithballs</a></td>
<td>1.1 Exploration - Pith balls and charging rods / cloths. Students explore relationship between charge and distance. Present as an inquiry demonstration by giving very little to no background information, negatively charging both balls. Then have students work with these materials while focused on answering a guided question. After individual and then small group exploration, come to a consensus as a class.</td>
</tr>
</tbody>
</table>
transfer process diagrams to define visible energy transfers that occur and come to a consensus model. “Indicators” and “factors” that influence that transfer can be identified.

1.3 Students define the components of the system, surroundings and interactions for a specified transfer process.

1.2 and 1.3 The discussion to define the system under consideration can be done with guiding questions that allow students to discuss this in small groups before coming to a consensus as a class.

Initially define the system to include all the components in the demonstration: the arm, cloth, rod, and pith balls. While all below are components, they are involved in a series of energy transfers, where components within each new system define an energy transfer.

1) Rubbing the rod with the cloth.
2) Then bringing the rod close to the hanging pith balls.
3) Then removing the rod and just considering the charged balls. 4)And then touching the balls to remove the charge.

1) Rubbing the rod with the cloth.
2) Then bringing the rod close to the hanging pith balls.
3) Then removing the rod and just considering the charged balls. 4)And then touching the balls to remove the charge.

4) The system under consideration toward the end first contains just the charged red and blue balls. Therefore one could redraw that system to show there is some interaction (a force) between them that acts at a distance.
5) If we knew the charge on each ball, we could calculate that force.

\[ F = \frac{k(q_1q_2)}{r^2} \] where Q is in Coulombs (Joules/volt) and r is in m

6) Notice how the system changes when the charged rod is brought near the balls. There was a transfer of energy from the rod to the balls because the balls moved. How could we calculate that energy transfer??
7) Energy transfer in the form of electrons moving (Depends upon how you define the system. This one goes all the way back to the well fed person. Assume a closed system that captures all the gas exchanged by the person.)

Atoms gain electrons in graphite on pith balls ← atoms gain electrons in the ebonite rod ← atoms in the fur give away electrons, movement of the arm converting mechanical energy into electrostatic energy force electrons to leave the fur ← conversion of chemical energy (food) into mechanical energy to move the arm

<table>
<thead>
<tr>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balls, rod, cloth, person present after eating</td>
<td>Balls, Person rubs rod with cloth. All else present.</td>
<td>Person touches to balls with rod. All else present.</td>
<td>Balls swing apart even without rod. All else present.</td>
</tr>
<tr>
<td>Unusable energy</td>
<td>Unusable energy</td>
<td>Unusable energy</td>
<td>Unusable energy</td>
</tr>
</tbody>
</table>

2.1st and 2nd Laws of thermodynamics

2.1 Real world experience of energy transfer

2.2 Students create energy transfer process diagrams to define energy transfers that occur.

2.3 Students explain how the animation illustrates the first and second laws. (not used here.)

2.4 Students create a snapshot of energy storage at the beginning, middle and end of energy transfer accounting for the first and second laws.

2.5 The teacher draws explicit

2.1, 2.2 and 2.4 were addressed in the discussion and drawings above.

2.5 The teacher should draw explicit attention to the first and second laws when discussing aspects of the demonstration.

2.4 Students could draw such structures above as a pie with a wedge for everything else at each stage.

Or they could draw a pie with wedges just for the movement of the pith balls by the rod. (redefining the system). Then the system includes only the charged balls and the charged rod.
<table>
<thead>
<tr>
<th>3. Fundamental particle interactions that drive energy transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Students manipulate interactive visualizations to discover interaction laws and make predictions regarding outcomes.</td>
</tr>
<tr>
<td>3.2 Students are guided to link the fundamental particle interaction explored to the real world experience encountered.</td>
</tr>
<tr>
<td>3.3 Students provide arguments to explain results using the interactive visualization or laboratory/experiment or demonstrations.</td>
</tr>
<tr>
<td>3.4 Teachers describe an application of that same particle interaction that drives energy transfer in another discipline.</td>
</tr>
</tbody>
</table>

| 3.2 The teacher asks students to explain the connection between the fundamental particle interaction and the real world experiences analyzed. |

<table>
<thead>
<tr>
<th>3.4 Application of Coulomb’s Law to Chemistry. One can use a similar formula to calculate the force between positively and negatively charged ions. When ions move across that distance, one can calculate the energy required or expended.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F = k \frac{q_1 q_2}{r^2} ) so ( E = k \frac{q_1 q_2}{r} ) because energy = Force * distance</td>
</tr>
</tbody>
</table>

| Note: The atomic radius diagram is a common visualization of the typical energy as an electron approaches a positively charged nucleus. This is something that students will again encounter in college. |

| 3.4 Connection to Biology: Discussion about how electrostatic charges are essential to aerobic respiration. Remind students of exploration in biology where they learned that electrons move across the electron transport chain. This results in the formation of ATP (as well as CO₂ and H₂O). Similarly, these charges are important in movement of electrons during photosynthesis and production of glucose plus oxygen. |

<table>
<thead>
<tr>
<th>4. “Joule” is a universal unit of energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 Students calculate work done in joules.</td>
</tr>
<tr>
<td>4.2 Students use the number line to position particular energy expenditure</td>
</tr>
</tbody>
</table>

| Assume that one has transferred \( 3 \times 10^8 \) electrons to each pith ball. Calculate the number of Coulombs on each pith ball \( (q_1 \text{ and } q_2) \), measure the distance between the pith balls, and calculate the Force*distance – or the energy expended to separate the pith balls. |

| \( q_1 \text{ (Coulombs)} = \text{number of electrons} \times 1.6 \times 10^{-19} \) (Coulombs) |
| \( F = k \frac{q_1 q_2}{r^2} \); \( k = 9 \times 10^9 \text{ Nm}^2/C^2 \) |

| The energy expended to separate the pith balls – assuming 10 cm distance between the pith balls was about \( 2 \times 10^{-7} \text{ Nm} \) or \( 2 \times 10^{-7} \text{ J.} \) |

| 3.1 and 3.3 Students explore Coulomb’s law interactive website and identify trends when the data is manipulated. An example is shown below. We will create our own version of this animation. [http://employees.oneonta.edu/viningwj/sims/coulombs_law_s.html](http://employees.oneonta.edu/viningwj/sims/coulombs_law_s.html) |
### 4.3 Teachers/students convert common units to joules in other disciplines.

### 4.4 Teachers/students refer to comparable energy expenditure in another discipline.

<table>
<thead>
<tr>
<th>We will develop an interactive, digital number line that shows images at various levels to illustrate examples of work done at different orders of magnitude. We will use as a reference initially information on relative energies at <a href="http://en.wikipedia.org/wiki/Orders_of_magnitude_energy">http://en.wikipedia.org/wiki/Orders_of_magnitude_energy</a>. We will also create a portable image for use without the computer.</th>
</tr>
</thead>
<tbody>
<tr>
<td>These are not comparable to the original problem, but one can discuss the magnitude of difference:</td>
</tr>
<tr>
<td>✷ Chemistry: Compare this to the energy needed to heat 3 x 10^8 molecules of ice to melt into water.</td>
</tr>
<tr>
<td>✷ Physics: Compare this to the energy expended to light a 10 watt night light for 1 second.</td>
</tr>
<tr>
<td>✷ Biology: Compare this to the amount of calories in one gram of oil. OR identify the amount of energy required to hold a 1 kg book at arms length for 1 minute.</td>
</tr>
<tr>
<td>✷ OR calculate the energy expended walking up the stairs – up 3 meters in 1, 10 and 100 seconds.</td>
</tr>
</tbody>
</table>

#### Clarify energy terms in scientifically accurate ways

<table>
<thead>
<tr>
<th>Students work on provided questions related to Coulomb’s Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answers can be checked using a Coulomb’s Law calculator.</td>
</tr>
<tr>
<td>We will look for online sites released to the public domain or create the specific examples required. An example is given below.<a href="http://www.endmemo.com/physics/coulomb.php">http://www.endmemo.com/physics/coulomb.php</a></td>
</tr>
</tbody>
</table>

- Introduction to Coulomb’s Law and the inverse square law formula
  - Charge polarity determines repulsion or attraction
  - Directly proportional for particle charges
  - Inversely proportional and exponential for particle distance
  - Coulomb’s Constant: 9.0 x 10^9 N•m^2/C^2
- 1 Coulomb is the charge transported by 6.2 *10^18 electrons passing a point in a circuit in 1 second.

All materials required will be either part of the public domain or we will create digital and other visual materials that fill that need specifically for this project. Mark Hoelzer, MFA in Web design has 1.1 months each year devoted to this work. His apprentice will devote 3 months/yr and the 2 undergraduates can contribute as well.
Group of Co-PI Scientists and Master Teachers

This is a letter of commitment for participating in the proposal entitled,” Energy Across Disciplines: Development and RCT Testing of Coherent Energy Curricula for Biology Chemistry and Physics.” I will participate in monthly meetings and correspondence between the meetings during the first year to develop the initial lessons and assessment with the core group of co-PIs, master teachers and lead evaluator. In the second and third years, I will continue to participate in the monthly meetings for the iterative development and validation of the lessons, assessments and workshop on Energy Across the Disciplines. I will spend 2 days each summer in the first 2 years to finalize curricula and assessments prior to the next years iteration and in the summer of the third and fourth years to prepare your presentations for the workshop. During the summers of the third and fourth years, I will attend the entire workshop, and participate in the general sessions as needed, and co-lead the presentations with the physics break-out sessions. Further, I will participate in the 4 hour, semi-annual Scientist/ Advisory Board meetings. contribute to papers that come from this work and develop a Science Bag presentation in the third year.

If you have any questions, please do not hesitate to contact me at cjhirsch@uwm.edu, or at 414-229-5748 or 414-229-5589.

Regards,

Carol Hirschmugl
Professor of Physics
University of Wisconsin – Milwaukee
August 5, 2014

Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee WI 53202-3109

Dear Ann,

I am writing to let you know that I am very happy to be a member of the “Energy across Disciplines: Development, Validation and Pilot Testing of Integrated NGSS-based High School Energy Curricula” project. I am an associate professor in the educational statistics and measurement area from University of Wisconsin – Milwaukee.

I will serve as a Co-PI as well as the lead evaluator for this project from September 2015 – August 2019. Specifically, I will be responsible for the statistical and psychometric analyses for the program. I will also supervise the daily data management work by a research assistant.

Regards,

Bo Zhang, Ph.D.
Associate Professor
Area Chair, Educational Statistics and Measurement Program,
School of Education, UW-Milwaukee
boz@uwm.edu
July 25, 2014

Ann Batiza, Ph.D., Director, The SUN Project
Milwaukee School of Engineering
1025 N Broadway
Milwaukee, WI 53202-3109

Dear Ann,

I understand that you are submitting a grant proposal to the Institute of Education Services to develop a NGSS-based high school energy curriculum for use in Biology, Chemistry, and Physics courses by teachers and students in Wisconsin. This curriculum will develop novel methods of teaching and connecting energy topics across the curriculum in these three disciplines. My qualifications for working on this project include teaching EDC 573: Methods of Teaching Secondary Science in the Graduate Teaching Certification Program at Concordia University Wisconsin in Mequon, WI since September 2003 as well as the Online EDC 885 Secondary Methods of Teaching for graduate students. I have taught Biology and Chemistry at Whitefish Bay High School/Shorewood High School for a total of 26 years. In each of these institutions I have written the curricula, taught energy concepts within each course, and mentored science teachers.

I am very eager to serve as a Co-PI on this project which will occur between September 2015 and August 2019. In this multifaceted role I would work with disciplinary master teachers to develop Next Generation Science Standards-aligned lessons using the Coherent Energy Framework for this project, help develop this Energy Across Disciplines Workshop for Teachers, work on revisions to the curriculum after reviewing formative assessments from the Advisory Board Teacher Teams, and attend the semi-annual Scientist/Educator Advisory Board meetings. During the summer of 2019 I would work with the disciplinary master teachers and scientist counterparts to deliver content and work with workshop participants.

As a former SUN Project Advisory Board member and an ongoing user of the extensive SUN Project materials in my teaching I am delighted to be involved in this new project. In this role I helped oversee development of the original SUN instructional materials and assessments and assisted in the summer teacher training sessions, and I evaluated student assessments of energy concepts. The SUN Project curriculum is an amazing support to the teaching and learning of cellular energetics concepts and has greatly enhanced student inquiry and problem solving skills of my students and the students of my colleagues.

This project is significant in that it brings together different disciplinary teachers and provides a framework to better teach energy topics to students over the course of their high school experience. Thank you for this opportunity to improve the teaching and hence learning of energy concepts in secondary science education!

Regards,

Marisa Awodey Roberts, M.A.
Adjunct Professor, Graduate Teacher Education Program, CUW, marisa.roberts@cuw.edu
Biology/Advanced Placement Biology, Whitefish Bay High School, marisa.roberts@wfbschools.com
Aug 5, 2014

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee WI  53202-3109

Dear Ann,

As an author of a textbook on molecular thermodynamics, the principal developer of the Jmol molecular visualization applet, and a long-time advocate of bringing deep understanding of concepts of entropy and energy to high school students and first-year college students, it is with great pleasure that I support your Energy Across Disciplines IES proposal.

I believe this proposal addresses a huge need in this area, particularly that students at the high school level develop a consistent and meaningful understanding of energy in all of their science courses. This can only be accomplished by the concerted effort of teachers in all sciences to develop a broad perspective of what energy is and how we can relate concepts of energy to their students. It is truly a proposal for the 21st century, and I believe it has the potential to have significant impact well beyond the stated goals.

I would be very happy to serve on your consultant team, meeting with you and your team both in person and remotely over the course of Sept. 2015 – Aug. 2019.

Sincerely,

Robert M. Hanson  
Larson-Anderson Professor of Chemistry  
Chair, Chemistry Department  
St. Olaf College  
Northfield, MN  
507-786-3107  
hansonr@stolaf.edu
July 30, 2014

Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee WI 53202

Dear Ann,

My name is Jonathan Knopp. I retired from the Milwaukee Public School System as a high school science teacher in 2001. Since then, I have remained engaged in secondary science education, primarily through a variety of roles with the International Baccalaureate program.

I would be happy to be a master chemistry teacher in the Energy Across Disciplines IES proposal for September 2015-August 2019. I understand that my work would include developing NGSS-aligned chemistry lessons through collaboration with a counterpart scientist and other master teachers, revisions after reviewing formative assessment from the Advisory Board Teacher Teams, and delivery of chemistry content during the workshop in the summer of 2019. This energy project is being modeled after the successful SUN project. As one who helped develop the SUN project, my familiarity with its strengths and weaknesses will be advantageous.

This project is extremely important because of its unique focus on energy in the NGSS which is not only timely but its cross-disciplinary nature will also foster sorely-needed conversations about common content between biology, chemistry, and physics teachers within each of the participating schools.

Regards,

Jonathan Knopp
Retired secondary science teacher and MSOE consultant

MSOE
knopp@mose.edu
July 31, 2014,

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee WI 53202-3109

Dear Ann,  

As a National Board Certified high school science teacher and department chair in the Oostburg School District, I have 15 years experience working with multiple age and ability group students. My experience in a variety of science disciplines (biology, chemistry, physics, earth and space science) along with my experiences in developing an interdisciplinary, vertical (2nd – 12th grade) science team, highly qualifies me for this program.

I am excited about being the physics master teacher consultant for this Energy Across Disciplines IES project from September, 2015 through August, 2019. In this role, I will be working with the Co-PIs and other disciplinary master teachers to NGSS-aligned lessons using the Coherent Energy Framework for this project, work on revisions after reviewing formative assessment from the Advisory Board Teacher Teams, work with Professor Carol Hirchmugl to deliver the physics content during the workshop in the summer of 2019, and lead my Oostburg Advisory Board Teacher Team.

Several years ago I was a SUN teacher and had the pleasure of working with Dr. Ann Batiza and her team. This experience was instrumental in developing my understanding about energy and has been influential in reshaping curriculum delivery to my students. As a master teacher consultant for the Energy Across Disciplines IES project, I am excited to work with scientists to develop lessons linking energy across all science disciplines as I know student learning and understanding will significantly increase.

Regards,

Terry Hendrikse  
Science Teacher and Department Chair  
Oostburg High School  
410 New York Ave  
Oostburg, WI 53070  
terry.hendrikse@oostburg.k12.wi.us
August 2, 2014

Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee WI  53202-3109

Dear Ann,

I am a recently retired professor of biochemistry at the University of Wisconsin-Madison, where for forty years I taught the introduction to biochemistry for undergraduate majors, and co-authored the textbook Lehninger Principles of Biochemistry (6th edition, 2013). I will be very pleased to work with you and your team in the project Energy Across Disciplines during the period 2015-2019. I will work with you in the development of materials that encourage cross-disciplinary approaches to the teaching of energy concepts. While I was Director of the Center for Biology Education, we worked with the biologists and physicists in developing a physics course aimed at biology and chemistry students, and I hope that my experience on that project will prove useful in your program. In teaching the biochemistry course, I think I have encountered every conceivable student misconception about energy, and perhaps that experience will be helpful to you, too.

I think that you are addressing a very important issue in education: the concepts of energy, work, and energy transfer.

Sincerely yours,

David L. Nelson
Professor Emeritus of Biochemistry
August 4, 2014

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee WI 53202

Dear Ann,

I am writing to formalize my interest in and offer my support for your Energy Across Disciplines IES proposal. I am able to participate up to 1.1 months per year starting in September of 2015.

As a practicing science illustrator and web designer with a Masters in Fine Art (MFA) in New Media development, I am confident my skills will be directly applicable to the proposed project. I am ready and willing to work with the described team, including a design intern, science advisory board and practicing educators. Our previous collaborations, including the SUN Project (Students Understanding eNergy), have been both successful and significant.

I look forward to our future work and put my full support behind the proposal. Energy is a fundamental principle of science and engineering, and it deserves the cross-disciplinary attention that your proposal describes.

Regards,

Mark Hoelzer  
Lead Designer, Center for BioMolecular Modeling  
Milwaukee School of Engineering  
1025 North Broadway Street, Milwaukee, WI 53202  
hoelzer@msoe.edu
Advisory Board Teacher Teams
July 31, 2014

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee, WI 53202

Dear Dr. Batiza,

Judy Weiss, a Biology and Biotechnical Engineering teacher at our school, has asked that I reiterate my support in connection with the Energy Across Disciplines Research Project, and I am happy to do so. Along with Judy, three other members of our science department are intent on participating in this research endeavor: Biology teacher Marisa Roberts, who is a Co-Principal Investigator for this project, Physics and Physical Science teacher Paula Krukar, and Biology and Physical Science teacher Katie Brown. It is my understanding that Paula, Katie and Judy are slated to participate as Advisory Board Teacher Team members, and that Judy is willing to take on the additional responsibility of Advisory Board Teacher Team Coordinator.

As Principal of Whitefish Bay High School for the past 15 years, I have had ample opportunity to observe and formally evaluate the work of these four teachers both within and outside of the classroom. Based on this experience, they have my full support in serving as members of the Scientist/Educator Advisory Board for this IES Energy Across Disciplines proposed work. I understand this commitment will require multiple meetings at MSOE outside of the school day over the next three years, along with monthly meetings at school to review and revise lessons being developed to facilitate energy related learning across our science curriculum.

Should you have any questions regarding my support for the involvement of the aforementioned WFBHS science teachers in the Energy Across Disciplines Research Project, please don't hesitate to contact me.

Sincerely,

[Signature]

William F. Henkle, Principal  
414-963-3873  
bill.henkle@wfbschools.com
July 11, 2014

RE: An “Energy across Disciplines” proposal in response to the Institute of Education Sciences RFA (CFDA 84.305A).

I am very excited to be writing this letter expressing my interest in the aforementioned proposed project regarding the study of energy across high school science curricula. I look forward to representing the Whitefish Bay High School biology program and coordinating the school effort. This project is slated to begin September 2015.

I have my master’s degree in Metallurgical Engineering and worked in manufacturing for 20 years before earning a post baccalaureate teaching certificate. I have been teaching high school science and engineering for 10 years at Whitefish Bay High School, in Whitefish Bay, Wisconsin. I have taught Physical Science, Biology, and Engineering and spent one year teaching Physics in Chongqing, China. I intend to participate in this program with my introductory Biology students. As an engineer and educator, I believe it is vitally important for students to have the opportunity for cross-curricular knowledge as we see more and more convergence of all sciences and technology at both the research level and in our daily lives.

Our high school is updating our science curriculum based on the Next Generation Science Standards and we have been discussing how to integrate the sciences as recommended in the standards. I believe this project will fit in perfectly with our goal of increasing our common vocabulary between our biology, chemistry, and physics courses. Applying this common vocabulary to curriculum regarding energy transfers will fit in with one of the main themes in the Next Generation Science Standards.

As part of this project, I am looking forward to being Advisory Board Teacher Team Coordinator at Whitefish Bay High School working with my chemistry and physics colleagues. We will be meeting once a month, starting in 2015, to pilot new materials and assessments and make recommendations regarding revisions and additional activities. In addition to our meetings within the school, I would welcome the opportunity to be a part of the Scientist/Teacher/Policy Maker Advisory Group for this project and attend quarterly meetings in Years 1 and 2 and semi-annual meetings in Year 3.

Our principal, Mr. Bill Henkle, is very supportive of this project as our high school strives to maintain our exemplary science program. I believe that this project will be an important addition to our science curriculum and I am looking to participating in the program. Please email me if you need any further information on my background or my interest in participating in this project.

Sincerely,

Judith C. Weiss
Science/Engineering Teacher
Whitefish Bay High School
1200 East Fairmount Avenue
Whitefish Bay, WI 53217
judy.weiss@wfbschools.com
414-398-3928
July 23rd, 2014

Ann Batiza, Ph.D.
Director, SUN
1025 N. Broadway
Milwaukee School of Engineering
Milwaukee, WI 53202-3109

Re: An “Energy across Disciplines” proposal in response to the Institute of Education Sciences RFA (CFDA 84.305A).

My name is Paula Krukar, I understand that you are submitting a grant proposal to the Institute of Education Sciences to develop and study the use of common language and visualizations of energy concepts in the high school science classroom. I am very eager to represent the Physics and Chemistry program at Whitefish Bay High School on this project which slated to start in September 2015. As a member of this group I will attend quarterly meeting in years 1 and 2 of this project, and 2 meetings in year 3. I understand that I will be a part of the Whitefish Bay High School Advisory Board Teacher Team, representing the Physics and Chemistry courses. As part of this team, we will meet each month to pilot new materials and assessments, and to make recommendations about revisions and additional activities to the curricula.

This is my 9th year teaching in the state of Wisconsin. I have spent the last 7 years working as a Chemistry and Physics teacher at Whitefish Bay high school. My current teaching assignment is an introductory course for Chemistry and Physics for freshmen and a junior/senior level conceptual Physics course called Physics Concepts and Applications. I was a participant in the Department of Energy’s Academics Creating Teacher Scientists (ACTS) program during the summers of 2007-2009. In this program we worked closely with research scientists to more closely align our teaching verbiage and strategies with what they use in their field and with research assistants. I have also been an advisor with Students Modeling a Research Topic (SMART team) program sponsored through the Milwaukee School of Engineering for the last 5 years. Both of these experiences have resulted in many changes in my teaching strategies and activities. I am excited to see what can come about with the collaboration across levels, schools and disciplines through this project.

This exciting program will develop a framework within which teachers can work to optimize and bridge the way students learn about energy across disciplines. In the past there has not been a process in which teachers of sequential science courses develop and implement these key connections. I feel there is a great need for teachers to develop the cross-cutting concepts within the Next Generation Science Standards between core scientific courses such as biology, chemistry, and physics. Helping students to see the important connections between courses and to use common vocabulary and explanations will increase student learning and academic success.

Thank you for this opportunity to develop an Advisory Board Teacher Team of science teachers to study and improve student understanding of energy relationships.

Regards,

Paula Krukar
Physics/Chemistry
July 24, 2014

Ann Batiza, Ph.D.
Director, The SUN Project
Milwaukee School of Engineering
1025 N Broadway
Milwaukee, WI 53202-3109

Re: An “Energy Across Disciplines” proposal in response to the Institute of Education Sciences RFA (CFDA 84.305A).

Dear Ann,

I am very interested in serving as a teacher role in your study of the use of common language and visualizations of energy concepts in the high school classroom for which you are requesting a grant from the Institute of Education Sciences. As a biology, chemistry, and biotechnical engineering teacher at Whitefish Bay High School I acknowledge the need to explore and further hone the teaching of energy concepts in my classes. I have taught life science and physical science for 6 years, both overseas in a village in Namibia for 2 years and in Wisconsin for 4 years. This is my third year teaching at Whitefish Bay High School.

I understand that this project will occur between September 2015 and August 2018 and will include quarterly meetings in Years 1 and 2 and semi-annual meetings in Year 3. Furthermore, I understand that my role would include participation in the Whitefish Bay High School Advisory Board Teacher Team. As a part of this learning community, I am eager to meet monthly beginning in December of 2015, to pilot new materials and assessments and make recommendations regarding revisions and additional activities. Our team will also benefit from examining the energy components of our curriculum across the various disciplines with the focus on building bridges of energy concepts from one course to the next.

An analysis of the efficacy of the teaching and learning of energy concepts in our courses will be greatly beneficial. Our students often view biology, chemistry, and physics as completely separate disciplines. A focus on the cross-curricular theme of energy through the Advisory Board Teacher Team platform will be a significant help in bringing to light to our students the intertwined nature of energy within these disciplines.

With the full support of my building administrators, we thank you for this opportunity to improve student understanding of energy relationships.

Sincerely,

Katie Brown
Biology, Chemistry, Physical Science, and Biotechnical Engineering
Whitefish Bay High School
July 15, 2014

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee WI 53202-3109

RE: An “Energy across Disciplines” proposal in response to the Institute of Education Sciences RFA (CFDA 84.305A).

Dear Dr. Batiza:

My name is Beth Kaminski, and I am the principal at South Milwaukee High School. It is with great pleasure that I offer my support and willingness to encourage the efforts of the teachers who will be part of the “Energy Across Disciplines” proposed work. Jeff Kubel, Joel Shilling and Kelly Farris-Renner will all serve as excellent leaders for this program.

Regards,

Beth Kaminski  
Principal  
South Milwaukee High School  
bkaminski@sdsm.k12.wi.us
August 5th, 2014

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee WI 53202-3109

Dear Ann,

My name is Jeff Kubel and I teach Physics and Earth Science at South Milwaukee High School. I have been teaching in this district for the past 25 years. I also taught 9th grade science at South Division High School for 2 years prior to coming to South Milwaukee.

Kelly Farris-Renner (K-12 science coordinator here at South Milwaukee School District) asked if I would be interested in being part of a Advisory Board Teacher Team regarding the Energy Across Disciplines IES starting in September of 2015. After reading about what this entails, I am definitely interested in this 3 year project. I was fortunate to have been involved in several other projects in the past, all dealing with NASA related science activities, and would like to get involved with this one.

If selected for this project, I would be very excited to work with the other teachers and scientists and be part of the Advisory Board Teacher Team.

Regards,

[Signature]
Jeff Kubel  
Physics and Earth Science  
South Milwaukee High School  
801 15th ave.  
South Milwaukee, WI  
kubelj@yahoo.com
8/2/14

Dr. Ann Batiza
Director, SUN
1025 N. Broadway
Milwaukee School of Engineering
Milwaukee, WI 53202-3109

Dear Ann

I am Joel Shilling a science teacher at South Milwaukee High School. I have taught science here for 23 years. I currently teach Chemistry, AP Chemistry, and Physics. In the past I have also taught Physical Science and Earth Science as well as several different forms of remedial learning classes for at-risk students. I am very familiar with both the range of students and science courses offered at our school.

One of my fellow teachers, Kelly Farris-Renner, asked if I would be interested in becoming involved with the Energy Across Disciplines IES Proposal starting in September of 2015 here at South Milwaukee High School. I have discussed the details of this endeavor with Kelly and I would like to be part of the Advisory Board Teacher Team. I would be very willing to work with the Scientist/Master Teacher Consultants to validate and iteratively assess and revise the new coherent Energy Curricula.

I understand the need for this work to optimize and bridge the way that students learn about energy across disciplines. This is quite an exciting opportunity and I am very interested to become part of the project.

Regards,

Joel Shilling
Chemistry, AP Chemistry and Physics Teacher
South Milwaukee High School
801 15th Avenue
South Milwaukee, WI 53172
414-766-5329
jshilling@sdsm.k12.wi.us
July 31, 2014

Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee WI 53202-3109

Dear Dr. Batiza:

My name is Kelly Farris-Renner, and I am a science teacher at South Milwaukee High School. I teach Biology, AP Biology and Anatomy and Physiology. In addition, I am the 9-12 science curriculum coordinator for the district. I am very excited about and willing to be part of the Scientist/Educator Advisory Board for the Energy Across Disciplines. I am very much interested in validating, assessing and revising the new coherent Energy Curricula. I believe this work will provide curricula that will further student understanding of energy and help decrease common misconceptions. I look forward to being a part of this program.

Regards,

Kelly Farris-Renner
Science Educator and 9-12 Science Coordinator
July 16, 2014

Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee WI 53202-3109

Dear Ann,

I am Scott Greupink, principal of Oostburg High School. I not only approve of, I am highly supportive of, the efforts of the teachers who will be part of the Energy Across Disciplines proposal and plan. I would certainly be excited to have the Institute of Education Sciences approve this grant so our teachers could be involved in this collaborative work at our school. I understand the commitment that will be necessary from our teachers—Terry Hendrikse, Colette Veldhorst, and Ted Schanen—both in meeting as a PLC, as well as with scientists and the Educator Advisory Board. I am completely supportive of their investment in this project and I believe it will be very beneficial for our science department in the long run. I see this collaborative work as central to our school goals and, therefore, support it fully.

Sincerely,

Scott Greupink
Oostburg HS Principal

Oostburg High School
410 New York Ave
Oostburg, WI 53070
sgreupink@oostburg.k12.wi.us
July 8, 2014

Dr. Ann Batiza
Director, SUN
1025 N. Broadway
Milwaukee School of Engineering
Milwaukee, WI 53202-3109

Re: The Energy Across Disciplines IES Proposal

Dear Dr. Batiza,

I am currently in my fifteenth year of teaching science spanning all science disciplines. Although high school CAPP physics is my primary area of discipline, I also teach CAPP medical terminology, advanced physics/engineering, and science in technology. In previous years I have taught biology, chemistry, microbiology, robotics, at risk physical science, middle school science, AP biology, anatomy and physiology, and astronomy. I am Nationally Board Certified in Science and the lead science chairman of the Oostburg High School and Oostburg School District.

I am interested in participating in the Scientist/Teacher/Policy Maker Advisory Board for this project and will attend quarterly meetings in years 1 and 2 and semi-annual meetings in year 3. I am willing to be part of the Professional Learning Community at Oostburg High School that meets once a month, starting December of 2015 to pilot new materials and assessments and make recommendations regarding revisions and additional activities. At the same time I will examine my energy curriculum across disciplines to see where bridges can be built from one subject to the next. My previous experience with the SUN program has been very positive. Students in my courses involved in the SUN program have shown a significant increase in understanding for energy transfer related to aerobic respiration and photosynthesis. Because of this positive experience, I am excited to be a part of the proposal and its focus on addressing energy across all middle school disciplines.

In addition to this high school level coordinator role, I am also interested and excited about being a science education consultant for the program. In this position I would work with the project staff and professional scientists to decipher energy understanding in the scientific community and organize this information into lessons and a curriculum for high school students and educators. Drawing from 15 years of high school level teaching experience in multiple disciplines, including biology, chemistry and physics and being nationally board certified in science will be advantageous in assisting in this capacity.

I look forward to working with colleagues and examining the energy curriculum across disciplines to see where connections can be built from one subject to the next. I recognize a need in my classroom to bridge the way students learn about cross discipline energy content to the implementation of the Next Generation Science Standards with regards to the cross-cutting concepts.

Sincerely,

Terry Hendrikse
Science Teacher
Oostburg High School
Oostburg, WI 53070
1-920-564-2436
Email: terry.hendrikse@oostburg.k12.wi.us
July 8, 2014

Dr. Ann Batiza  
Director, SUN  
1025 N. Broadway  
Milwaukee School of Engineering  
Milwaukee, WI 53202-3109

Re: The Energy Across Disciplines IES Proposal

Dear Dr. Batiza,

I am currently in my fifth year of teaching. In 2008, I graduated from Northwestern College in Orange City, IA with a Bachelor of Arts in Biology and endorsements in coaching, middle school and secondary education. From 2009-2013, I taught 8th grade life science and biology at Milton Middle School. Now, I am teaching high school chemistry at Oostburg High School.

I am interested in participating in the Scientist/Teacher/Policy Maker Advisory Board for this project and will attend quarterly meetings in Years 1 and 2 and semi-annual meetings in Year 3. I am willing to be part of the Professional Learning Community at Oostburg High School that meets once a month, starting December of 2015 to pilot new materials and assessment. I am also willing to make recommendations regarding revisions and additional activities based upon going through the pilot program in the PLC and my classroom.

Furthermore, I look forward to working with colleagues to examine the energy curriculum across disciplines to see where connections can be built from one subject to the next. I think this is an opportunity to optimize and connect the way that students learn across subjects, and I look forward to bridging the energy curriculum throughout the various disciplines. Additionally, I am willing to look at how the energy curriculum can be implemented with the Next Generation Science Standards and the various cross-cutting skills emphasized within those teaching standards.

Regards,

Colette Veldhorst  
Science Teacher  
Oostburg High School  
Oostburg, WI 53070  
1-920-564-2436  
Email: colette.veldhorst@oostburg.k12.wi.us
July 8, 2014

Dr. Ann Batiza
Director, SUN
1025 N. Broadway
Milwaukee School of Engineering
Milwaukee, WI 53202-3109

Re: The Energy Across Disciplines IES Proposal

Dear Dr. Batiza,

I am currently in my tenth year of teaching in the middle and high school sciences in the Shorewood, WI and Cedaredge, CO school districts. During this time I have taught a variety of courses including physical science, life science, biology, physics, geoscience, etc. Now, I am teaching high school biology, anatomy and physiology, and advanced biology at Oostburg High School.

I am interested in participating in the Scientist/Teacher/Policy Maker Advisory Board for this project and will attend quarterly meetings in Years 1 and 2 and semi-annual meetings in Year 3. I am willing to be part of the Professional Learning Community at Oostburg High School that meets once a month, starting December of 2015 to pilot new materials and assessment. I am also willing to make recommendations regarding revisions and additional activities based upon going through the pilot program in the PLC and my classroom.

Furthermore, I look forward to working with colleagues to examine the energy curriculum across disciplines to see where connections can be built from one subject to the next. I think this is an opportunity to optimize and connect the way that students learn across subjects, and I look forward to bridging the energy curriculum throughout the various disciplines. Additionally, I am willing to look at how the energy curriculum can be implemented with the Next Generation Science Standards and the various cross-cutting skills emphasized within those teaching standards.

Regards,

Ted Schanen
Science Teacher
Oostburg High School
Oostburg, WI 53070
1-920-564-2436
Email: ted.schanen@oostburg.k12.wi.us
Wednesday, August 6, 2014

Dr. Ann Batiza
Director, SUN
1025 North Broadway
Milwaukee School of Engineering
Milwaukee, WI 53202-3109
Batiza@msoe.edu

Dear Dr. Batiza:

This is a letter of support for my school’s and my teachers’ participation in The Energy Across Disciplines IES Project Proposal, sponsored by MSOE.

I am going into my eighth year as principal at Greendale HS and am confident that these individuals are of the highest quality educators, replete with great work ethics, that we have in our high school. I will support the involved staff members with time and resources necessary for their participation.

Please contact me at steve.loces@greendale.k12.wi.us with any questions you may have.

Sincerely,

[Signature]

Steven J. Lodes, Principal
Greendale High School
7/25/2014

Dr. Ann Batiza  
Director, SUN  
1025 N. Broadway  
Milwaukee School of Engineering  
Milwaukee, WI 53202-3109

Re: IES Energy Across Disciplines Project Proposal

Dear Dr. Batiza:

I am writing to express my interest in being a part of the IES Energy Across Disciplines Project. Amy Zientek referred me to your project.

Currently, I teach Chemistry, Honors Chemistry and AP Chemistry at Greendale High School. However, over the past seventeen years, I have taught a variety of science classes at both the high school and the college level. I facilitated development of project-based integrated science and engineering curricula for the Marquette University Upward Bound Math and Science summer programs and led the most recent revision of our Honors Chemistry and Chemistry curricula at Greendale High School.

I am willing to be part of the Scientist/Teacher/Policy Maker Advisory Board for your project and will attend quarterly meetings in Years 1 and 2 and semi-annual meetings in Year 3. I am also willing to be part of the Professional Learning Community at Greendale High School, to pilot new materials and assessments and make recommendations regarding revisions and additional activities.

A lack of consistent language and methodology for teaching energy concepts helps to contribute to student misconceptions about a range of very important scientific ideas and prevents students from making key connections between ideas in different disciplines. Developing common language and instructional strategies that can be used by teachers of different disciplines will help to combat these problems. I feel like my skills and experience will allow me to be an asset to your project and am happy to participate. Should you have any further questions for me, please feel free to contact me at melissa.senn@greendale.k12.wi.us.

Regards,

Melissa Senn

Melissa Senn
Dr. Ann Batiza  
Director, SUN  
1025 N. Broadway  
Milwaukee School of Engineering  
Milwaukee, WI 53202-3109

Re: The Energy Across Disciplines: IES Proposal

To whom it may concern:

Participating in an advisory role for the Energy Across Disciplines Project is an amazing opportunity for me as it provides an outlet to discuss and collaborate with colleagues and scientists. I have taught science for the past nine years (AP Biology, Biology, Life Science, Anatomy & Physiology, Physical Science, Integrated Life Science) and been involved in a myriad of research and science teacher professional development programs throughout my career. My experiences with programs at the Milwaukee School of Engineering have been among the most rewarding. The 2009-2011 Students Understanding Energy (SUN) Program at M.S.O.E. completely changed the way in which I facilitate photosynthesis and cellular respiration topics with students. SUN provided me with a greater understanding and appreciation for both processes, and it enabled me to incorporate modeling and real-life application exercises into the curriculum. In Summer 2014, I earned my Ph.D. in Curriculum and Instruction with a minor in Biochemistry. It has been a pleasure simultaneously participating in programs like SUN that align to the research I am exploring – essential elements of science teacher professional development. Currently, I am a full-time science educator at Greendale High School. I have 120 students, and can’t wait to pilot ideas with my students that will help foster their understanding of energy.

As a participant in the Scientist/Teacher/Policy Maker Advisory Board for this Project, I am willing to attend quarterly meetings in Years 1 and 2 and semi-annual meetings in Year 3. I am also willing to be part of the Professional Learning Community at Greendale High School that meets once a month, starting in December of 2015 to pilot new materials and assessments and make recommendations regarding revisions and additional activities. Additionally, I am excited to examine my energy curriculum across disciplines to see where bridges can be built from one subject to the next. This work is essential in order to optimize and bridge the way that students learn across disciplines and/or tools to implement the NGSS with regards to this cross-cutting concept. Developing a common ontology for energy concepts is essential to move students forward into systems thinking; whereby, energy is not just a concept that is explored at the subject-level, but at the thematic level.

Sincerely,

Amy Zientek  
Science Educator  
Greendale High School  
Email: amy.zientek@greendale.k12.wi.us  
Phone: 414-507-6022
July 29, 2014

Dr. Ann Batiza
Director of SUN
1025 N. Broadway
Milwaukee School of Engineering
Milwaukee, WI 53202-3109

Dear Dr. Batiza,

I am a science teacher currently teaching in the School District of Waukesha. I am responsible for team-teaching Chemistry and Physics. Our high school is an alternative learning setting for students in the district. I have been teaching since 1991. I am licensed in high school science (physics, biology, earth space) as well as alternative education. I participated in the SUN Project in 2009.

I would like to be a part of the advisory board for this project. I am willing to commit to attend quarterly meetings in Years 1 and 2 and semi-annual meetings in Year 3. I am also willing to be part of the Professional Learning Community at Harvey Philip High School in Waukesha. As a PLC, we will meet once a month, starting in December of 2015 to pilot new materials and assessments as well as make recommendations regarding revisions and additional activities. We will also work to bridge our curriculum between subject areas—using energy, a NGSS cross-cutting concept, as tools to help us increase student learning.

Thank you for your time!

[Signature]

Sabrina Massey
Science Instructor
Harvey Philip High School
smassey@waukesha.k12.wi.us
July 30, 2014

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee WI  53202

Dear Ann,

I am a high school science teacher at Rufus King International School. I have been teaching for Milwaukee Public Schools for 23 years with certifications in Biology, Chemistry, and Environmental Science.

I want to be part of a Teaching Team for Rufus King International School to participate in the Energy Across Disciplines study starting in September of 2015.

The team’s objective is to contribute to the development, assessment and revision of a coherent energy curriculum aligned with the New Generation Science Standards across science disciplines. The NGSS requires students to understand energy in ways that traditional energy curriculum does not support. Through a coherent curriculum students will make connections across the sciences that increase comprehension of energy principles, and students’ ability to apply them.

Regards,

Vivienne Weber  
Science teacher  
Rufus King International School  
1801 W. Olive Street  
Milwaukee, WI 53209  
webervk@milwaukee.k12.wi.us
August 1, 2014

Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee WI 53202-3109

Dear Ann,

My name is John Kish and I a biology/chemistry/environmental science certified teacher at Rufus King International School in Milwaukee, WI. I am willing to be part of the Teacher Team for my school for this Energy Across Disciplines IES proposal starting in September of 2015 who will work with the Scientist/Master Teacher Consultants to validate and iteratively assess and revise the new coherent Energy Curricula.

With the local adoption of the Next Generation Science Standards I feel that this work will be essential in the proper implementation and assessment across curricula of the energy performance expectations.

Regards,

John Kish
Science Department Chair
Rufus King International School
1801 W. Olive St.
Milwaukee, WI 53209
kishjj@milwaukee.k12.wi.us
Advisory Board Scientists and Education Policy Makers
August 4, 2014

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee WI  53202-3109

Dear Ann,

I am willing to serve on the Scientist/Educator Advisory Board for this Energy across Disciplines IES proposal starting in September of 2015. I know that this will entail discussions of the project including scientific accuracy of the curricular materials at two meetings per year for three years.

My qualifications include the following. 1) I am director of Education and Outreach for the Great Lakes Bioenergy Research Center (https://www.glbrc.org/). 2) I am the lead PI on a USDA/AFRI award to prepare learners—including Native American youth—to pursue bioenergy and sustainability-related studies. 3) For over 25 years I have taught bioenergetics to undergraduates at the University of Wisconsin, and have received several teaching awards for my approach to this topic.

Enthusiastically,

Richard Amasino  
Member, U.S. National Academy of Sciences  
Professor, Department of Biochemistry, University of Wisconsin, Madison
Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee WI  53202-3109

Dear Ann:

I am a Professor (tenured) in the Physics Department of the University of Wisconsin-Milwaukee and a member of UWM's Laboratory for Surface Studies, a preeminent interdisciplinary center. I have taught all levels of Physics at UWM the past 16 years, and have presented aspects of my research in public lectures on science. I am an established researcher in the field of surface structure and epitaxy of semiconductors. I am a member of the American Physical Society, AVS (formerly the American Vacuum Society), and the American Association of Physics Teachers. My research has been funded by the US National Science Foundation, the US Department of Energy, the Petroleum Research Fund, and by The Research Corporation. I have published about 60 peer-reviewed journal articles in my field.

I am writing to convey my interest in serving on the Advisory Board for the project you are heading up on Energy Across Disciplines IES. I strongly support this project, as I perceive that many students and many ordinary citizens harbor misconceptions about the role and sources of energy, as well as its fate during conversions. Let me consider an example. I reflect back on the debates and discussions that surrounded President George W. Bush’s push to develop hydrogen-powered cars; during that time there was a maddening amount of misinformation in the media, which reappeared in everyday discussions, implying that hydrogen could serve as a primary source of energy (rather than a storage medium). If all citizens had been trained in a curriculum such as the one to be developed under the aegis of this project, the correct issues and challenges would have been obvious to the citizenry, and would have been more effectively addressed.
In any event, I feel I can provide useful guidance and oversight for the Energy Across Disciplines IES project by participating in the Scientist/Educator Advisory Board in Sept. 2015 (or whenever is appropriate), and will be eager to work with educators and scientists from other disciplines at periodic meetings as your team endeavors to develop a common “language” to describe energy transformations.

Regards,

Paul F. Lyman,
Professor of Physics
University of Wisconsin-Milwaukee
plyman@uwm.edu
08-05-2014

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee WI 53202-3109

Dear Ann,

I am director for the BioMolecular Engineering (BioE) Program at Milwaukee School of Engineering (MSOE) and a professor in the department of Physics and Chemistry. I am a molecular biologist/biochemist. I have been involved in preparing and teaching courses and laboratory activity that include metabolism and bioenergetics for fifteen years.

I will be happy to serve on the Scientist/Educator Advisory Board for the Energy across Disciplines IES proposal starting in September of 2015 to provide input at two meetings per year for three years to oversee the accuracy of the scientific content of curricular materials developed.

Working with you in the past has been a pleasure and I look forward to working with you again.

Best Regards,

[Signature]

Gul Afshan  
Director, BioMolecular Engineering  
Physics and Chemistry Department, MSOE  
1025 N Broadway  
Milwaukee, WI 53202  
PH: 414-277-7211  
Fax: 414-277-2878  
afshan@msoe.edu
August 5, 2014

Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee WI 53202-3109

Dear Ann,

Thank you for the opportunity to be involved with the Energy across Disciplines curricula development project. As an engineering professor specializing in materials and manufacturing processes, with an interest in thermodynamics, I see the importance for an understanding of the basic concepts related to energy. I understand the time commitment for the Advisory Board is 2 meetings per year for 3 years and the primary responsibility of the board is oversight for the accuracy for the content for the curricular materials. I am happy to have involvement with a project that can help develop a better understanding of the concept of energy and energy transfer that is such an important part of economic growth.

Regards,

[Signature]

Cynthia W. Barnicki, Ph.D.
Professor
Program Director, B.S. Engineering
Mechanical Engineering Department
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee, WI 53202
barnickc@msoe.edu
August 5, 2014

Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee WI 53202-3109

Dear Ann,

My name is Dr. Eryn Hassemer and I am an Assistant Professor in the BioMolecular Engineering (BioE) program at the Milwaukee School of Engineering (MSOE). I believe that I could be an asset on the Scientist/Educator Advisory Board for the Energy Across Disciplines IES proposal due to my molecular and cell biology, biochemistry, microbiology and cell culture expertise.

Since I am an educator at MSOE, I understand the interface between the fundamental science concepts and the pedagogical practice. I want to be able to help facilitate the bridge between the energy curriculum and the students. Creating a spark of interest in fundamental energy concepts or even learning in general is a very rewarding endeavor.

Best regards,

Eryn L. Hassemer, Ph.D.
Assistant Professor
Department of Physics and Chemistry
BioMolecular Engineering Program
Milwaukee School of Engineering
1025 N. Broadway
Milwaukee, WI 53202
Phone: 414-277-2322
E-mail: hassemer@msoe.edu
4 August 2014

Dr. Ann Batiza  
Director, SUN  
Milwaukee School of Engineering  
1025 N. Broadway  
Milwaukee WI 53202-3109

Dear Ann,

I am a professor of physics and the R.D. Peters Professor of Materials Science at the Milwaukee School of Engineering and am currently serving a three-year term as a member of the Editorial Board of The Physics Teacher, one of two professional journals published by the American Association of Physics Teachers.

I appreciate the opportunity to serve as a member of the Scientist/Educator Advisory Board for your proposed IES project on Energy across Disciplines. During the 1990s I designed and offered a course on Hands-On Electronics for middle school and high school science teachers that was taken by 96 teachers in southeastern Wisconsin. I believe my experience in teaching those middle school and high school teachers will enhance my ability to contribute to meeting the challenges faced by the Advisory Board for your proposed project.

Regards,

A. James Mallmann  
A. James Mallmann  
R. D. Peters Professor of Materials Science, and  
Professor of Physics  
414-277-7317  
mallmann@msoe.edu
July 22, 2014

To Whom It May Concern:

This is a letter of support for the latest project being developed by Ann Batiza and colleagues at the Milwaukee School of Engineering. We are knowledgeable about the Students Understanding eNergy (SUN) project work and support that locally development and implemented effort. Teachers have made significant changes in their teaching because of their experiences with SUN. Their students learned significantly more about biological energy transfer and continue to benefit because of the SUN project. This current proposal has the potential for a similarly significant impact.

The Milwaukee School of Engineering has aligned this project with the Next Generation Science Standards. These standards call for cross-disciplinary treatment of energy in their implementation. This new proposal is the vehicle teachers need to develop a conceptual understanding of what that means and the curricular ideas to put that into practice. Energy as a concept is often misunderstood by teachers. Because of this, student misconceptions about energy are fostered. This project's alignment to the Next Generation Science Standards and their Coherent Energy Framework will provide teachers with the understanding and materials needed to teach energy in a coherent manner and reinforce concepts learned as students go from one science class to the next.

There is a need for unique tools with which teachers can implement the cross-cutting concept of energy within the Next Generation Science Standards. The SUN manipulatives, the hydrogen fuel cell, and photovoltaic cells used in this project will allow students to learn about and demonstrate their knowledge of energy concepts in the context of scientific practices.

The Department of Public Instruction (DPI) is willing to provide a representative to meet with the larger advisory group twice each year for three years starting in the fall of 2015 to provide ideas and support and to assist with progress monitoring of the project. DPI will help recruit teacher participants through DPI's bi-weekly mailings to each district, using available science outreach to teachers, and promoting this effort via a link on the departmental website. We look forward to this project being funded. Learning from the teachers involved in this cross-cutting science education conversation and spreading the word about its success would fit well in our science education mission.

Sincerely,

[Signature]
Rebecca J. Vail, Director
Content and Learning Team

RJV:bk
August 4, 2014

Dr. Ann Batiza
Director, SUN
Milwaukee School of Engineering
1025 North Broadway Street
Milwaukee, WI 53202-3109

Dear Dr. Batiza:

I am writing to express Milwaukee Public Schools’ support and commitment to participate in the IES - Energy Across Disciplines project. This project aims to address the need for teachers, and students, to understand energy better as it applies across disciplines.

The program’s focus on effective teaching and a cross-discipline approach aligns with our theory of action for improvement in science education. We commit to participating in the Scientist/Educator Advisory Board for three years, beginning in the fall of 2015, and we will identify eight high schools to be a part of the cluster, randomized trial to take place in 2018-19 involving science teachers.

The program laid out in this proposal will be of value to our school district. The scientist/educator partnership will develop validated and integrated NGSS-aligned curricula regarding energy across the high school science disciplines. The proposed project will help teachers build capacity in order to prepare students for making wise decisions about energy sources and energy use.

This proposal represents a collaborative effort in order to support our students in the area of science and we are pleased to be a partner in this effort.

Sincerely,

Darienne Driver, Ed.D.
Acting Superintendent of Schools

DD/MT/tms