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EduCycle: Bicycle-based Low Power Lighting Demonstration

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EduCycle

Bicycle-based Low Power Lighting Demonstration

A Major Qualifying Project Report
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Project Advisor and Mentor

Abstract

This report describes EduCycle, a system for demonstrating the reduced energy requirements of modern lighting in a hands-on manner to elementary school students. EduCycle consists of a bicycle trainer connecting a bicycle to a generator and a bank of incandescent, compact fluorescent (CFL), and light emitting diode (LED) light bulbs. The EduCycle system facilitates experiential learning by allowing the user to physically experience the amount of power required by each type of lighting. EduCycle has been designed from the ground-up to be portable, durable and safe, and was beta tested on 3rd grade elementary school students. Surveys collected from the beta test indicate that the students achieved the intended learning outcomes of the project.

Acknowledgements

We extend our gratitude and appreciation to all the individuals who contributed to the EduCycle project. By far the biggest thanks goes to our project advisor, Prof. Donald R. Brown III. Professor Brown guided us to complete this project within two terms and advised us about many practical aspects of the design and volunteered his son Max to test our system. We would also like to thank Professor Lifeng Lai for his feedback and input about our project.

We would like to thank Professor Stephen J. Bitar, who spent hours helping us with valuable guidance with the designing and debugging of our system. Adam Sears, Sarah Chamberlain, David Ephraim and many others in Washburn Shops provided us invaluable help in designing and manufacturing many important components of our design. James Filice and Xu Chen provided us with invaluable help and advice about electronics.

Finally, we would like to acknowledge Advanced Circuits for their generous support of our project by donating custom printed circuit boards for this project.

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Introduction

The invention of the incandescent lamp by Thomas Edison in 1878 enabled millions of people over the years to conveniently perform day-to-day activities when sunlight is not available. Lighting also consumes an enormous amount of energy, depleting fossil fuels and contributing to foreign dependence and global warming. NIST scientist Yoshi Ohno states, "Lighting uses 22 percent of the electricity and 8 percent of the total energy spent in the country" [1]. The production of electricity to match the increasing demands of the world has serious detrimental effects on Earth and the environment. Thus, it is imperative that we reduce our usage of electricity so as to lower the demand for production. Educating young children about energy conservation is extremely important because consumer preferences are primarily influenced by existing technology [2]. It is important for the next generation of decision makers to understand the power savings and consequential environmental benefits created by technological advancements.

Since its invention, the incandescent lamp has been characterized by a technological monopoly in the residential lighting sector. In spite of extensive promotion by utility companies and the government, incandescent lamps still account for approximately 87 percent of the energy consumed by lighting in homes [3]. Fluorescent tubes were introduced into the residential lighting market in the 1960s. They offered improved lifespans and efficiency but failed in the residential market because of incompatibility with existing lamp fixtures. Today, the two main alternatives to the incandescent bulb are the compact fluorescent lamp (CFL) and the light emitting diode (LED). CFLs emit light from a mix of phosphors and use fluorescence to provide more efficient lighting in the same form factor as incandescent bulbs. Solid-state LED lighting provides up to twice the efficiency of fluorescent lamps [2]. Further reductions in power consumption can be achieved by research and development of new lighting technologies and by encouraging habits such as turning off lights and appliances when they are not required.

Since children have significantly shorter attention spans relative to adults [4], a hands-on approach must be taken to keep them constantly engaged. The objective is for students to learn about different lighting technologies by physically powering light bulbs. This type instruction is called experiential learning and draws from the idea learning is a process whereby concepts are derived from and continually modified by experience [5]. Students will physically experience that solid-state LED lighting uses far less power to provide similar lighting as incandescent bulbs. Feeling this difference will teach several important lessons. The most obvious lesson is that LED lamps are more efficient than incandescent or compact fluorescent lamps. Students will also learn about the negative environmental consequences of electricity generation and habits to conserve electricity. Finally, we will encourage students to make decisions such as what type of light bulb to use by considering the lifecycle costs as opposed to initial costs alone. With these ideas in mind, we believe that the EduCycle project can effectively teach children about the importance of new lighting technology its role in preventing global warming.

We have designed and implemented EduCycle, an educational platform which combines theory and practice by enabling students to physically experience modern lighting. While there are several do-it-yourself solutions which provide energy demonstrations for elementary students, most demonstrations are not hands-on or require electrical engineering expertise. Commercially available experiential learning solutions are available but have limitations. The Watt Power Education kit from Wind Stream Education is a promising solution which uses a hand-crank to power a light box which holds both an incandescent light bulb and a CFL light bulb [5]. The solution is portable and safe but costs over $1,000 including shipping and relies on hand cranks, which make it difficult to generate energy. The EduCycle innovates by offering a cost effective solution which enables students to feel the different energy consumption of incandescent, LED and compact fluorescent lamps while powering the light bulbs with their own bicycles.

1 Background

1.1 Energy consumption and Global Warming

The United States alone consumed over 3,856 billion kilowatt-hours of electricity in 2011, which is approximately 13 times greater than the electricity used in 1950. [6] In order to accommodate this significant increase in energy consumption, both the number of power plants and the average output power have multiplied over the past 60 years. The figure below shows the increase in production, separated by method.

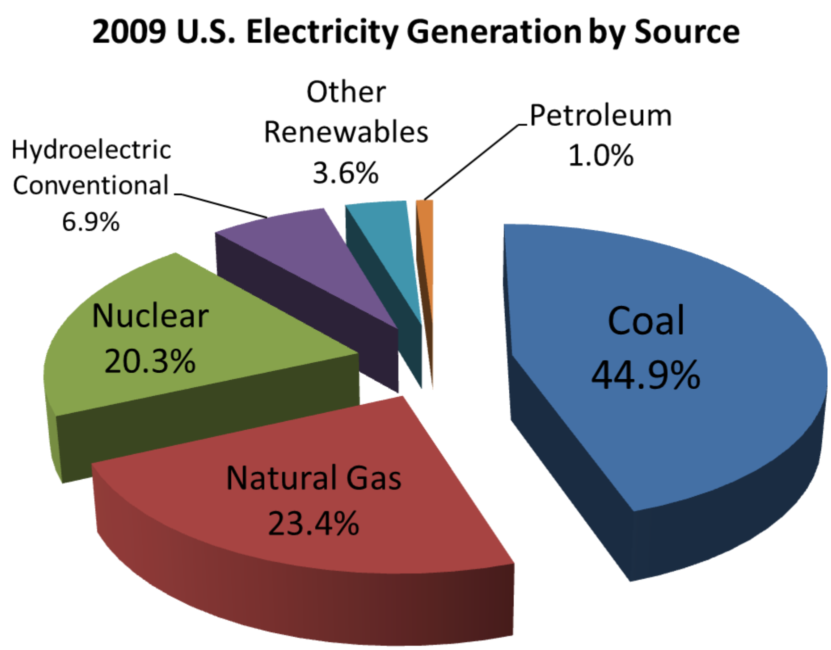

Figure 1 - Energy Generation by Source in the United States in 2009. **[7]**

Figure 1 shows that coal, natural gas, and nuclear fuels are the most common methods of generating electricity. The top three sources of electricity are non-renewable and both coal and natural gas release emissions which contribute to global warming when burned. Nuclear energy, gas and petroleum are largely imported and contribute to foreign dependence. Wind and solar power cannot meet the energy demands of the United States.

Power plants, which rely on coal, oil, natural gas, and nuclear fuel, produce electricity by boiling water into steam. This steam turns large turbines, generating electrical energy. Burning coal, oil or natural gas heats the water but also releases carbon dioxide and other

"Greenhouse Gas Effect." Nuclear power points generate the heat required to produce steam by a physical process called fission which splits atoms of uranium in a nuclear reactor. The fuel is consists of small hard ceramic pellets of uranium that are packaged into long, vertical tubes which can be inserted into a reactor. [8] Burning uranium releases hazardous nuclear waste which is difficult and expensive to dispose and can cause serious damage to humans and the environment.

Greenhouse gases refer to gases which trap outgoing long-wave radiation from the earth to space, warming of the planet. The natural greenhouse effect makes the earth habitable. Gases which contribute to the greenhouse effect include water vapor, carbon dioxide, ozone, and the methane and nitrous oxide [9]. Evaporated water exists in the atmosphere, and helps to block an excessive amount of sunlight from entering the atmosphere. What little thermal radiation does enter the atmosphere is held within, since it is blocked from leaving freely. This is a cyclical and natural process, but human activities such as deforestation and large scale fossil fuel-based power plants have resulted in greenhouse gases well in excess of the natural amount [9].

The burning of fossil fuels in power plants results in greenhouse gases, such as carbon dioxide, methane, and nitrous oxide entering Earth's atmosphere in large volumes. These gases persist in the atmosphere for decades, and sometimes centuries. Burning fossil fuels for power generation as well as for heat and transportation have disrupted the natural cycle and created an accumulation of greenhouse gases in the atmosphere. Carbon dioxide has increased 31% since preindustrial times, from 280 parts per million by volume (ppmv) to more than 370 ppmv today, and half of the increase has been since 1965 [9]. We must reduce our consumption of electricity, since these power plants damage the environment at an exponential rate. As a great fraction of the world's energy goes towards lighting, it is important to educate the next generation about the environmental impact of using excessive energy for lighting.

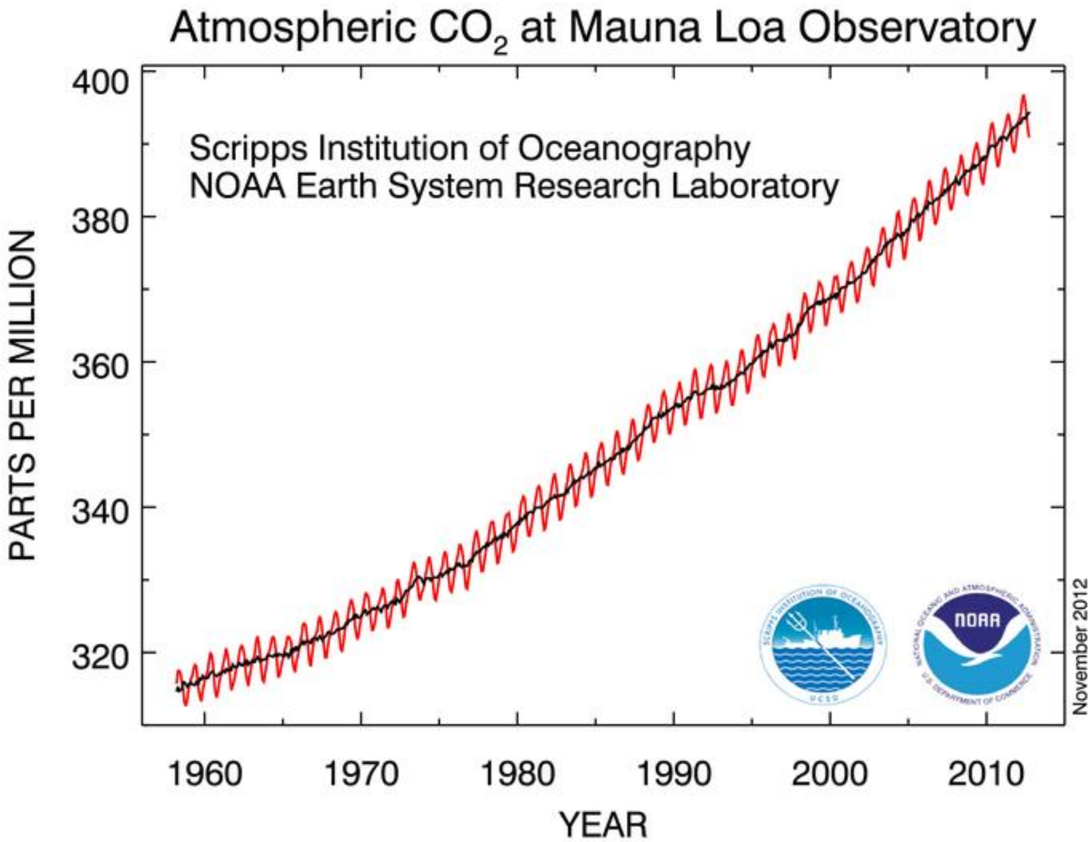

Figure 2 - Concentration of Carbon Dioxide in Earth's Atmosphere since 1960 **[10]**

These additional greenhouse gases make it difficult for the thermal radiation of sunlight to come in, but also make it proportionally more difficult for the thermal radiation to leave. The most obvious result of this has been a rise of temperatures around the globe. According to NASA's earth observatory, the global average surface temperature rose .6 to .9 degrees Celsius between 1906 and 2005. The rate of temperature increase has nearly doubled in the last 50 years as well [11]. See the figure below for an illustration of this phenomenon.

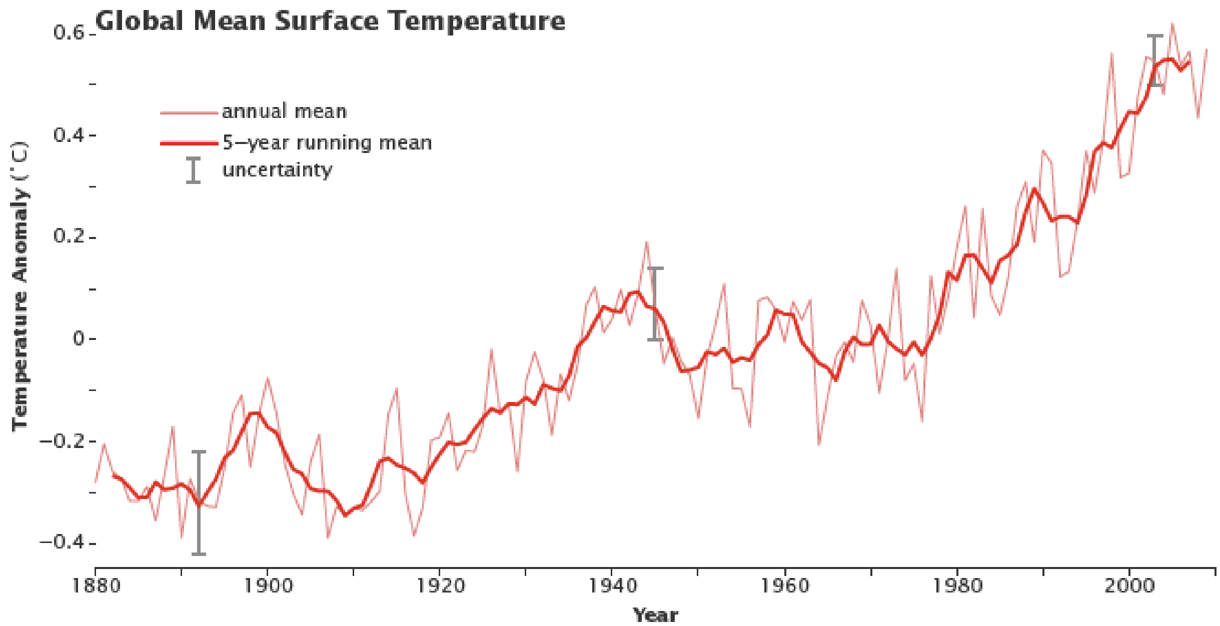

Figure 3 - Temperature anomalies across the globe **[11]**

Global warming has been detrimental to the environment. The rising temperatures are causing the polar ice caps to melt, which will exacerbate the reduction of light reflected by the sun. Furthermore, the sea levels will rise and the ecology based around the ice caps (polar bears, penguins, etc.) will die out. Global warming poses a serious threat to the welfare of Earth and its inhabitants. A serious effort must be made to reduce our consumption and dependence on toxic fossil fuels.

1.2 Lighting Technology

There are currently three main types of bulb available for use in the home: LED (Light-Emitting Diode), CFL (Compact Fluorescent Lamp), and Incandescent. Incandescent bulbs are by far the oldest and most commonly used bulbs. Invented in 1878, Incandescent bulbs are currently one of the least efficient forms of lighting, producing only about 12 to 25 Lumens per Watt [12].

Figure 4 - Incandescent bulb (Image used under the GNU Free Documentation License)

Incandescent bulbs store an inert gas. When electricity travels across the horizontally placed filament in the center, the gas is excited and produces light. Most of the energy produced by produce by the bulb is wasted as heat rather than light [12].

Compact Fluorescent Light bulbs are designed to fit directly into the same form of sockets as incandescent bulbs.

Figure 5 - Compact Fluorescent Light **[13]**

The two main parts of a CFL bulb are the electronic or magnetic ballast, and a gas-filled tube. Similar to Incandescent bulbs, the ballast excites the gas, which generates light. This reaction is more efficient. A typical CFL can provide anywhere between 45 and 72 Lumens per Watt [12]. This is several times more efficient than a typical Incandescent bulb.

Light-Emitting Diodes are the most efficient of the three forms of lighting. They will create anywhere between 64 and 100 Lumens per Watt. LEDs are semiconductors that emit light when an electric potential is applied across their nodes.

Figure 6 – Typical LED Light bulbs (public domain)

The table below shows a cost analysis and lifespan of typical Incandescent, LED, and CFL bulbs:

Table 1 - Cost analysis and lifespan of typical averages of each type of bulb **[12]**

	Incandescent	CFL	LED
Lifespan (hours)	2,000	8,000	25,000
Bulb cost over 10 years (usage of 6 hours per day)	$4.49	$10.95	$17.52
Energy cost over 10 years (15 cents/kWh)	$197.10	$42.71	$29.57
Total	$201.59	$53.66	$47.09

1.3 Government Initiatives for Energy Conservation

Government, non-profit groups and corporations have made efforts to educate people about climate change and the importance of reducing energy usage. Around 2006, the environmental movement began to gain huge momentum. Grocery stores, movies, and pop culture endorsed the concept of “going green.” Websites and television shows promoted the message, and the green movement became a phenomenon. Both adults and children became more conscious about consuming plastic bags and bicycling. Bicycle traffic counts across major corridors grew about 71% between 1995 and 1998 in San Francisco alone. New York has an extensive transit system which allows residents to travel for free via bike, walk and public transport [14]. It is also commonplace for kids’ movies such as Wall-E and Happy Feet to show the effects of environmental disasters.

The green movement has brought awareness to the issue of Global Warming and has led the government to pass legislation that promotes modern technology to reduce the environmental impact of human activities. The government has imposed stricter regulations on cars which account for around 20% of manmade carbon dioxide (CO2) by imposing per-mile CO_2 emission standards as well as fuel economy targets [15]. In the United States and Canada, utility companies have promoted CFL usage by giveaways and price reductions; however, the federal government has done very little to phase out incandescent bulbs. Therefore, it is essential to educate young students about modern lighting technology.

Government initiatives to reduce energy conservation such as tax credits, carbon credits and Energy Star certification do not resonate well with children since they are aimed at adults. More efforts must be taken to inform the new generation about environmental challenges and to help them to reduce their environmental impact. Current efforts mostly involve classroom lectures about abstract concepts such as the finite supply of fossil fuels, foreign dependence and global warming. Schools do not provide hands-on experiences that allow students to understand what energy is, how electricity is generated and why electricity must be consumed wisely.

2 Design Requirements and Features

The EduCycle is a bicycle-based low-power lighting demonstration system that is designed to educate elementary school children about the reduced energy requirements of modern lighting. The basic underlying system for this project is an efficient bicycle-based generator system and an easy-to-use switching apparatus which loads the generator with incandescent, CFL, and LED lights. The system that we design will be portable, durable, and safe and will be demonstrated to inspire young children about the marvels of modern lighting technology by enabling them to directly experience the power required to light the different technologies.

In order to make it possible for the user to ensure that pedaling is not too easy, we have decided to use three of each kind of bulb. Lighting three LED bulbs won't be too difficult, but when the system switches to CFL, it will become slightly harder. Lighting three incandescent bulbs rated for 50W each will mean that the system must receive a total of 150W in order to light all three incandescent lights. This will be very difficult for most people. Since the Generator and the DC-DC Regulator won't be 100% efficient, we must assume that the user will have to generate values of closer to 200W in order to completely light up three Incandescent lights.

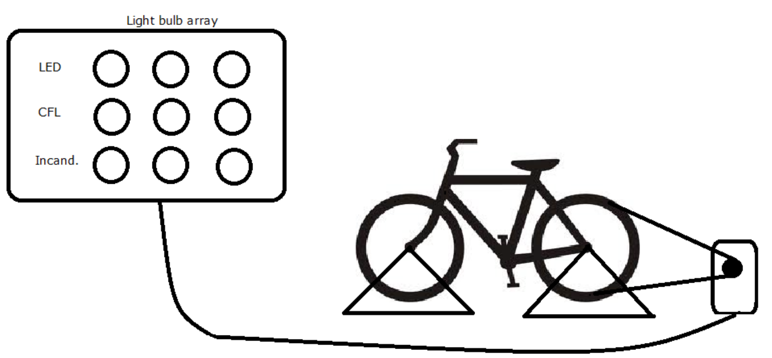

Figure 7 - Diagram showing overall operation of EduCycle

Figure 4 shows the high-level operation of the system that we have designed. The bicycle has a switch that chooses which type of lighting to use and its wheel rotates an idler mounted onto a DC generator to create power which is then supplied to one of the lighting systems.

Based on the target audience of the EduCycle, there are several core requirements that our product must meet in order to effectively achieve its goals:

1. The user should be able to feel a tangible load difference based on the light bulb they are using. It should be much easier to pedal the bicycle with an LED light bulb, and far more difficult when it's using an Incandescent light bulb.
2. The device should challenge the users, especially at the incandescent stages. Knowing that most adult humans can generate up to 300 W of power [14], we cut the number in half for children. The device should allow the children to feel a 150W load at its most difficult levels.
3. Efficient energy conversion – losses are inevitable in any generator but our system must be designed to avoid unnecessary conversion stages so that as much energy as possible generated from the bicycling effort is transferred to the lighting systems.
4. Safety – since the product is being used by elementary school children, our product must be designed with safety as a priority. Enclosures should protect users from electrical dangers as well as any sharp edges.
5. Portability and weather safety – our system must be portable so that it can be moved from one classroom to another and from one school to another without difficulty. Our product should also be capable of being demonstrated both indoors and outdoors.
6. Intuitive user interface – our system should enable easy switching between lighting sources and should enable children to engage and visualize the energy and the conversion processes to provide a superior educational experience.

3 System Components

When designing the EduCycle, there were a few main components that needed to be decided upon. Some components had major effects on the rest of the design, so each piece had to be researched carefully to ensure the best overall user experience and device performance.

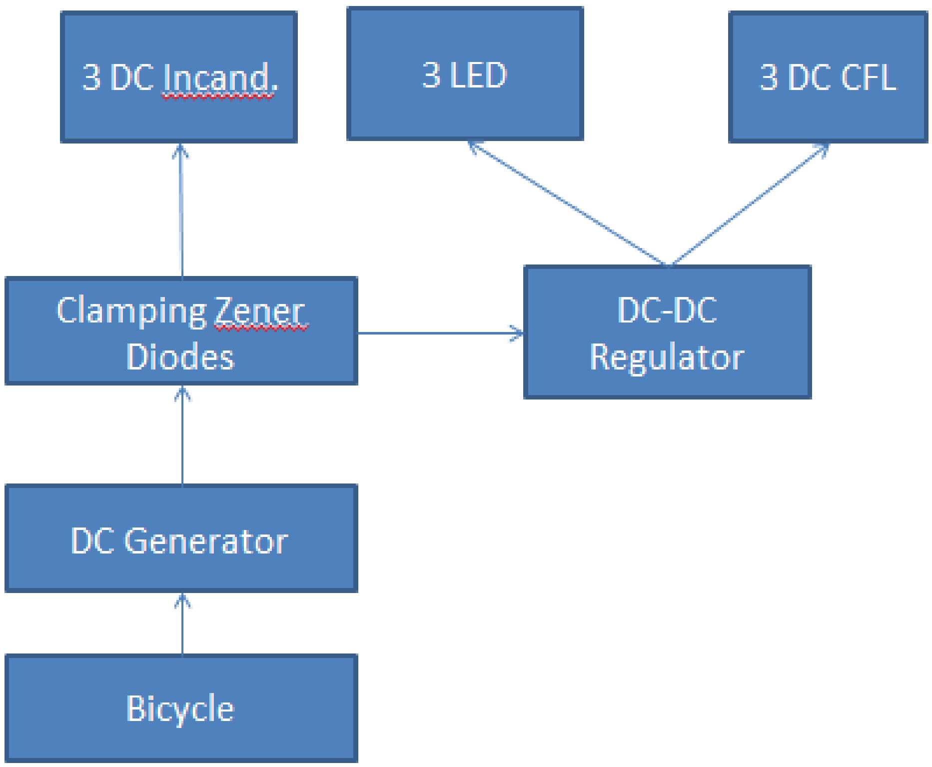

Figure 8 - High level block diagram of full system

3.1 Overview of Lighting Technologies

The incandescent light bulb consumes the most power. In this project, we are using a 50-watt incandescent light bulb and LED and CFL bulbs which are equivalent in terms of light output. Below we have a table that shows power consumption, lighting technology and brightness of the bulbs that are used in our EduCycle system.

Lighting Technology	**Power Consumption (watts)**	**Brightness (lumens)**
Incandescent	50	500
Compact Fluorescent	9	585
Light Emitting Diode	6	360

3.2 Energy Generation

Since we wanted to minimize the conversion losses and lower costs, we chose to use an entirely DC-based system. Converting to and from AC power introduces a new and unnecessary step to the system. The generator is a major component of the project as it translates mechanical power into electrical power and energy losses from this component cascade into the rest of the system. The EduCycle uses the 36 V, 300 W motor from Shenzhen Unite Industries. This is a brushed motor which is typically used for electronic scooters though the power rating, cost and form factor make it useful for the MQP as well.

Figure 9 – Shenzhen Unite Industries 1016 M DC Generator

3.3 DC Generator and Power Characterization

The manufacturer of our DC generator claimed that it was rated for about 400W, but our research indicated that it was only rated for about 300W [16]. Fortunately, our system does not require more than 150W (50W for each Incandescent) at maximum load.

Since there is extremely limited documentation on the DC generator, we decided to perform a system power characterization on the generator. Power characterization measures the energy losses of the bicycle and of the DC generator. A bicycle with an energy measurement device was connected to the EduCycle trainer. The DC generator was connected to a capacitor which was connected to three resistors (1 Ω, 2.2 Ω, and 3.3 Ω). The output power was calculated using the measurement of the volt-meter in parallel with the resistor and $P = V^2/R$.

Resistance	Input Power	Output Power	Efficiency
1 Ω	50 W	23.0 W	46%
	100 W	54.8 W	55%
	150 W	70.5 W	47%
2.2 Ω	50 W	25.5 W	51%
	100 W	53.0 W	53%
	150 W	82.8 W	52%
3.3 Ω	50 W	34.7 W	69%
	100 W	63.7 W	64%
	150 W	87.6 W	58%

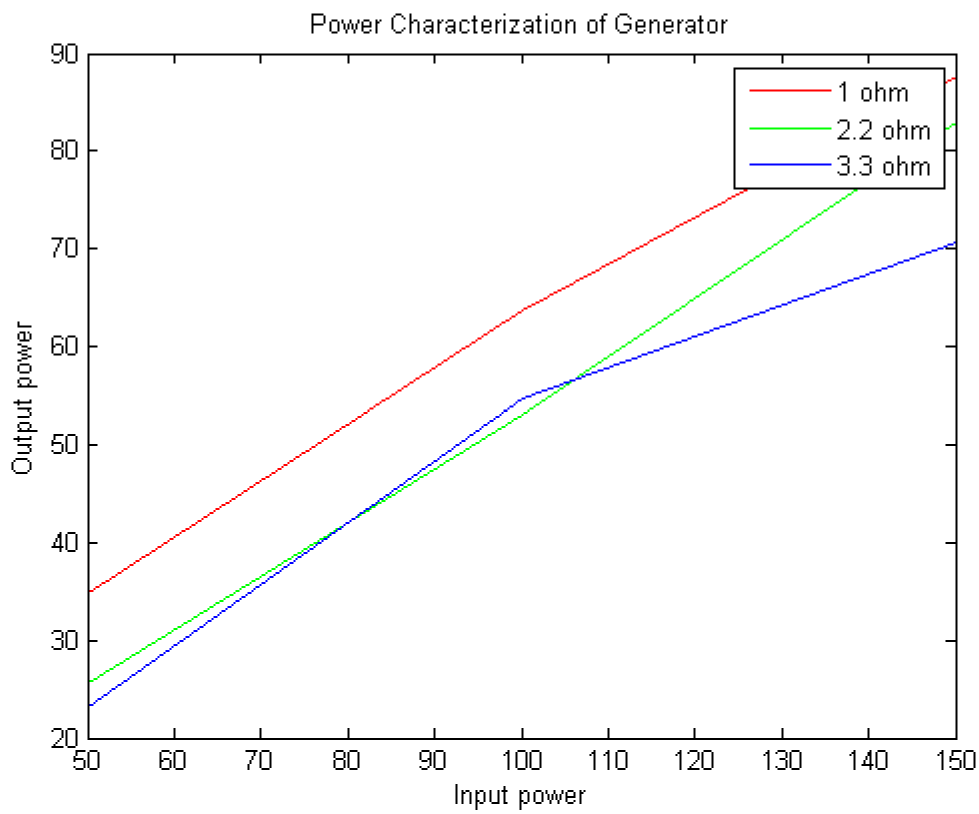

Figure 10 – Power characterization curve

The power characterization shows that the system is fairly inefficient. The peak efficiency was of 69.39% is attained when powering the 3.3 Ω resistor with 50 watts and the lowest measured efficiency is 46.08% when powering the 1 Ω resistor with 50 watts. The efficiency appears to increase slightly as the resistance increases although variation is limited. While the inefficiency is high, this is not an issue as it will linearly increase the effort and amplify our statement about the inefficiency of incandescent lamps.

3.3 Voltage Regulation

Voltage regulation was necessary, in particular because the sensitive within the CFL bulbs need a highly regulated voltage in order to operate safely. Since highest load in the system would be 150W, the device chosen was CUI Inc.'s VHK200W 12V DC-DC Converter. The device is designed to handle up to 200W, with surge voltages of up to 50V (typical operation is between 10V and 36V). The maximum current rating of the device is 16.7A, which is much higher than the maximum current that will be required to operate the system.

3.4 Zener Diodes

While the original prototype for EduCycle specified used DC/DC regulator as the input voltage for all of our light bulbs, we discovered that commercial DC/DC converters are designed to provide an extremely stable output waveform. These systems have built-in protection circuitry as well as complex internal mechanisms which disable the output when they determine that a stable output cannot be generated. They only turn on when the input voltage and current is high enough to support the load. When used with incandescent lamps, there is an extremely visible discontinuity in the load. Therefore, Zener diodes are used in parallel with the incandescent bulbs to clamp the voltage to approximately 12V.

Manufactured by Solid State, each 1N3311B Zener diode can handle up to 50 Watts of power and has a reverse breakdown voltage of 12V.

Figure 11 - Solid State 1N3311B 50 Watt Zener Diode

4 Realization of Final Design

Below is a detailed block diagram of our final electronics design.

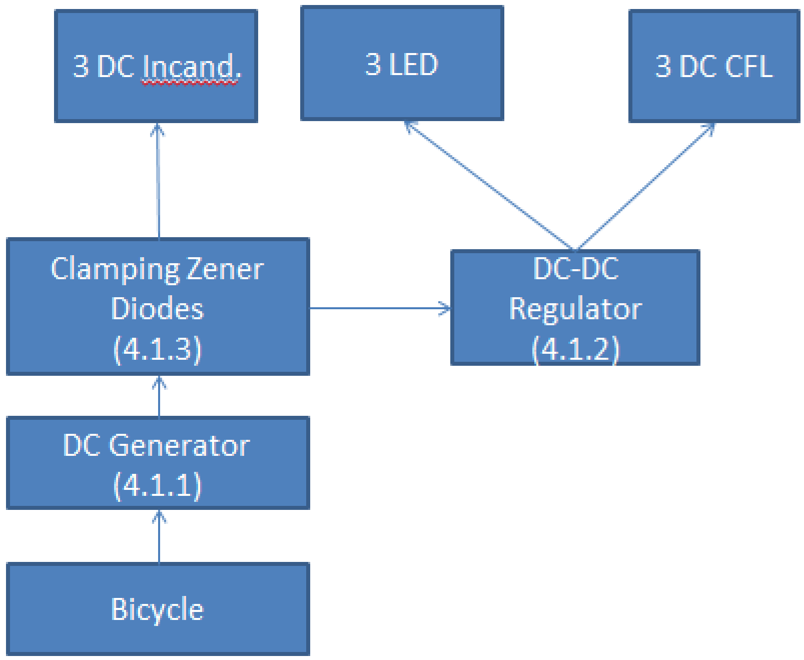

Figure 12 - Final Electronics Design

In the end, we decided on using all DC light sources in order to minimize the amount of energy conversion required to light up a bulb. The power is created by a bicycle trainer that has a DC generator attached to it.

4.1 Electronics

The major components of the electronics design included the DC-DC converter, the Zener diodes, the switching circuitry, and the DC generator.

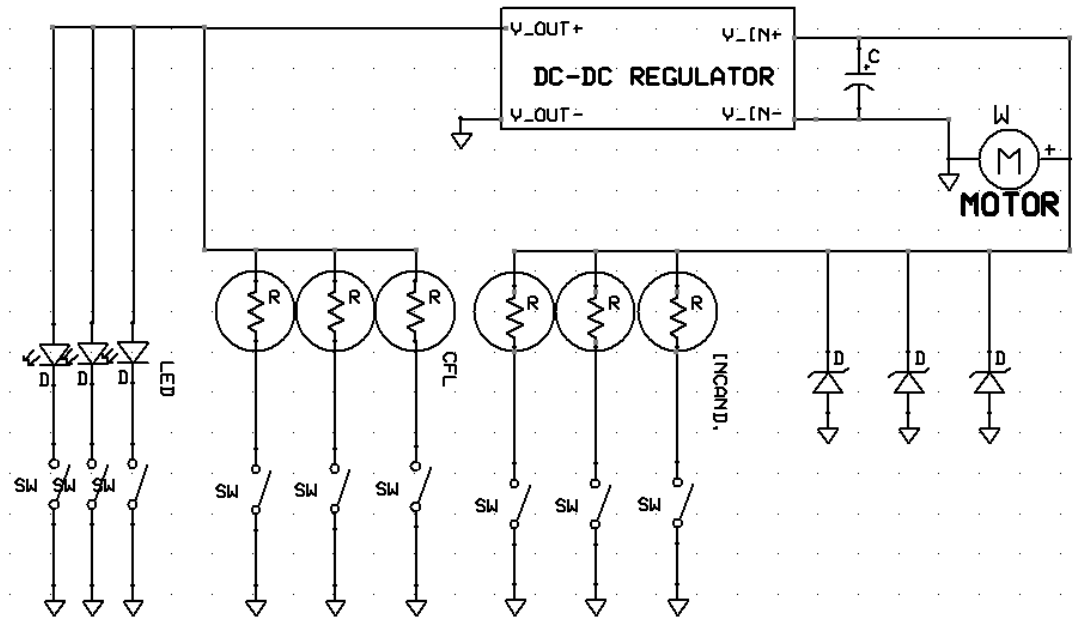

Figure 13 - Full electronics schematic

The schematic shown in Figure 13 shows every light bulb, all in parallel, along with three 50W Zener diodes with reverse breakdown voltages of 12V.

4.1.2 Voltage Regulation

The voltage regulator we decided upon was CUI Inc.'s VHK200 series (see image below).

Figure 14 - VHK200W Series

The operation of the device itself is uncomplicated. Providing the device with an input within the acceptable range will result in a constant 12V output.

The problem with interfacing the generator to the regulator was the enormous ripple voltages coming out of the generator (see Figure 15 below).

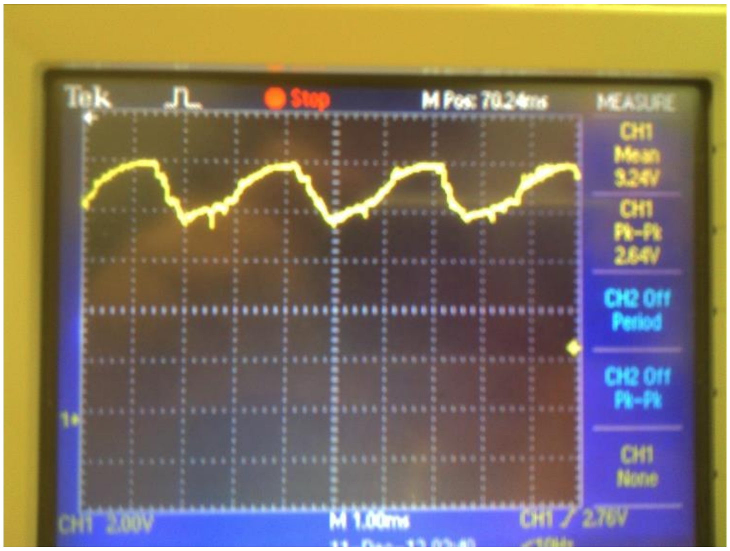

Figure 15 - Rippled voltage coming out of generator

A waveform with such a huge variance in voltage caused issues with the operation of our regulator, since as the user pedaled, the power generated would oscillate back and forth over the minimum threshold required to activate the regulator.

A capacitor approximately 3300 micro farads in size was needed in parallel with the input ports of the regulator to combat the rippling voltages being output from the generator. Figure 16 below illustrates this.

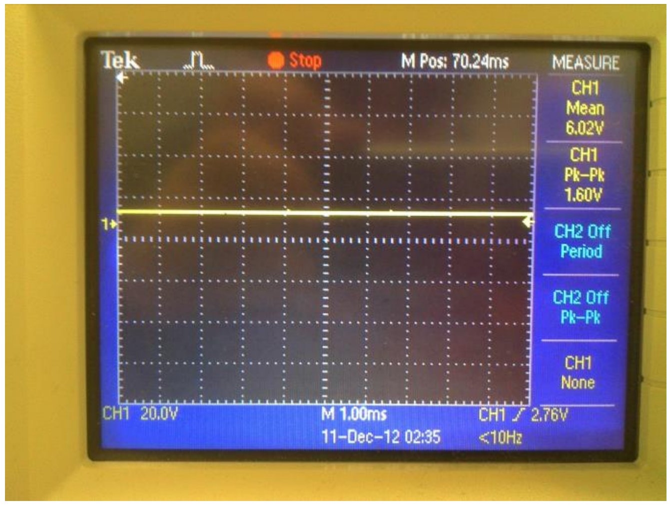

Figure 16 - Smoothed voltage output

With an output current of up to 16.7A at 12V and an input voltage range of 10-36 Volts, this device is more than sufficient to process the voltages and currents to turn on any of the light bulbs.

4.1.3 Zener Diodes

In the early prototype, all 3 types of bulbs were connected directly to the regulator, and Zener diodes were not part of the design. Once the first prototype was up and running, an odd behavior was observed. The LED and CFL lights turned on exactly as expected, and the first Incandescent bulb also turned on perfectly. When the second Incandescent bulb was turned on, both would start flickering on and off. After taking some voltage readings, we discovered that the regulator was reading the power input, and comparing it to the required power output. Since it did not have enough power to turn on both light bulbs, it would immediately turn off. If the user just barely managed to generate over 100 Watts, the regulator would turn on, but immediately turn off again once the power dipped slightly below 100 Watts. This caused serious usability issues, because if the user was not generating more than 100 Watts, the regulator would turn into an open circuit and the user would feel no load when pedaling.

Since the incandescent bulbs could be safely operated within a range of 11V to 15V, three identical 50 Watt Zener diodes with a 12V reverse breakdown voltage were selected. The incandescent bulbs were no longer connected to the regulator. They were no longer connected directly to the generator output in parallel with the Zener diodes to clamp the voltage at 12V.

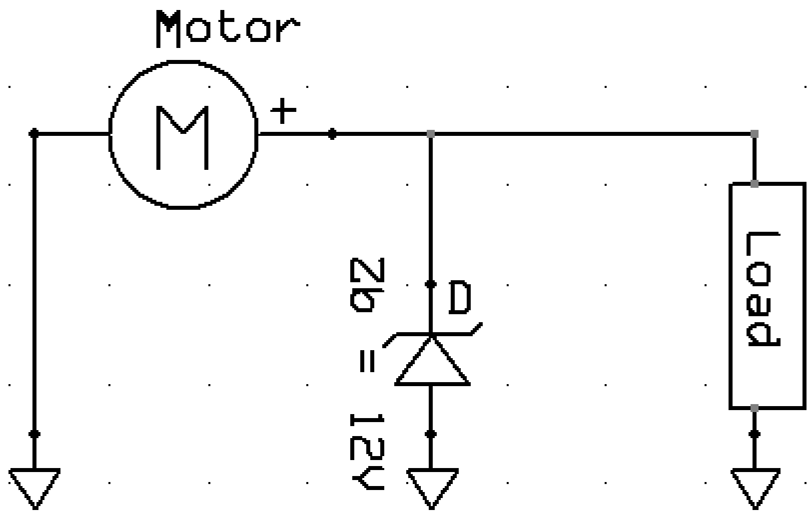

Figure 17 - Zener clamping circuit

This configuration resolved the flickering issues caused by the adaptive circuitry in the regulator. The user now feels the entire load of the incandescent bulbs, whether or not they are generating enough power to light them up. As the power generated increases, the bulbs light up dimly and progressively get brighter as more power is generated.

The Zener diodes did not clamp the voltage perfectly to 12V (sometimes the voltage would go as high as 12.46V), but if the voltage was slightly off, it wasn't a major concern since the bulbs were designed to handle up to 15V.

4.1.4 Assembly of electronics

Wiring the electronics in an efficient manner in such a tight space proved to be a difficult task. To minimize the amount of soldering that needed to be done, terminal strips (also known as terminal blocks) were used. See figure 14 below.

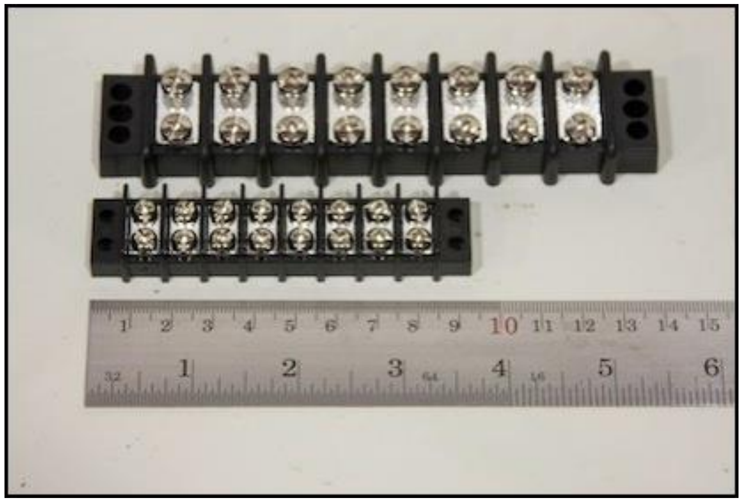

Figure 18 - Terminal Block, available in a variety of lengths and sizes

In order to connect a wire to a terminal block, one must first crimp a spade lug to a wire, and then slide that spade lug into the terminal block.

Figure 19 - Spade lug

Furthermore, all of the ports on a terminal strip can be bussed together, effectively making a rail to which many devices can be connected, while only having to provide a single input line.

This feature allowed us to minimize the amount of wires that needed to be routed. Only 4 terminal blocks were required: two for the output of the generator (V+ and V-), and another two for the output of the regulator. All of the bulbs, switches, and Zener diodes could be connected to these as necessary.

4.3 Mechanical Design of Bicycle-Based Generator

The mechanical design for the EduCycle interfaces the bicycle to the rest of the system and serves as the “power plant” for EduCycle. The mechanical interface enables efficient conversion from the mechanical energy of the bicycle wheel rotation to electrical energy and mounts onto both children’s and adult bicycles. This platform is designed from the ground-up for effective indoor and outdoor educational presentations and delivers key features such as portability, sturdiness, safety, and simple setup and adjustment. The mechanical platform is also designed entirely from aluminum and steel, providing an iconic, high-quality industrial design.

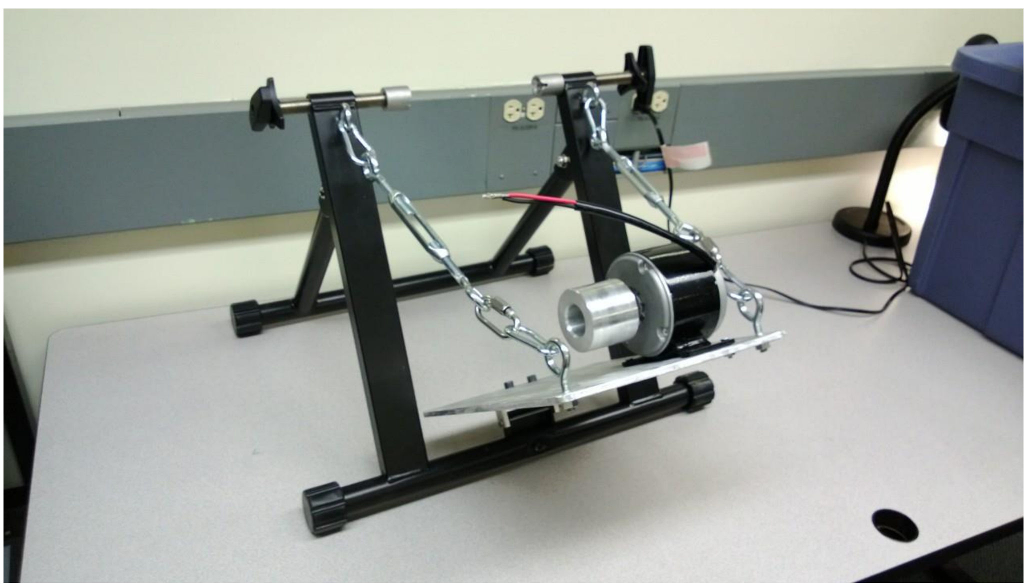

Figure 20 – EduCycle Bicycle Generator platform

4.3.1 Interface between bicycle wheel and DC Generator

The cylindrical idler transfers the mechanical energy of the rotating tire of the bicycle mounted on the trainer to the DC generator. The idler was modeled using Solidworks and the manufacturing was precisely specified using the ESPRIT CAM software. The final part was= machined from a single block of 6061 aluminum alloy. Additionally, the part features an inner diameter of ½ inch which provides sturdiness and added weight for a flywheel-like effect. The idler is open in one faced and closed on the other face. The closed face features a small hole for a screw to attach the idler onto the motor. The aluminum idler shown below, provides excellent traction with the bicycle tire without causing wear and is both safe and well-constructed.

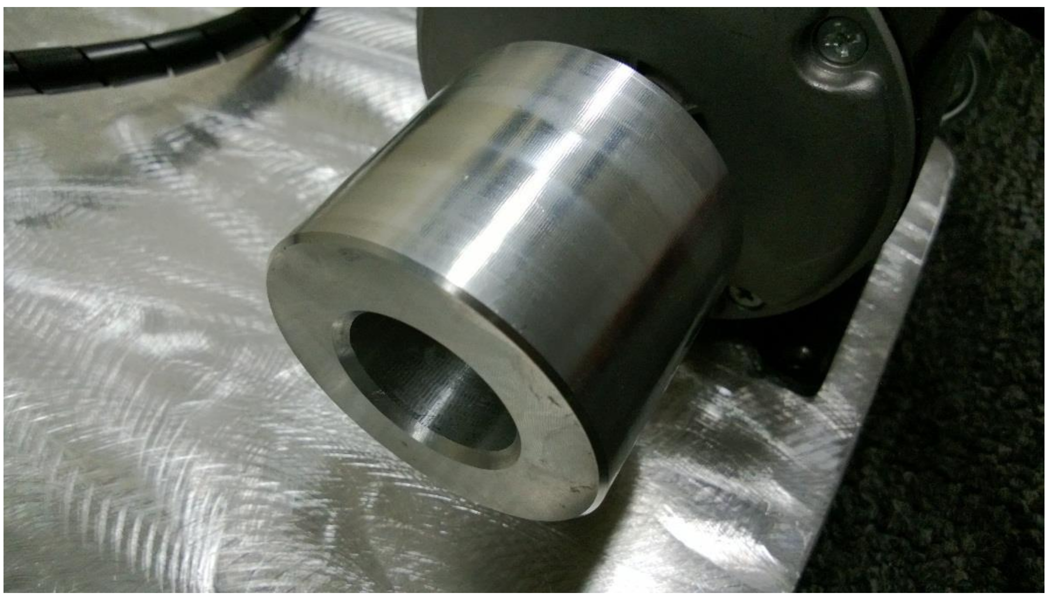

Figure 21 – Photograph of aluminum idler attached to DC motor

4.3.2 Metal Plate Holding DC Generator and C-Bracket

To position the motor so that the idler can interface with the bicycle tire while remaining attached to the overall system, we built a metal plate which mounts onto the trainer. This involved developing a CAD model assembly to determine the interfaces between the new bracket, the plate and the motor and purchasing sheet metal of sufficient dimensions. The design was manufactured by drilling holes using a drill press and carefully sanding the edges to achieve a uniform chamfer on all edges. Avoiding sharp edges was an important consideration in the design as sharp edges pose a safety hazard to children. Both the top and bottom faces of the surface were uniformly finished using a metal grinding wheel. Below, we show the CAD model for the plate along with the motor, the motor plate and the new bracket.

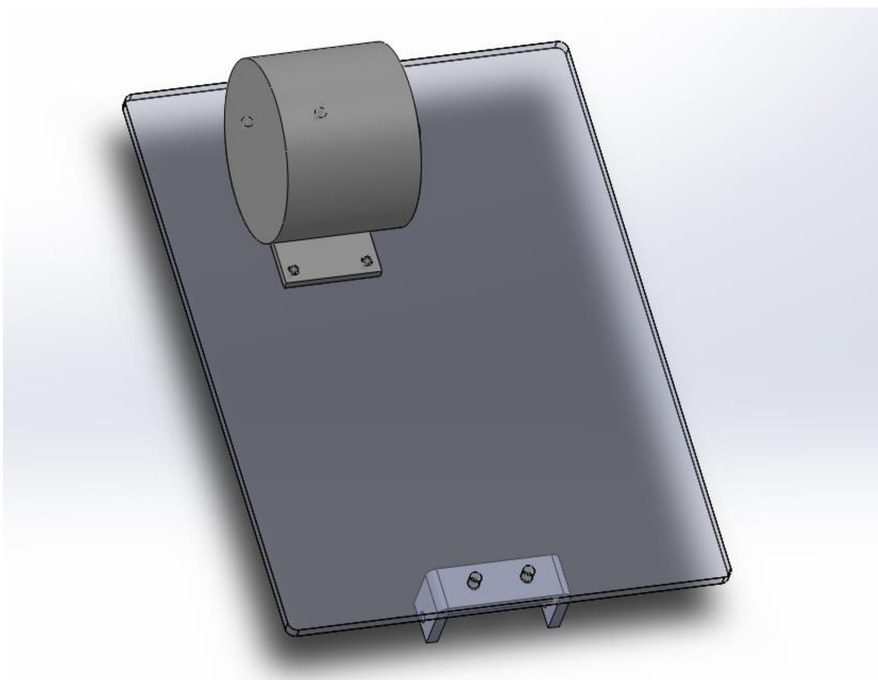

Figure 22 – Metal plate with DC

The plate was designed from ¼ inch thick aluminum as this thickness provides resistance to deformation under normal stress and students accidentally stepping on the plate. The plate was designed to be 13 inches long and 10 inches wide. The 13 inch plate length supports bicycles as small as 16 inches and the 10 inch width is small enough to fit between the legs of the trainer.

To securely hold the plate onto the trainer, we designed an aluminum channel-fitting C bracket. The C-brackets attaches onto two points of the metal plate to prevent in-place rotation and can be rotated to change the angle of the metal plate. The inner channel of the bracket was designed to fit securely into interface provided by the channel using a long screw that extends through the C-bracket. This bracket was first designed as a CAD model using Solidworks, shown in Figure 23. The CAD model was then implemented as a CAM program using ESPRIT and manufactured using a CNC machine. The bracket was machined to be ¼ inch thick so it would not deform under stress as is extremely common in thin metal brackets. Finally, we drilled holes which aligned with the holes on the aluminum plate using the drill press so that the aluminum plate could be mounted on the trainer.

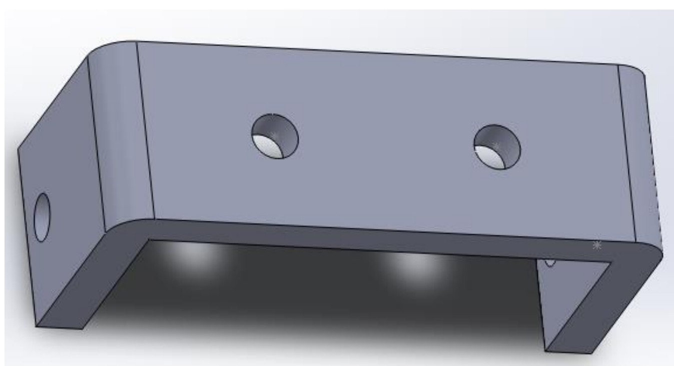

Figure 23 - CAD Drawing of the C-bracket

Figure 24 – Picture of C-bracket,

4.3.3 Adjustment Mechanism for the Mechanical Plate

To be effective in classrooms, simple setup was an extremely important goal from the onset of this project. We designed a simple and intuitive adjustment mechanism for the system so that EduCycle can be setup without difficulty within minutes for both adult and kids' bicycles of various heights. Following adjustment, the idler should firmly contact the bicycle tire with appropriate traction.

In EduCycle, two turnbuckles adjust the angle of the metal plate for the height of the bicycle. The turnbuckle is a device which provides very fine adjustment, elongating or contracting depending on the direction of rotation. As shown in Figure 25 below, each turnbuckle is connected to eye-hooks on the trainer and on the plate. Spring-links connect the turnbuckle to the eye-hook and provide additional extension which may be needed with larger bicycles. The rubber tires behave like springs, allowing for acceptable performance without perfect adjustment. To provide sufficient length to support the aluminum plate and to connect the eye hooks on the trainer and the base to the turnbuckle, spring links are used.

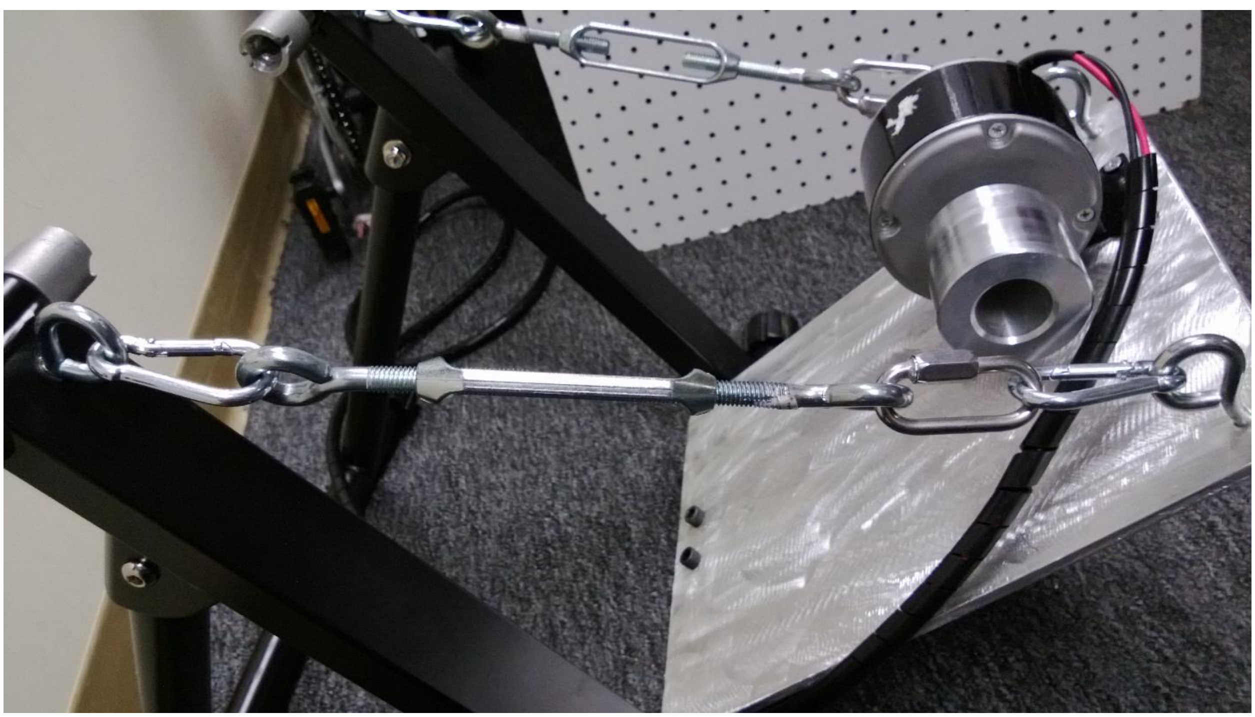

Figure 25 – Picture of a turnbuckle

4.4 Display Box Design

The display box is a core component of EduCycle and directly interfaces with users. The goal of our design was to develop a system which expresses the educational vision of our project and elicits the excitement of elementary students. For an educational demonstration, our project must be durable, portable and simple to set up. The components need to be laid out logically and must be held firmly in place. Displaying the light bulbs in a manner that is relevant to the user was imperative since the system is designed to provide an interactive user experience.

The solution for our display box is to use a musician's crate and to custom manufacture the interior housing which seats the electronics using acrylic and wood. The musician's crate is extremely robust and provides insulation against external shock. It is extremely portable and offers sufficient viewable area to demonstrate all the lighting systems and enough volume to easily accommodate the components used in this project. For transparency and to protect our components, our system uses a front and back acrylic panels. The acrylic plates hold the light bulbs and the regulator. Held below the acrylic casing by standoffs is a layer of wood. This layer of wood holds the terminal blocks and routes wires to enable a clean appearance.

Figure 26 - Assembled Display Box

4.4.1 Musician's Crate

The musician's crate we selected was Odyssey FZ1200 Flight Zone Universal 1200 Style DJ Turntable Ata Case. The dimensions of this box are 21.5"(w) x 9.625"(h) x 17.375"(d) and the box contains two inner faces, one of which is slightly taller than the other. The taller side offers 4.25 inches of usable height and will be used to showcase the electrical components of our design such as the light bulbs, regulator and microcontroller board.

Figure 27 – Musician's Crate

The box folds open with a hinge although both sides are entirely detachable. The box also supports a handle for easy carrying and a locking mechanism to prevent accidental damage or injury. Finally, it has a hole on the back of the box which can be used to easily route wires to connect the lighting system to the generator. This box provides a platform upon which our electronics can be elegantly displayed.

4.4.2 Wood Plate and Acrylic Box

EduCycle aims to elicit excitement in elementary students about electronics and about energy conservation. The acrylic display box enables these students to clearly see the different lighting technologies while also protecting our electronic components.

The choice for acrylic was made because it is transparent, durable and has strong impact strength compared to glass. Furthermore, it can be easily cut at WPI using the laser cutter unlike other plastics such as polycarbonate. Transparency is important because the light emitted from the bulbs should be visible to students for the system to be effective. Having a visible regulator provides an opportunity to explain the components of the system. For plate below the acrylic housing, wood is ideal because composite wood is cheap, can easily be painted and drilled and is quite strong. In this case, transparency is not needed or desired.

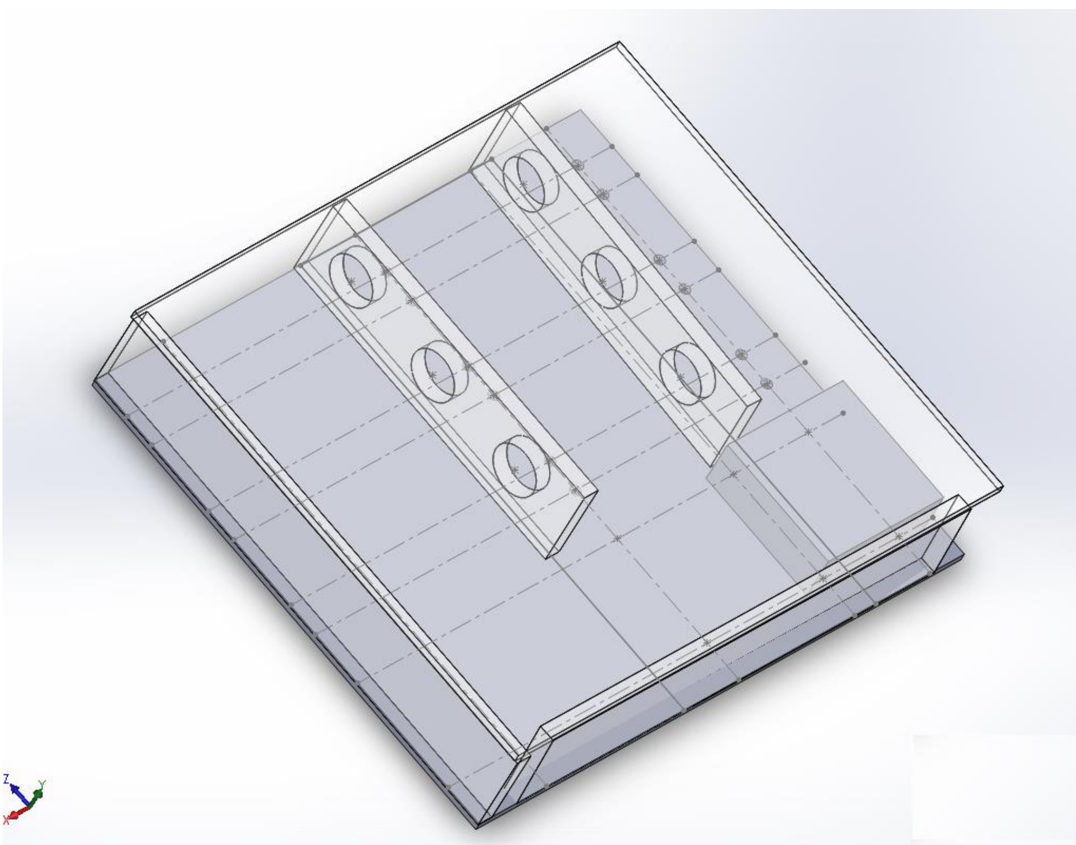

Figure 28 - CAD Drawing of the Acrylic Display Box and Wood Plate

The internal layout of the display unit was designed to be extremely sturdy and to maximize the educational aspect of EduCycle. Within the acrylic display box are two long columns of acrylic with laser-cut holes to support Edison-screw lamp holders. These acrylic panels are held to the bottom plate using tapped screws. The incandescent and CFL bulbs are held sideways in order to expose a greater surface area of the bulb and consequently more light. Metal standoffs hold the two acrylic plates are held at a distance of 2.75" by at each corner. The LED holders go into the rear plate through laser-cut holes and are held onto the rear plate using Loctite. Wires pass through the rear plate and into the wood where terminal blocks route them neatly.

This system provides a number of features. Most importantly, the system is held tightly in place and the light bulbs and electronics are well protected. Secondly, four screws remove the front and users can easily replace of light bulbs which is necessary for easy set-up. The system is relatively weatherproof and can be used in fair weather for outdoor demonstrations.

4.4.3 Switching System

EduCycle uses a switching box that on the side of the display box to individually control each light bulb. The holders for the light bulb have been laser cut from a 1/4" block of black acrylic to match the surface of the side of the box. The top row of switches control the incandescent bulbs. The middle row of switches control the compact fluorescent lamps while the bottom row of switches control the LED lamps. The incandescent bulbs really enable the user to “feel the load” even when they do not generate sufficient power because they are connected in parallel to the Zener diode. The incandescent and CFL bulbs only turn on and draw current when the capacitor values exceed a threshold in the regulator.

Figure 29 - EduCycle Switching System

5 Effectiveness of EduCycle

To determine the effectiveness of EduCycle, we presented an educational demonstration using EduCycle at Spring Street Elementary School in Shrewsbury. We discussed how electricity is generated and the negative environmental impacts of electricity generation and introduced the concept of power. We used six 18 x 24 foam board posters as electronic presentations are not portable. Following the presentation, we administered a simple survey which asked students which lighting technology is most efficient to assess the knowledge of students before testing our system. Five students (31.25%) believed that CFLs are the most efficient lamp while eleven students (68.75%) believed that LED lighting is the most efficient. No students believed that incandescent lamps are the most efficient.

The effectiveness of the demonstration far exceeded our expectations. After using our system, all students were aware that LED lighting was more efficient than CFL or incandescent bulbs and physically experienced the inefficiency of incandescent lighting. Moreover, students gained an immense curiosity about lighting and asked about why a television uses more power than a phone and about how the motor works. Students were also interested in understanding how nuclear plants and solar panels work. They also gained an appreciation for how much energy is used by lighting and the necessity to conserve energy. The presentation met and exceeded our goals by teaching students about the amount of power used by various lighting technologies and by kindling their curiosity about energy and electronics.

6 Conclusion

The EduCycle is an innovative educational platform which enables students to physically experience the amount of energy required to power LED, CFL, and incandescent bulbs. Unlike similar educational demonstrations, EduCycle allows users to turn on one, two, or three of each bulb to experience different levels of challenge. EduCycle also uses bicycles which are highly efficient and generate significant energy so the resulting lighting is bright enough to illuminate a small room. The EduCycle platform is portable, durable and highly reliable, exhibiting an iconic black and metallic industrial design which stands apart from typically dull educational demonstration systems. Various lights are switched on or off using a switch panel on the side of the display box although future revisions may support switching using a wireless module on the bicycle and progressively turning on more lights based on output brightness.

7 Future Work

Given the limited time constraints of this project, there were some features we would have liked to see that we simply did not have time to implement. There were also design mistakes made that we hope can be resolved by future teams and project costs that can be reduced.

7.1 Replacement of regulator

It was originally intended that the VHK200W regulator would manage all three forms of light bulb. Once the regulator was ordered and testing was under way, we realized the VHK200W would not work as desired with the incandescent bulbs. Now that the Zener diodes were managing the current and regulation of the incandescent bulbs, the maximum power required was approximately 27W (9W per CFL). This could easily be achieved with a much cheaper and more commonly available voltage regulator.

7.2 Automating the switching circuitry

EduCycle currently uses nine manual switches to actuate every individual light bulb. This requires a presenter to stand next to the Display Box and turn on more lights when the user is ready to. This mode offers some advantages as the presenter has more control over the flow of the presentation, but we feel that a more automatic switching circuit might enhance the user experience by making the system more precise. As soon as user generates enough power to turn on the next bulb, the next bulb switches on. We designed a simple circuit that uses a microcontroller (MSP430G2553) to use power MOSFETS (IRF1324Pbf) as switches. The current output of the generator could be translated to a voltage by a Hall Effect sensor and read into the ADC of the microcontroller.

7.3 Software-based Visualization

EduCycle currently uses six 18 x 24 posters to educate children about pollution and the need for modern lighting. This is very simple and unlikely to fail but the system can be far more immersive and interactive. To enable a highly interactive visualization experience, the product can include an interactive real-time display which shows a graph of the power generated, the total cumulative energy in watts, and educational text consisting of scrolling blurbs about the history of the lighting system that they are using. The system can also display derived calculations such as the amount of energy that would be used by switching to another type of lighting technology. The software visualization can be loaded onto a Linux-based evaluation board running the Intel Atom processor and an LCD display can be mounted onto the other side of the musician's crate.

7.4 Support for USB Charging or AC appliances

EduCycle currently only supports internal light bulbs. Students may wish to plug in their MP3 players or cell phones into the EduCycle for charging. Alternatively, users may wish to plug in AC appliances such as televisions, laptops, desktops or household lamps. This way, users can feel the power consumption of a variety of objects and compare them against each other or against light bulbs. Supporting USB devices would require a 5 V, 2 A regulator and should be straight-forward to implement in the system. To support AC appliances, an inverter needs to be added to the system to transform the DC into 130 V 50 Hz AC electricity.

7.5 Support for Energy Storage

Portable devices are everywhere today and include the iPad, the iPhone and laptops. Energy storage is a key concept that can be easily taught. Students using EduCycle can learn about different types of batteries using the same light bulbs. One option would involve adding a lead acid or Nickel Cadmium battery and adding a switch to activate the battery so users can see how much energy is stored by seeing how long a light bulb stays on. This can also be useful for storing surplus energy from the pedaling or for games

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8 - Appendices

8.1 Appendix A – Future Work: Automated Switching Interface

Below, we describe in detail our original plans for the automated switching. Some aspects of the design will need to be changed.

The circuit below shows an example of the relationship of each MOSFET and its respective light bulb:

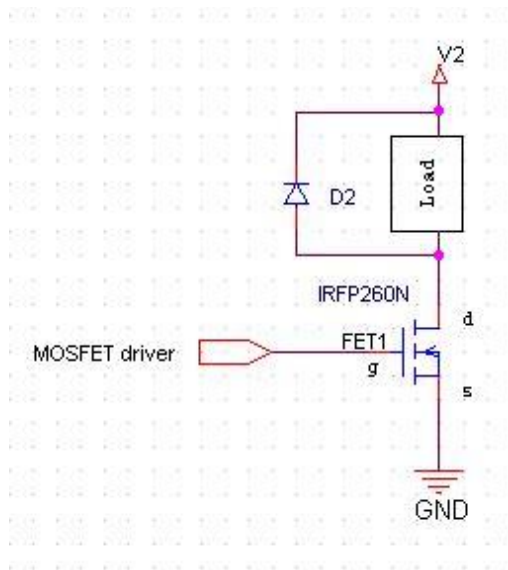

Figure 30 - N-Channel MOSFET used as a switch

The MOSFET selected for this project was the IRF1324Pbf. This is an N-Channel Power MOSFET which can handle up to 300W of power, well above the maximum threshold of our system. The gate threshold voltage ranges from 2.0V to 4.0V. This can easily be achieved by a microcontroller with logic levels of 0V and 3.3V.

In order to read the voltage coming out of the generator, we had to first scale down the voltage and current by using a voltage divider circuit (this later became wrong). Light bulbs are turned on sequentially as the user generates more power with the bicycle.

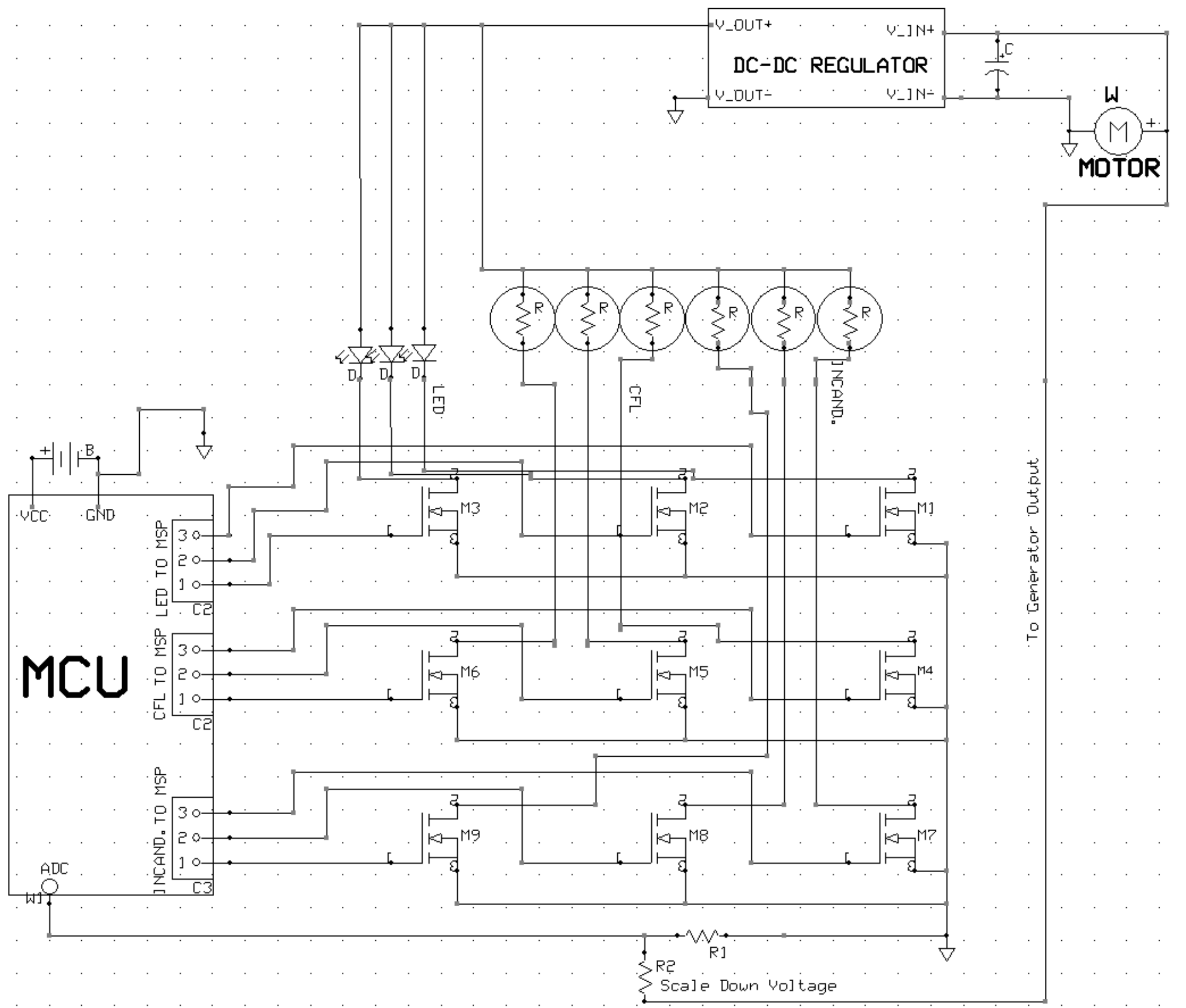

Figure 31 – Early Electronics schematics for automated switching

The schematic above outlines the proposed electronics system. The motor at the top right is the voltage source. The voltage is smoothed by a 3300 microfarad capacitor to provide an output ripple suitable for the DC-DC regulator. The DC-DC regulator provides 12V to the light sources, which are all connected to the MOSFET drains as shown in Figure 8. Setting the gate voltage to 'high' results in a complete circuit; this allows current to flow through a given light bulb to the common ground. The gates are connected to the microcontroller, which is powered by a simple battery. At the bottom of the schematic, there is a voltage divider which scales down the capacitor voltage so it can be read by the ADC (this is no longer technically possible, since the Zener diodes are clamping the generator to a constant 12V. See section 4.1.6.2.1)

Soldering this system to a generic PCB by hand was the least optimal solution, since the amount of connections and buses that could potentially be soldered erroneously was too high. Additionally, we considered the fact that the board had to be physically robust and capable of being put in the trunk of a car without any issues. Manually soldering all the connections and cables by hand left too much to chance, which meant we had to design a PCB for the circuit.

In our situation, Eagle was the best software to use, since it had a rather user community and it was free.

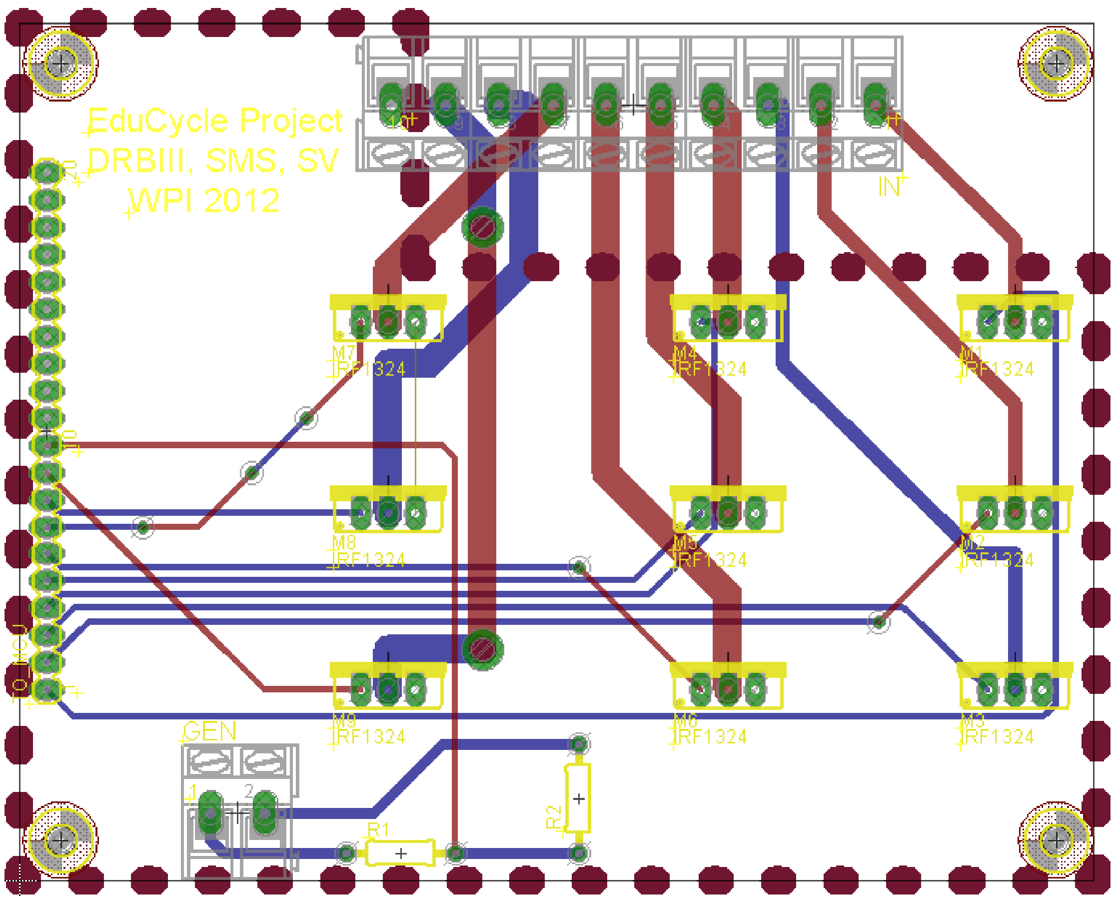

Figure 32 - PCB Layout for MOSFET Switching Circuit

All of the MOSFET Source pins and light bulb grounds connect to a common ground plane on the top and bottom layers of the board. Header pins are laid out on the left side to allow the MSP to interface easily with the gates of the MOSFETs. The traces here are significantly smaller than the ones connecting to the MOSFET sources, since they will be carrying much less current than the MOSFET Sources and Drains themselves.

The Drain pins have large traces because they will be carrying relatively high currents. This holds true especially for the MOSFETs that will channel the current for the Incandescent light bulbs. Thus, a trace size of 100mil was chosen for all the power traces.

Temp Rise	10 C	20 C	30 C
Width (mils)	Max Current (A)		
10	1	1.2	1.5
15	1.2	1.3	1.6
20	1.3	1.7	2.4
25	1.7	2.2	2.8
30	1.9	2.5	3.2
50	2.6	3.6	4.4
75	3.5	4.5	6
100	4.2	6	7.5
200	7	10	13
250	8.3	12.3	15

Table 2 - Table outlining trace width in mils and its current-temperature tolerance

At the bottom, there is a terminal block input for the generator output, which will be fed into the MSP, as mentioned before. The terminal block at the top will connect to the positive terminals of the light bulbs. Socket 10 on that terminal block will be connected to the collective minus terminals of all the bulbs.

8.1.1 Revisions Needed to PCB Design

When we designed the PCB, the system did not use Zener diodes in the circuit. Once Zener diodes were added, the generator output voltage was clamped to approximately 12V. This meant that we could no longer use voltage measurements to calculate the current through the capacitor (and thus the total power output of the generator). In the future, the ADC on the microcontroller must be connected to a Hall Effect sensor or a light sensor to measure current.

A disconnect in the ground plane caused further issues with our PCB. The ground ports for the regulator's V_{out-} port and the microcontroller's ground port were effectively isolated from all of the MOSFETs except for M7. This was due to traces cutting across the board on both layers shared by the ground plane, isolating M7, the MCU ground, and the regulator ground. The eight other MOSFETs were interconnected, as proved by a continuity test, so the fix for this issue was to connect a wire from the Source pin of M7 to the Source pin of any other MOSFET. This would result in all grounds become interconnected, as originally intended.

8.2 Appendix B – Future Work: Software Visualization

To provide a fully immersive and interactive experience for EduCycle users, our product planned to includes an interactive real-time display, though this was not included in our final product due to time constraints. This display would show users a graph of the power generated, the total cumulative energy in watts. The display would also show users scrolling text consisting showing the history of the lighting system that the user is pedaling, the amount of energy that would be used by switching to another type of lighting technology, and other contextually relevant information. Such a system could also notify students about achievements which reward them when they pedal more light bulbs.

To make the development process simple, a prototype was developed using Java and ran from an Intel Atom-based embedded board running Linux. To display the results, our design included using LCD on the other side of the musician's crate. In our design, the embedded board is powered via a wire that is routed out of the musician's case along with the monitor. Acrylic structures would enclose the monitor and embedded board in well-defined structures.

The software prototype required an MSP430-based Launchpad to be connected to the computer via USB. An event-driven architecture will be used to process samples and to update the real-time graph which displays the power over time. The Java-based SWING framework powers the user interface which starts on system boot.

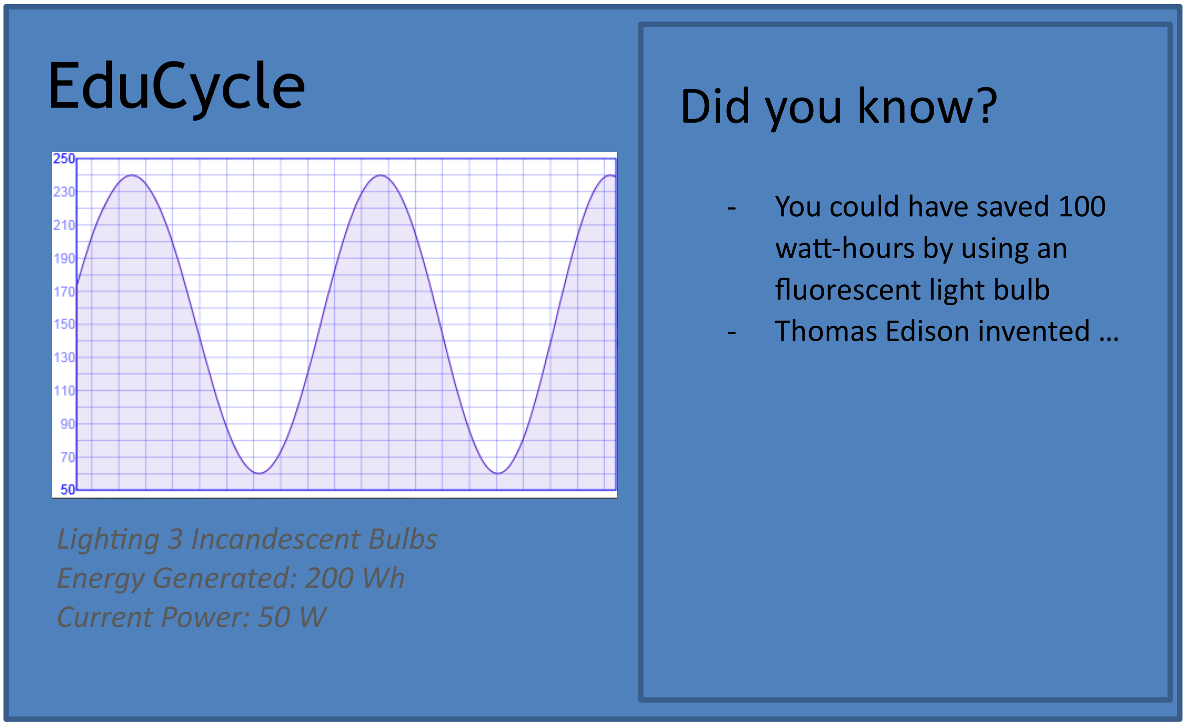

Figure 33 - Concept of the EduCycle Visualization User Interface