PORTABLE FLUORESCENCE ILLUMINATOR

FINAL DESIGN REVIEW

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The Illuminators

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STATEMENT OF DISCLAIMER

EXECUTIVE SUMMARY

This Final Design Review (FDR) document outlines the senior design project implemented by a team of three mechanical engineering students at California Polytechnic State University, San Luis Obispo for a professor in the biochemistry and chemistry department, Dr. Javin Oza. The project involved designing and manufacturing a portable ultraviolet fluorescence illuminator that will indicate the fluorescent glow of biomaterials for viewing purposes. The goal was to create a portable product out of recyclable material that can be used in field applications and increase accessibility to affordable science equipment. The initial sponsor and user interviews, technical background research, product research, and project objectives develop the specific requirements for the portable fluorescence illuminator in conjunction with the sponsor's requirements and define the project's outcome goals. The concept design demonstrates the results of the concept ideation process and indicates the design direction of the team. The final design of the illuminator details all of the features and parts incorporated into the device and how it meets Dr. Oza's specifications. The manufacturing plan outlines the materials, manufacturing operations, and assembly necessary to make the device. The design verification plan describes the various engineering tests that will be used to verify the illuminator meets the sponsor's specifications. The included project timeline contains all major milestones that were met over the duration of the project. The final conclusion includes reflections on the project and recommendations for the uses and future applications of the product.

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1. INTRODUCTION

Dr. Javin Oza, a professor in the biochemistry and chemistry department at California Polytechnic State University, San Luis Obispo presented the problem of an accessible and portable ultraviolet illuminator for biological research and discovery. In the field of synthetic biology, researchers use ultraviolet illuminators in their laboratories to view the glowing output signal from fluorescently-dyed biomaterials like DNA samples after a reaction has taken place. However, many commercially available ultraviolet illuminators are usually very expensive, are not portable for field uses, or are not accessible to the general public. Our team, comprised of three mechanical engineering students, has a project goal to design and build a portable ultraviolet fluorescence device that meets our sponsor’s requirements and improves accessibility to quality scientific equipment. This document describes the initial background research for the project and establishes project objectives. It presents the concept ideation process resulting in the concept design of the device; it also describes the final design of the illuminator, its features, and total cost of materials. It describes how the illuminator is assembled and the engineering tests that will verify the device meets Dr. Oza’s specifications. Lastly, the document defines the plans for project implementation from start to completion, showing the effective project timeline.

2. BACKGROUND

In order to form our understanding of the scope of the project, our initial background research consisted of three separate categories: sponsor/user interviews, technical literature, and product research. We conducted sponsor and end-user interviews to distinguish the specific customer requirements for the project. The technical literature found regarded future applications and industry standards involving our project. Our product research focused on finding competitive current products and relevant patents that indicate key features and technology that would potentially be useful to our project.

2.1 Sponsor/End-User Interviews

Sponsor Interview

We interviewed our sponsor, Dr. Oza, to understand his vision, requirements, and goals for the outcome of the project as well as obtain background on the biological processes and testing that require UV fluorescence illuminators. At the initial meeting, he clarified that his main goal is to “increase access [to scientific discovery], and decrease cost,” (Oza) emphasizing the importance of accessibility in our project’s outcome. The necessary design components for the UV transilluminator and Dr. Oza’s specific requirements for our project are:

Necessary Design Components

- UV lighting system
- Incorporated electrical system to power lighting system
- Heating element to speed up reaction times and produce 20˚C change in temperature
- Fits standard test vials

Needs/Wants

- Able to quantify different levels of glow with the ImageJ application
- Portable, able to be carried in one hand
- Small form factor
- Low production cost
- Manufactured with biodegradable/sustainable material, easily disposable
- Accessible to many people, increases accessibility to scientific fieldwork
- Able to be assembled/disassembled quickly
- Collapsible
- Utilizes different visible light-filtering screens to view glow

Our group determined that some desired, but not required goals mentioned by the sponsor at the initial meeting may not be in the direct scope of our project. However, the goal of making the illuminator a commercialized product could be carried out by future senior project teams.

End-User/Student Interviews

Our group also interviewed a few of Dr. Oza's student lab assistants, Logan Burrington, Philip Smith, Nicole Gregorio, Max Levine, and Byungcheol So. Each could be a potential end user of the final product. Their needs and wants as customers have dual function: as lab researchers, they would benefit from a portable transilluminator device to assist them in work. As college students in STEM majors, they would benefit from access to a cheap transilluminator that would enable them to easily conduct scientific experiments.

Like Dr. Oza, the students identified portability and a small form factor as very important requirements for the illuminator to have. Also, to increase the fluorescent light output, the lab assistants desired an increased surface area to volume ratio of the device. They believed that durability, the ability to use multiple filters, and an adaptor to fit different sized tubes would also be beneficial features for the illuminator (Burrington, et al.).

2.2 Technical Research

Illuminator Applications

There is an abundance of useful applications for a portable UV fluorescence illuminator in the fields of biology research and development. The transilluminator is mainly used as a fluorescence detection device for the glowing signal output of biomaterials. The need for an illuminator is high, especially for a product that is of low cost and easily accessible to many.

The UV transilluminator is a useful tool in order to indicate the complete production of a vaccine with iVAX, an "*in vitro* bioconjugate vaccine expression" (Stark, et al.). iVAX produces multiple individual doses of vaccines that protect against bacteria such as various strains of *E.coli*; it also does not need to be transported at very cold temperatures. This increases the amount of people in the developed and developing world that have access to antibacterial vaccines.

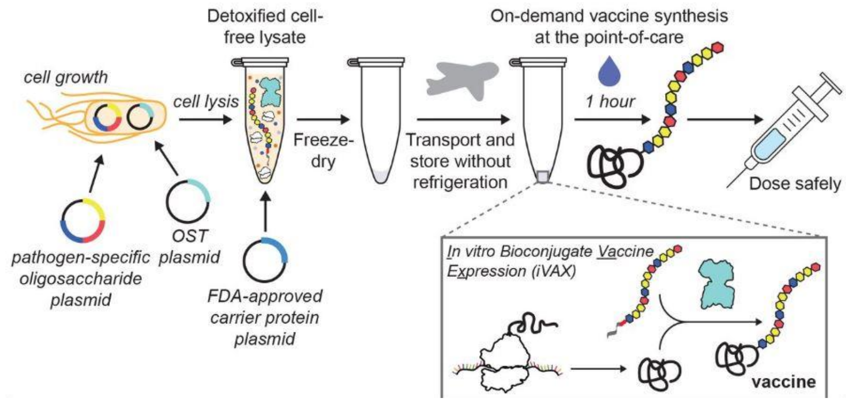


Figure 1. iVAX Vaccine Synthesis Process Diagram. (Stark, et al.)

Another field of biology that incorporates the need for a portable fluorescence device is the field of bacteria detection. The development of a portable microfluidic polymerase chain reaction (PCR) device by researchers at Teesside University in the United Kingdom utilized a microfluidic PCR chip that slid between three different temperature zones to activate a fluorescent glow output (Salman, et al.). PCR is a process by which multiple copies of a segment of DNA can be made. The main application for this portable device would be to rapidly identify infectious bacteria for medical purposes.

Movements toward low-cost fluorescence detection systems are being attempted by using dye-type DNA-staining reagents. In one study, the researchers' DNA detection system cost less than $100 in hardware and the fluorescent output was tested with cyan LEDs and black light (Motohashi). The black light system accomplished greater detection of DNA fragments when compared to a commercially used UV transilluminator.

UV transilluminators also are involved in classroom applications. A college biochemistry class at Bandung Institute of Technology in Indonesia used UV transilluminators in a lab exercise involving enzyme preparations to view indication of fibrinolytic activity (Nurachman, et al.). Fibrinolysis is a bodily process that prevents blood clots from forming. The transilluminators detected the glow from fluorescent dye and indicated a complete reaction.

Finally, a global movement, dubbed "DIYbio" (do-it-yourself biology), involves a community of people pursuing "biology outside of scientific institutions by amateurs, students, [and] 'hobbyists'" (Landrain, et al.). The DIYbio community tries to make an impact on global health issues in the fields of modern molecular biology and synthetic biology by conducting research in laboratories that are not institution affiliated. They support opening access to state-of-the-art biology equipment for amateur scientists. While our group does not recognize or deny the validity of the DIYbio community's practice, we believe that their mission to improve the general public's access to scientific equipment and testing is a goal we would like to achieve with our project and the portable fluorescence UV illuminator.

<u>Government Standards</u>

Some industry and government standards involved in the project include the maximum UV light exposure regulated. UV transilluminators operate at standard wavelength bands of 254, 312, and 365 nanometers (Berkeley Lab). It is also standard to protect the user from UV radiation using a filter on the device that filters out some or all the UV radiation, and UV light should never be looked at directly.

According to a UV transilluminator radiation exposure study by Farhang Akbar-Khanzadeh and Mahdi Jahangir-Blourchian, UV transilluminators expose operators working in proximity to the transilluminator to UV radiation. This radiation may be in excess to exposure regulations, and this overexposure occurs even though the operator is only exposed to the UV radiation for short amounts of time. Guidelines recommend that users should have appropriate shielding and protective equipment when working with transilluminators.

2.3 Product Research

The product research conducted indicates existing products with potential features that we may incorporate into our design, as well as their level of portability and accessibility to the general public.

The main competition to our project is the miniPCR P51 Molecular Fluorescent Viewer, shown in Figure 2a. The P51 has an all-in-one molecular visualization system and DIY assembly, allowing students to easily conduct various fluorescence-viewing "Learning Labs" also made by miniPCR (miniPCR). The P51 incorporates the necessary fluorescent illuminator components: UV lighting, an integrated power source, a filter to view the fluorescence through, and ability to hold standard test vials. Its outer material, cardboard, is also recyclable. However, its assembled form is portable but not easily carried in one hand, as seen in Figure 2b; the product also does not seem easily collapsible after assembly. The P51 is too large to be easily carried and stored in field applications, but it is widely accessible to students at a price of $28.

Figure 2a. miniPCR P51 Molecular Fluorescent Viewer. (miniPCR)

Figure 2b. miniPCR P51 with Fluorescent Glow. (miniPCR)

<u>Portable Devices</u>

A team at Northwestern University created a portable UV fluorescence illuminator (Figure 3) for the rapid detection of water contaminants. This illuminator's outer case is 3D-printed and rigid; the device includes cheap LED lighting and a stage-lighting filter to view the fluorescence (Alam, et al.). The device also includes a printed circuit board stored inside the case that connects LEDs and other electrical components like the battery and power switch. While durable and likely cheap to manufacture, it is not available to the public because it was designed and created only for the researchers' testing purposes.

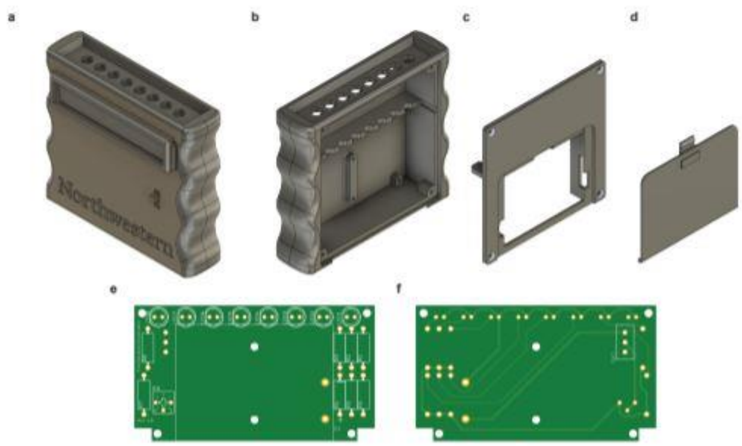


Figure 3. Northwestern 3D-Printed UV Transilluminator. (Alam, et al.)

Amplino, shown in Figure 4, is a low cost, portable PCR (polymerase chain reaction) device that allows users to detect small quantities of DNA in samples (Nordling). It is able to complete diagnostic testing in order to detect environmental hazards, crop-threatening organisms, animal pathogens, and parasites and viruses (Amplino). Although it is portable and effective in function, it is not an available product to buy and still too large to be easily collapsed or held in one hand. No information on Amplino has been updated since 2015.

Figure 4. Amplino Portable PCR Device. (Amplino)

The Crystal Technologies Handheld UV Lamp shown in Figure 5 is hard plastic and outputs high intensity UV at wavelengths of 365 nanometers, 264 nanometers, or a combination of both (Thomas Scientific). The lamp can come corded or with rechargeable batteries and can sustain three hours of continuous use. However, the lamp would need to be used in conjunction with a dark background or in a dark room to view fluorescence, and the corded version of the lamp would not be useful for field applications.

Figure 5. Crystal Technologies Handheld UV Lamp. (Thomas Scientific)

<u>Benchtop Devices</u>

The Accuris E3000 UV Transilluminator in Figure 6 is a benchtop device that allows for the fluorescent detection of DNA samples and outputs ultraviolet (UV) light at a midrange of 302 nanometers (Transilluminators.com). It incorporates an acrylic cover to view the UV light safely and two UV intensity settings. The device has a compact design for a benchtop unit, but it cannot be handheld or portable due to its requirement of a plug-in power source. This device costs a little less than $1,000, making it a viable instrument for classroom lab use but not for general purpose uses.

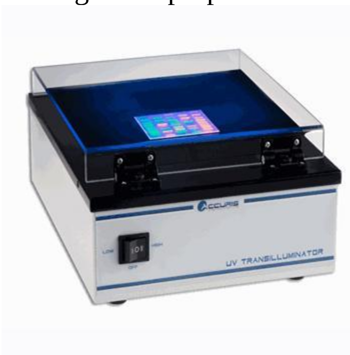


Figure 6. Accuris E3000 UV Transilluminator. (Transilluminators.com)

The BioTek Cytation 5 Cell Imaging Multi-Mode Reader shown in Figure 7 conducts quantitative data collection and imaging of samples in slides, Petri dishes, flasks, or 6- to 384- well microplates (Fisher Scientific). Dr. Oza's lab at Cal Poly uses this device for their research and development. The device outputs the results to a connected software program for real-time data tracking. However, it is a benchtop unit that requires a plug-in power source, affecting its portability. The high level of necessary scientific knowledge to use this device and quantify the resulting data makes it inaccessible to the general public and most non-scientific professionals. It is extremely expensive at over $61,000.

Figure 7. Biotek Cytation 5 Cell Imaging Multi-Mode Reader. (Fisher Scientific)

Other Products

The accessibility to scientific equipment and portability needs specified by our sponsor are directly related to the needs answered by the invention of the Foldscope shown in Figure 8, a mostly paper microscope that utilizes principles of origami in its form. Like a typical microscope, it has magnification capabilities up to 140 times and a resolution 2 microns (Foldscope Instruments). The cost of its parts should total to less than $1, and nearly half a million Foldscopes have been disseminated around the world.

Figure 8. Foldscope. (Foldscope Instruments)

Relevant Patents

The relevant patents regarding ultraviolet transilluminators and ultraviolet lighting devices are in Appendix A. A table consisting of each patent number, patent description, and image (if available) identify the key features and purpose of each product. Keywords used in Google Patent search to find these products consisted of “portable UV illuminator” and “UV transilluminator.”

3. OBJECTIVES

The requirements set forth by our sponsor defined the challenge of the portable fluorescent illuminator and the scope of the project. From these requirements, our team created a boundary diagram depicting the project’s scope and the aspects of existing illuminators we seek to improve. Furthermore, Quality Function Deployment (QFD) was performed to determine the most important specifications to our sponsor and the engineering tests and tolerances to meet each specification.

3.1 Problem Definition

Researchers in the field of molecular biology utilize ultraviolet (UV) illuminators to view the fluorescent output of UV-sensitive substances. However, current devices used to test fluorescence are expensive, not portable, difficult to use, and lack accessibility to the general public. The purpose of this project is to develop a portable and inexpensive ultraviolet illumination device capable of testing fluorescence in any research environment or classroom. The device will increase people’s accessibility and applications of this illuminator outside of laboratory walls.

3.2 Boundary Diagram

The boundary diagram in Figure 9 illustrates the scope our team has set for the project and demonstrates the specific goals we would like to achieve. The boundary is drawn around items that our team has control of in the project; everything outside the boundary is an uncontrollable variable. The portable illuminator is drawn clear to show the internal components.

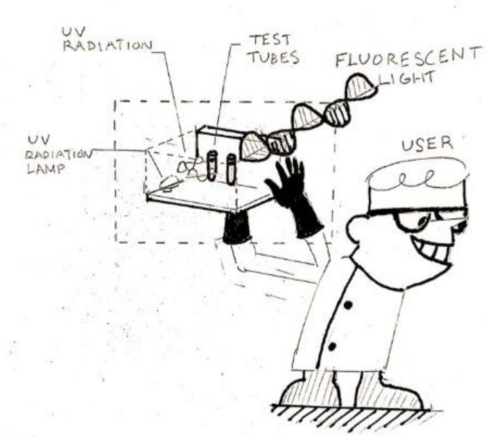


Figure 9. Illuminator Boundary Diagram.

The user should be able to carry the device in one hand for it to be portable, which is why the boundary is drawn around the outer form of the transilluminator. Our team will also be able to control the material the device is made of. The inner components, such as the ultraviolet lighting, test vials, power source, heating element, and electrical wiring are all under our control to choose and position within the device. The intensity of the fluorescent output seen by the user can be controlled through the filter types and UV light source positioning within the device.

The variables that our team does not have control over include the user and the chemical reactions occurring inside the test vials. The user is shown outside the boundary because the product should be designed to be used by a variety of people, and the user is key in viewing fluorescent output. Although our project is integrated with the science involving the fluorescent output signals of biomaterials, the types of chemicals placed in the vials and improvement of chemical reaction times are not within our scope.

3.3 Quality Function Deployment

In the QFD (Quality Function Deployment), we listed our customer requirements and the engineering requirements that will be tested in our final design. QFD exists to analyze the customer's needs and compare them with engineering specifications and tests. This ensures maximum customer satisfaction with the final product, and it develops an understanding of the most important customer needs and engineering specifications for the product. The full QFD, in its "House of Quality," can be found in Appendix B.

The most important specifications for our project, as determined by the QFD, are luminosity, assembly time, and the stored dimensions. These are closely followed by cost and the assembled dimensions. These specifications all contain major roles in determining the portability and accessibility of our device, and they will carry the most importance when testing our product to ensure our sponsor's needs are met.

Table 1 displays a list of the specifications and the targets for this project determined from the QFD, ranked in order of importance. Each of the specifications shown above have a target assigned to them that we will strive to meet with our final design. Each specification has a tolerance, risk, and compliance associated with them. The tolerance is the range of deviation from the nominal target deemed acceptable in the final design. The associated risk is the evaluation of how difficult it will be to meet these targets. Finally, compliance is the types of evaluation our team will be doing to ensure each specification's target requirement has been met and is within the tolerance range we defined.

Table 1. Engineering Specifications and Requirements.

SPEC. #	SPECIFICATION DESCRIPTION	SPECIFICATION	TOLERANCE	RISK	COMPLIANCE
1	Luminosity	Maximize Output	Max	M	S, I
2	Assembly Time	10 Minutes	Max	L	T
3	Production Cost	$11	Max	H	I
4	Stored Length	15 inches	+ 3 in	M	I, A
5	Stored Width	15 inches	+ 3 in	M	I, A
6	Stored Height	1 inch	+ 0.5 in	M	I, A
7	Assembled Length	7 inches	Max	L	I
8	Assembled Width	4.5 inches	Max	L	I
9	Assembled Height	1.5 inches	Max	L	I
10	Weight	5 lbs.	Max	L	I
11	Recyclable	85% weight	Min	M	S, A
12	Deformation Force	10 lbf	Min	H	A, T
13	Drop Height	48 inches	Min	L	T

Risk: L = Low, M = Medium, H = High

Compliance: A = Analysis, T = Test, I = Inspection, S = Similarity

Each specification is explained in further detail:

1. Luminosity is a complicated specification since Dr. Oza did not know what exact level of luminosity, or glow, he desired. It is also a factor that will affect cost drastically since UV lights of higher luminosity will inevitably cost more. Dr. Oza desires a luminosity level that can achieve the best fluorescence output from the biological samples. For our project, no personal protective equipment (PPE) should be needed to protect the user from UV radiation. The UV light filters and the outer enclosure will protect the user from radiation exposure.
2. The ease of use, or usability, and accessibility were some of our client's requirements. For the device to be easy to use, the device must be assembled and be ready for use within 10 minutes maximum.
3. Cost is another major driving factor for this design. Since the device should be accessible to everyone, including students at Cal Poly, it should cost no more than $10.

4 - 6. Stored dimensions affect the portability of the device. Dr. Oza desired the device to have a small form factor when disassembled for storage to insure portability.

7 - 9. Assembled dimensions are crucial since they will dictate the form factor of the device as well as how many test vials can be tested at once within the device. The assembled dimensions also affect the ease of use requirement as something too small or too bulky will affect the ease of use.

10. Since portability is a major requirement of this project, the device should be as light as possible. In this case, a weight of 5 lbs. is an acceptable target to satisfy the portability requirement.

11. Our client would like the device to be comprised of disposable/recyclable material. The set target is 85% weight recyclability. The electrical components such as the UV LEDs, batteries, and wiring will not be recyclable.

12 -13. Drop height and stiffness/deformation are strength and rigidity requirements that our team deemed necessary after our research and consideration as to how this device will be used. The device will be handled by students, used in the field where it will be exposed to the elements, and exposed to loads or shocks if dropped or carried in a backpack. This specification to ensures the durability requirement of our client is met.

The high-risk specifications of our project are production cost and deformation force. These are both related to the components and materials used to manufacture the device. The production cost depends greatly on the types of LEDs, outer casing material, and electrical hardware we choose to use in our product. The production cost is also tied into our most important specification, luminosity; with better quality ultraviolet LEDs, the price may be greater. Also, since the product is to be made of a lightweight and recyclable material, the device may not be able to withstand 10 lbs. of force. The product's structural integrity may fail at lower weights and not meet the specification.

4. CONCEPT DESIGN

The concept ideation process consisted of performing functional decomposition, creating function prototypes, and evaluating different functions in Pugh and weighted decision matrices in order to develop the final concept design of the portable fluorescence transilluminator. The final concept has two variations, folded box and matchbox, that will be tested with users to understand the best configuration for simple assembly and ease of use. The folded box configuration is shown in Figure 10 and the matchbox configuration is shown in Figure 11.

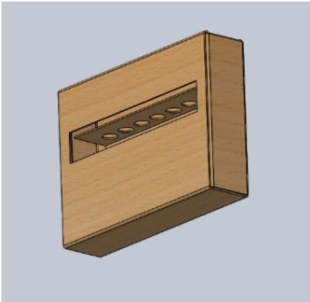


Figure 10. Folded Box Illuminator Concept.

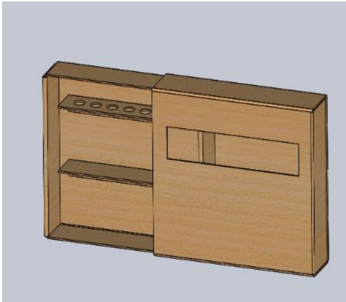


Figure 11. Matchbox Illuminator Concept.

4.1 Concept Development/Ideation and Function Concept Prototypes

To develop multiple concept ideas for the portable fluorescence illuminator, our team's ideation processes included functional decomposition and brainsketching. Functional decomposition consisted of dividing the portable fluorescence illuminator into its main functions and creating a function tree outlining the sub-functions and the ideas for each. Ascending from the bottom of the function tree describes "why" a function is necessary, and descending down from the top of the function tree branches explains "how" a function will be achieved. The function tree for the portable fluorescent illuminator in Figure 12 outlines the three major functions for the illuminator device: it must allow the viewing of a fluorescent glow, illuminate biological samples, and increase accessibility. Each sub-function underneath defines a more specific method to achieve the main function.

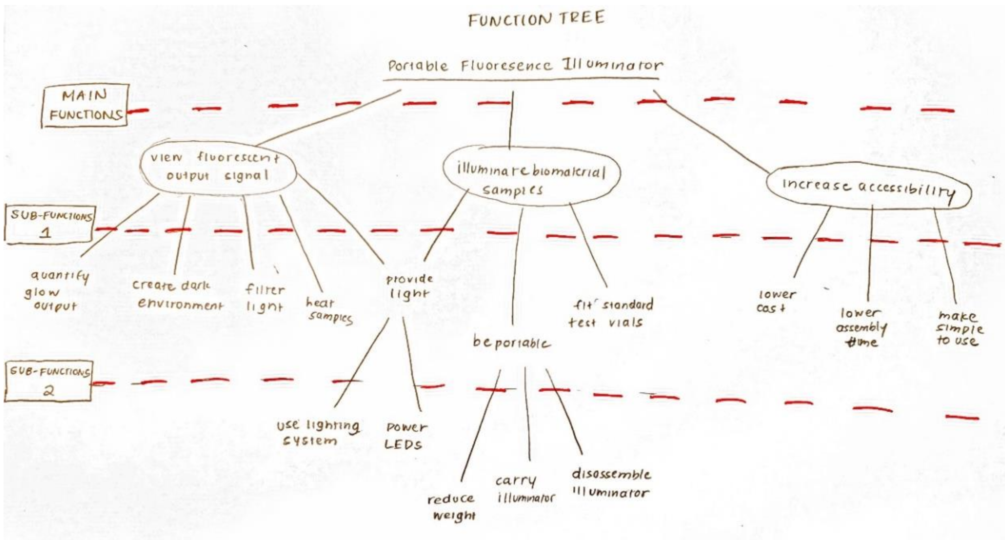


Figure 12. Functional Decomposition Function Tree.

The various ideas generated to achieve each of the sub-functions, compiled in Appendix C, were produced without regard to feasibility, practicality, or number of ideas. The team freely wrote the ideas on sticky notes and placed the note under the specific sub-function written on a board during the functional decomposition process. The main goal was to have at least five or more ideas for each sub-function and at least 150 or more ideas in total.

The team also used brainsketching to design new concept ideas. For five minutes, each member drew a sketch in his/her logbook of an envisioned prototype and added desired features. After, our team switched logbooks and continued to add features on another member's sketch for another five minutes. This was done a third time to make sure all members had an opportunity to sketch on others' ideas. The sketches from the brainsketching exercise in Appendix C display new concepts not considered in functional decomposition. These concepts include a cylindrical illuminator shape, finger holders for a small illuminator, LED light strips positioned in a circle, a heating element achieved with hot pack heating beads, and an accordion-folded illuminator held up by outer flaps.

Our team developed function prototypes mainly from cardboard, tape, and plastic test vials to model a few of the function concepts generated during the functional decomposition and ideation processes, shown in Appendix D. These models allowed the team to visualize how certain ideas would work and indicated which functions would be easy or difficult to manufacture in the future.

4.2 Pugh, Morphological, and Weighted Decision Matrices

The final concept was determined through analysis using Pugh matrices that weighed each function's various ideas against each other, a morphological matrix that created full concepts out of the different functions, and a weighted decision matrix that compared the full concepts and their alignment with the specifications in the QFD.

4.2.1 Pugh Matrices

A Pugh matrix compares the different ideas for a specific function using a set of criteria. One idea is used as the “datum” to compare every other idea to. The datum is assumed to best meet the criteria and have a resulting score of 0. The values of +, -, or S are assigned to an idea corresponding to whether it is better, worse, or the same, respectively, as the datum in meeting the criteria specified. The amount of +, -, and S are added up for each idea to determine how well the other ideas match the criteria with respect to the datum. A negative score indicates that the idea does not meet the criteria as well as the datum, a positive score indicates that the idea meets the criteria better than the datum, and a score of zero means that the idea meets the criteria on the same level as the datum.

Each of the five Pugh matrices in Appendix E were developed for one of the illuminator’s functions: shape, ultraviolet lighting system, test tube orientation, filter holder, and collapsible form. As expected, the datum ideas in each Pugh matrix were the best amongst the others; these ideas were the most likely to be included in the final design concept.

4.2.2 Morphological Matrix and Concept Sketches

The morphological matrix shown in Figure 13 displays the various ideas for each aspect or function of the illuminator. Full concepts for the illuminator were generated from the matrix by choosing one idea in each column. For example, one full concept that our team generated was a horizontal box shape with an LED strip lighting system, horizontal and upright oriented test tubes, a corner holder for the filter, and a folding method to collapse the device.

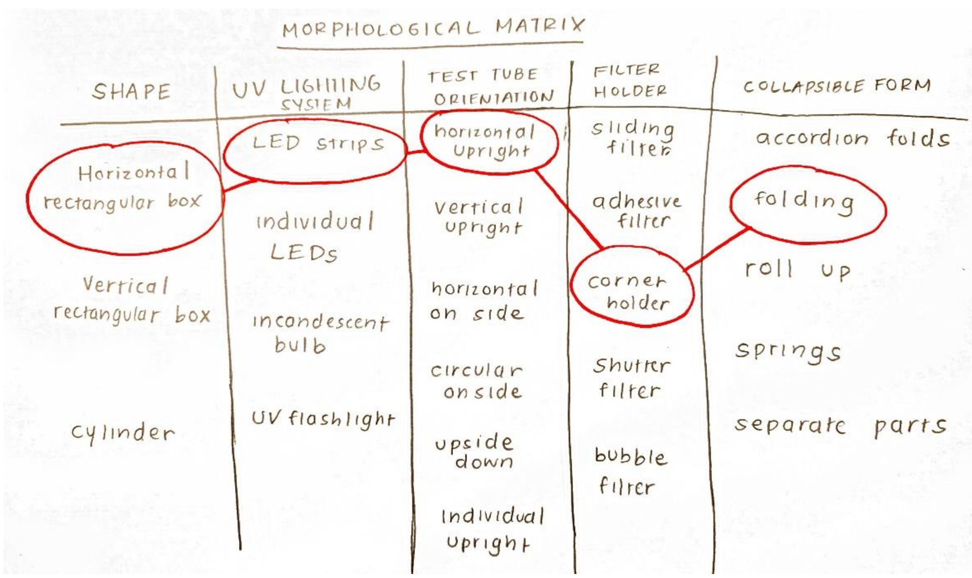


Figure 13. Morphological Matrix.

Each member of our team generated two concepts from the morphological matrix, and the team produced one more concept together. While choosing between different ideas in a column, the team considered feasibility in application and manufacturability. The seven full concepts in Table 2 detail the results from the matrix, and Figures 14-20 display the sketches of Concepts 1-7, respectively.

Table 2. Illuminator Full Concepts and Functions.

CONCEPT NO.	SHAPE	UV LIGHTING SYSTEM	TEST TUBE ORIENTATION	FILTER HOLDER	COLLAPSIBLE FORM
1	Horizontal rectangular box	LED strips	horizontal upright	corner filter holder	folding
2	Horizontal rectangular box	individual LEDs	individual tubes	slider filter	folding
3	Cylinder	individual LEDs	circular on side	adhesive filter	separate/removable parts
4	Horizontal rectangular box	individual LEDs	horizontal upright	slider filter	accordion folds
5	Vertical rectangular box	individual LEDs	flat on side	shutter filter	folding
6	Cylinder	LED strips	horizontal upright	corner filter holder	accordion folds
7	Horizontal rectangular box	LED strips	horizontal upright	corner filter holder	separate/removable parts

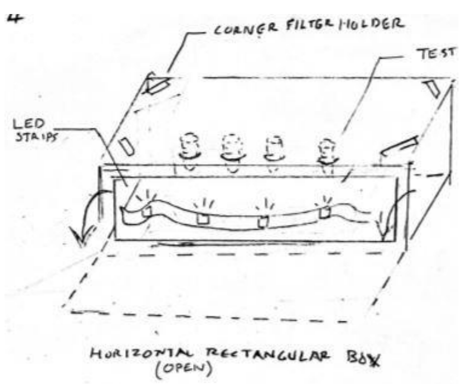


Figure 14. Illuminator Concept 1 Sketch.

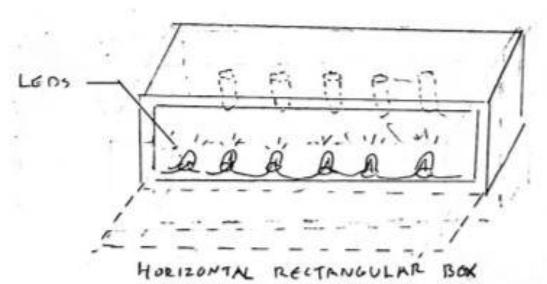


Figure 15. Illuminator Concept 2 Sketch.

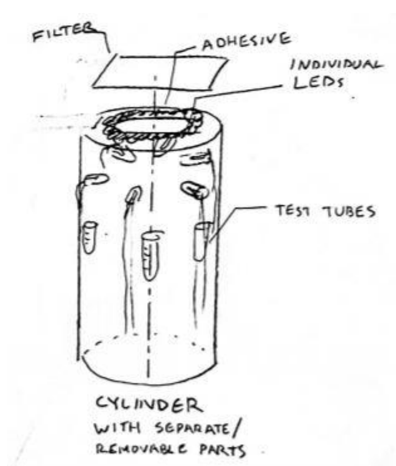


Figure 16. Illuminator Concept 3 Sketch.

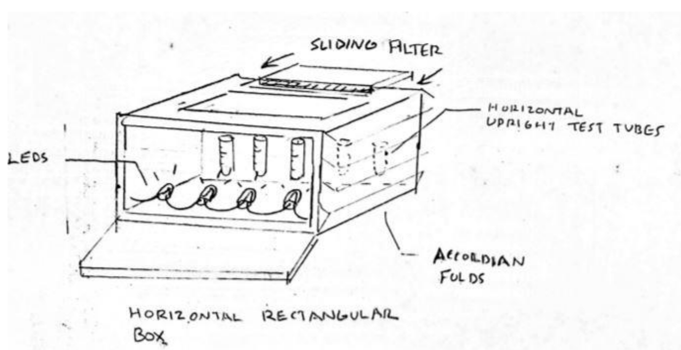


Figure 17. Illuminator Concept 4 Sketch.

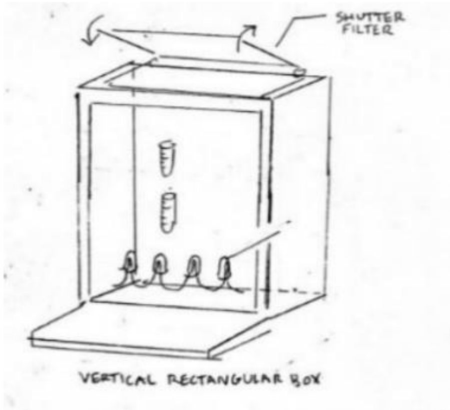


Figure 18. Illuminator Concept 5 Sketch.

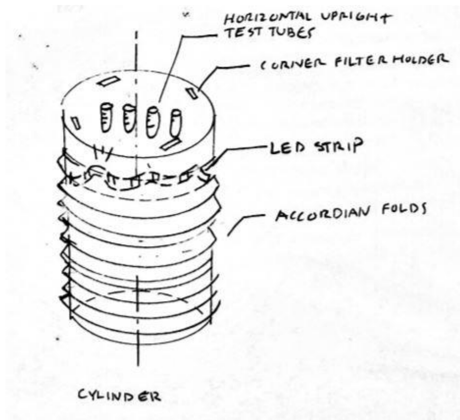


Figure 19. Illuminator Concept 6 Sketch.

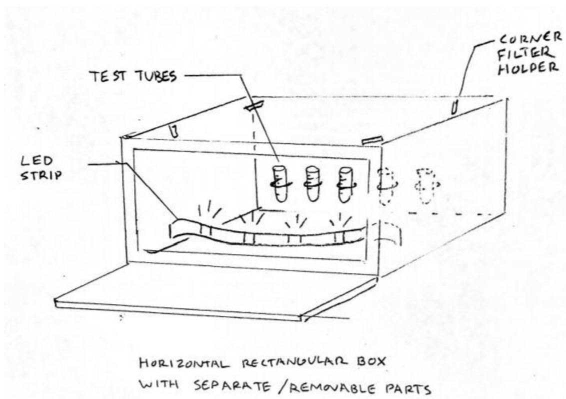


Figure 20. Illuminator Concept 7 Sketch.

A box shape was present in five of the seven concepts because it is an uncomplicated shape to manufacture and assemble. The concepts all incorporated either ultraviolet LED strips or individual LEDs because they would be the easiest to incorporate with a compact electrical system. The collapsible form included some type of folding or separate/removable parts, which may be the quickest form of disassembly. Orienting the test tubes in a horizontal, upright fashion was featured in most of our concepts because it would be the simplest orientation to ensure the samples stay at the bottom of the test tube and that the ultraviolet light hits the samples. The test tubes would also be easiest to install into or remove from the device. Various filter ideas were incorporated into the concepts; the idea used most frequently was the corner filter holder. Some unpopular ideas included the "bubble" filter, upside down and vertical test tubes, and a flashlight UV system, most likely due to foreseeable assembly or manufacturing issues.

4.2.3 Weighted Decision Matrix

The weighted decision matrix in Appendix F compared the nine illuminator concepts against each other using the QFD's specifications and weights. For each specification, the concept was ranked on a scale from 1-5, 5 meaning the concept matched the specification perfectly. The concept ranking was also multiplied with each specification's weight, and the result of the multiplication for each specification was added for each concept into a total.

The best concept, determined by the highest score from the weighted matrix, was Concept 1 due to its high rankings with the major specifications of portability, UV lighting, usability, and a small form factor. The second and third best concepts were Concept 7 and Concept 5, respectively, which also ranked high on the major specifications of portability and usability. Concepts 3 and 6 were amongst the lowest-ranked concepts due to the difficult cylindrical shape to manufacture and assemble out of cardboard.

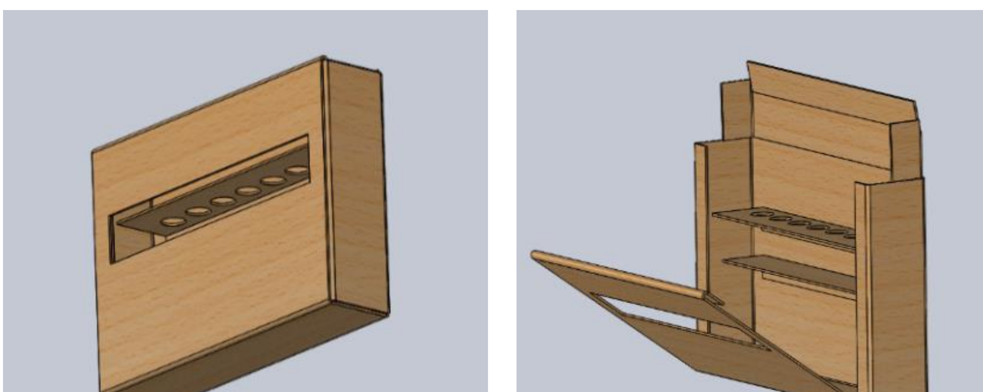
The only difference between Concepts 1 and 7, the top two concepts, were the differences in collapsible form. Otherwise, they both included LED strips, upright, horizontally oriented test tubes, and a corner filter holder. A device with only one main part to assemble or disassemble like Concept 1 would be easier to manufacture and store compared to a device with separate parts like Concept 7, which is why Concept 1 ranked higher.

Instead of one final design for the illuminator, our team determined that it was best to have two concept configurations based on Concepts 1 and 7. The concepts are similar, and it would be beneficial to receive user feedback on the assembly time, ease of use, and portability aspects of each design. This feedback would help distinguish the better configuration and any design modifications that need to be made.

4.3 Concept Design

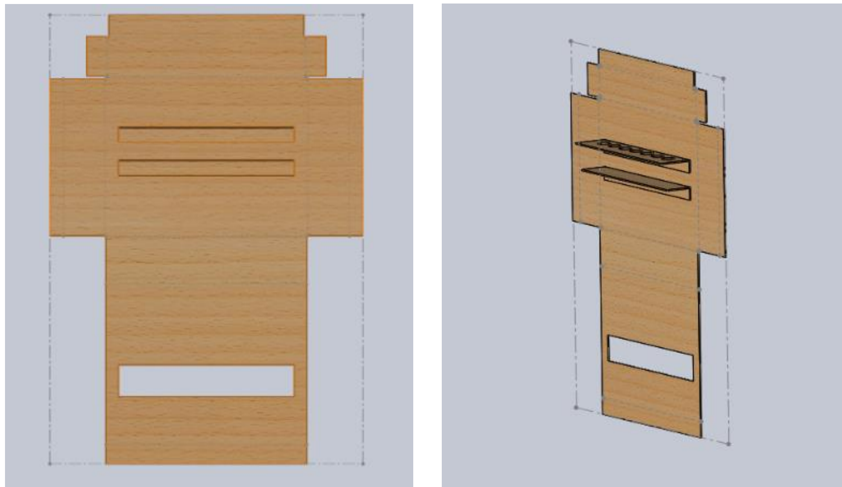
The final design concept's two variations each feature the same general design for the lighting system and light filter orientation; each also uses the main shape of a horizontal, rectangular box. Both incorporate ultraviolet LED light strips and have the light filter held by its corners in a cut out slit.

The simplest variation of the illuminator, the folded box, shown in different configurations in Figures 21 and 22, is folded from a single piece of material. It utilizes tabs that can be entered into slits or tucked behind flaps to hold the illuminator's shape. The front of the illuminator contains a cutout for the filter and folds over the location of the test vials.



(a) Folded *(b) Slightly Unfolded*

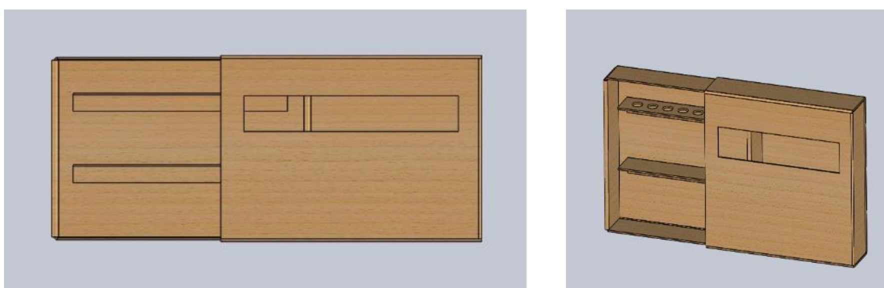
Figure 21. Folded Box Illuminator, Folded and Slightly Unfolded Isometric Views.



(a) Front (b) Isometric

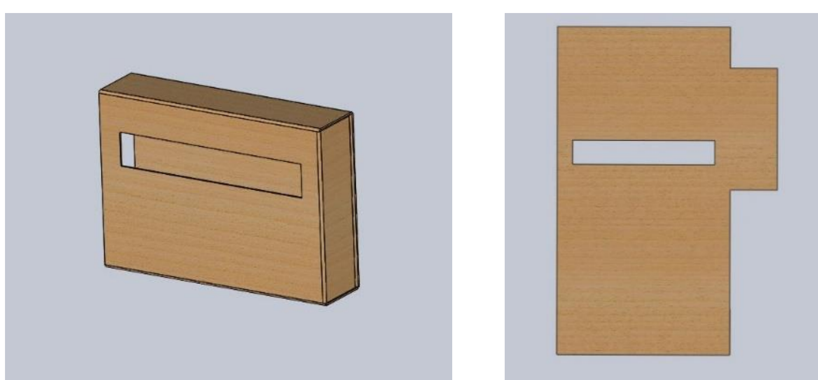
Figure 22. Folded Box Illuminator, Unfolded Front and Isometric Views.

The second variation of the illuminator, shown in Figures 23-25, has a matchbox form with an outer case holding the filter that slides over an open-faced box containing the test vials and electrical components. Both variations are folded because it is an easy assembly method for users and a simple way to avoid using fasteners or large amounts of glue.



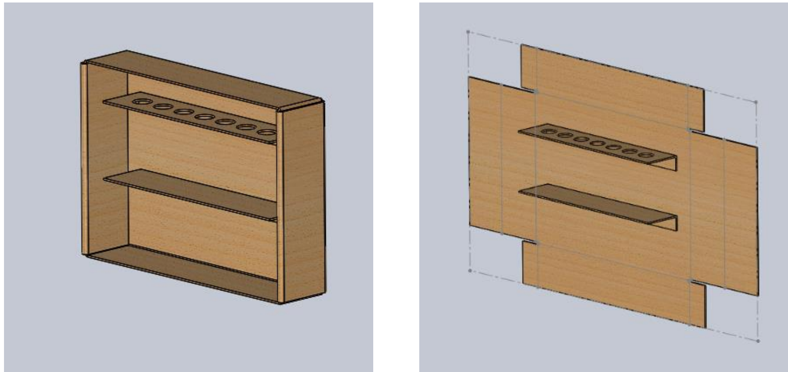
(a) Front (b) Isometric

Figure 23. Matchbox Illuminator, Front and Isometric View.



(a) Folded (b) Unfolded

Figure 24. Matchbox Illuminator, Outer Sheath Folded and Unfolded Views.



(a) Folded *(b) Unfolded*

Figure 25. Matchbox Illuminator, Inner Box Folded and Unfolded Isometric Views.

Each design, which will be manufactured out of thin cardboard or some paper-based product, has small slits around the viewing window to hold the ultraviolet light filter. The test vials will be lined up in front of the viewing window in a horizontal, upright fashion, held in place by a horizontal flap protruding from the back edge with holes cut out to nest the test tubes in. Underneath the test tubes, the ultraviolet LED light strip will be adhesively attached on another horizontal flap to light the bottom of the samples. Finally, the battery to power the light strip will be secured in a cutout that utilizes negative space at the bottom of the illuminator.

The concept prototypes manufactured out of chipboard and kraft paper depict the physical representations of the illuminators along with the approximate proportions. The folded box illuminator in Figure 26 depicts the folding method with various tabs to hold the illuminator’s shape. The matchbox illuminator in Figure 27 demonstrates the “negative space” battery holder using a cutout strip. Some elements not included in both prototypes are the corner filter holder, the light filter, the test tubes, and the electrical components for the device.

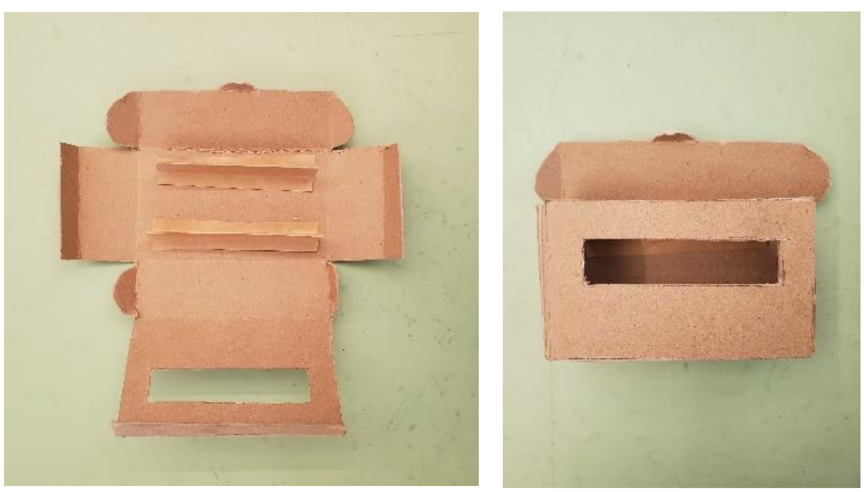


Figure 26. Folded Box Illuminator Concept Prototype with Tab Folds.

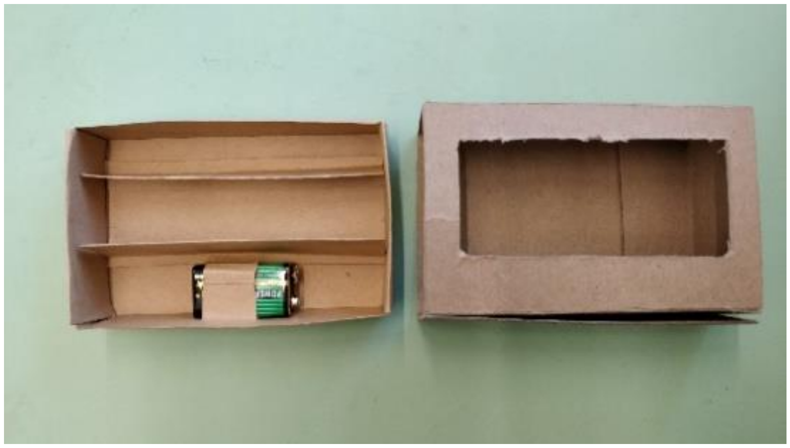


Figure 27. Matchbox Illuminator Concept Prototype with Battery Cutout.

The size of each illuminator is no longer than 6 inches in length, 5 inches in width, and 2 inches in height. The goal is for the device to be handheld by students and adults, so it is key to eventually minimize the size of the device. The electrical components will fit inside the outer casing and be attached with some form of adhesive to the bottom of the illuminator. The holes or cutouts to hold the test tubes will accommodate the standard sizes and fit the tubes snugly. The user should be able to place the test tubes and electrical components in the appropriate locations before folding up the illuminator into its assembled form; the user should also be able to remove the components after collapsing the illuminator.

Some undetermined parts of the final illuminator concept are the positioning of the ultraviolet lights, electrical systems, and heating element to obtain the best fluorescent output. The positioning of the lights will greatly affect how the user views the output, and the heating element is necessary for the chemical reaction and fluorescent glow to occur. Furthermore, the type of heating element is still undetermined. Our team has considered using heating coils or even the activation particles from hand warmers, but more material research must be conducted to determine a feasible method to heat the samples.

4.4 Preliminary Design Risks

Prior to any actual testing or manufacturing, our team considered the risks involved in creating the portable fluorescence illuminator. The Design Hazard Checklist in Appendix G indicates that utilizing a battery as a power source, ultraviolet radiation, and potential unsafe use would be main hazards involved in creating the illuminator. The light filters covering the viewing windows should filter out the ultraviolet radiation and protect the user, but safety precautions in the event of unintended use should be considered. As a safety measure in the design of our device, the ultraviolet lighting could remain off until the illuminator case is fully closed to contain the UV lighting, triggering a button of some sort to turn on the lights. This could also be incorporated for the heating element, so the heating element is not active when the device is disassembled or test tubes are not in the device.

If our device incorporates a heating element that has a high-power output or a high heat output, the issue of fire hazards may arise since the illuminator will most likely be made of flammable material. Some preventative methods in such an event would be to use insulating material to coat or surround the heating element and protect the user and device from burns or flames.

5. FINAL DESIGN

The final design of the portable fluorescence illuminator was developed out of the concept design for the matchbox configuration. The final design consists of three main components: the sheath, the box, and the electrical circuit. After the Critical Design Review, our team made modifications to the illuminator design to simplify the assembly and manufacturing processes. Through some preliminary analysis, our team determined that the design meets Dr. Oza's specifications for size, cost, and recyclability. Most importantly, the design contains components such as a heater and ultraviolet LED lights that allow it to operate as a functional illuminator. Furthermore, our team considered the safety, maintenance, and repair of the device, as well as the various failure modes associated with our design in a Failure Modes and Effects Analysis (FMEA). An indented bill of materials (iBOM) provides the cost and source of each individual part needed to make the device as well as the total cost to create one illuminator.

5.1 CDR Proposed Final Illuminator Design

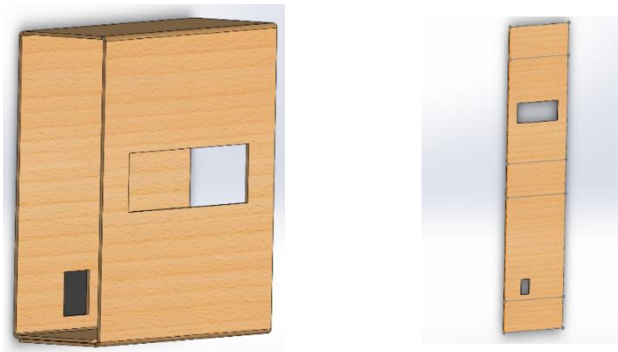
The design described in the following section is the initial final design conceived by the team at the Critical Design Review (CDR). However, due to changes in the LED light type post-CDR, many of the illuminator's design features such as size, electrical circuit, and filter placement could be simplified. These design changes will be further explained in a later section.

The illuminator's final design is in the matchbox configuration. It contains three main subassemblies: the sheath, the box, and the electrical circuit. While the electrical circuit and test samples are placed in the box, the sheath slides over and around the box to view the fluorescent glow. The matchbox configuration was chosen over the folded box configuration because it better met our sponsor's criteria for size, reusability, and safety measures. The illuminator's final design, shown in Figure 28, is slightly modified from the concept design with a slightly different shape for the sheath and box, as well as a different test tube rack design. Furthermore, the design also incorporates an electrical circuit consisting of a battery, an ultraviolet UV LED strip, a limit switch, and an adhesive heating strip that fits inside of the recyclable housing. The circuit will be used to heat and illuminate the biological samples while controlling when the UV light can be on.

Figure 28. CDR Final Illuminator Design.

5.1.1 Sheath and Box

As shown in Figure 29, the sheath of the illuminator is similar to the concept design; however, the side flap has been removed. The folded dimensions of the sheath are 5.2” × 5.2” × 1.75” in length, width, and height, respectively. There is a 3.6” × 1” window cutout in the front for the acrylic light filter, which will be attached with adhesive double-sided tape. Furthermore, there is a small slot cut out on the back of the sheath for the battery switch to be accessible to the user while the illuminator is in use.



(a) Folded *(b) Unfolded*

Figure 29. CDR Sheath, Folded and Unfolded Views.

The box, shown in Figure 30, is an open-faced box, similar to the concept design. However, the flattened layout is slightly modified to add more flaps on each side so the box can hold its shape well when assembled. When folded, the horizontal tabs on the upper and lower panel help the lengthwise walls stay upright when tucked under the flaps for the walls on the left and right. The vertical walls of the box also have a thickness of 0.18”, making the sides more robust and the overall design more secure. When folded, the dimensions of the box are 5” × 5” × 1.5” in length, width, and height, respectively, creating some clearance with the sheath. Similar to the sheath, it contains a 0.5” square slot cut on the center panel for the battery switch.

(a) Folded *(b) Unfolded*

Figure 30. CDR Box, Folded and Unfolded Views.

Both sheath and box are meant to be assembled by the user. The sheath can be cut out of cardboard or some other rigid paper-based material, while the box can be made out of cardstock or kraft paper for easy folding and a robust shape. Two 2-D templates, complete with lines for cutting and folding, were created for both parts; the templates are shown in Figures 31 and 32. The letters on the figure correspond to the different panels and flaps on each piece, the dotted lines represent cutting lines, and the red lines denote folding lines. The templates can be printed on 11” × 17” pieces of paper or traced onto cardboard and used to make the device.

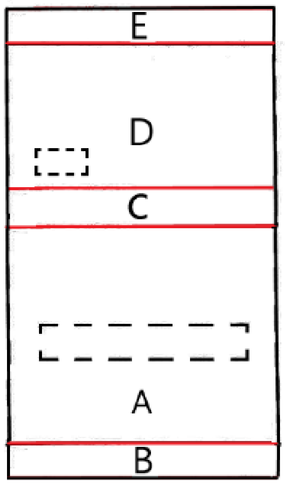


Figure 31. CDR Sheath Template.

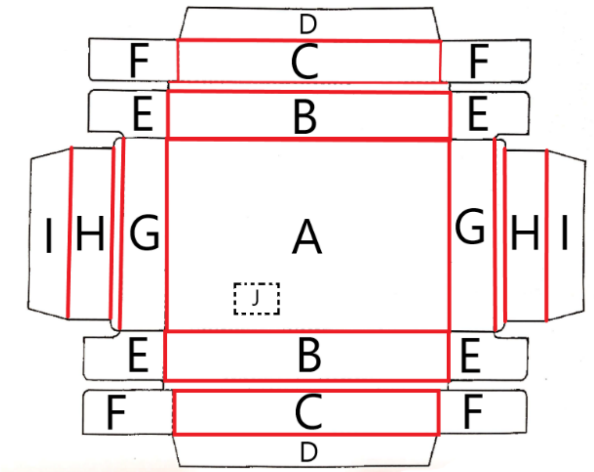


Figure 32. CDR Box Template.

5.1.2 Electrical Circuit and Removable Panel

The electrical circuit is one of the most critical components of the overall design. It incorporates a 9-volt battery, an adhesive polyimide heater, an ultraviolet LED light strip, and two limit switches. The circuit diagram is shown in Figure 33.

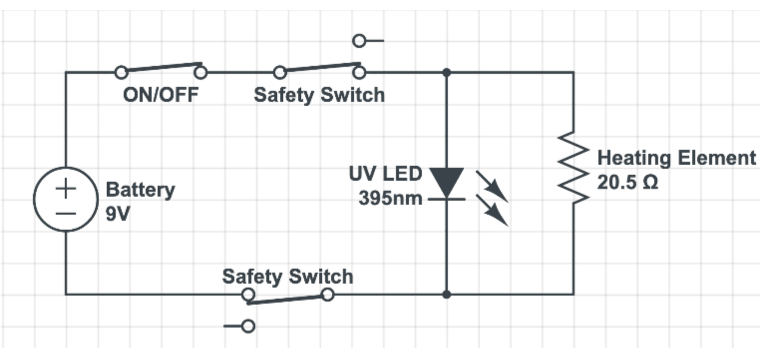


Figure 33. CDR Illuminator Electrical Circuit Diagram.

The entire assembly of the box and the electrical components is shown in Figure 34. The 9-volt battery powers the entire circuit and will be held in a battery case that comes with an on/off switch. The UV LED lights have a wavelength of 395 nanometers, which is used to excite the fluorescent glow of the biological samples. The heater, placed directly below the test tubes, heats the samples with a change in temperature of 20˚C to speed up the initial reaction that produces the fluorescent glow. The two limit switches placed at the bottom of the box act as safety precautions so the LED lights do not turn on when the box is not in the sheath. Both switches must be engaged and the battery switch must be set to "on" before the LED lights will turn on.

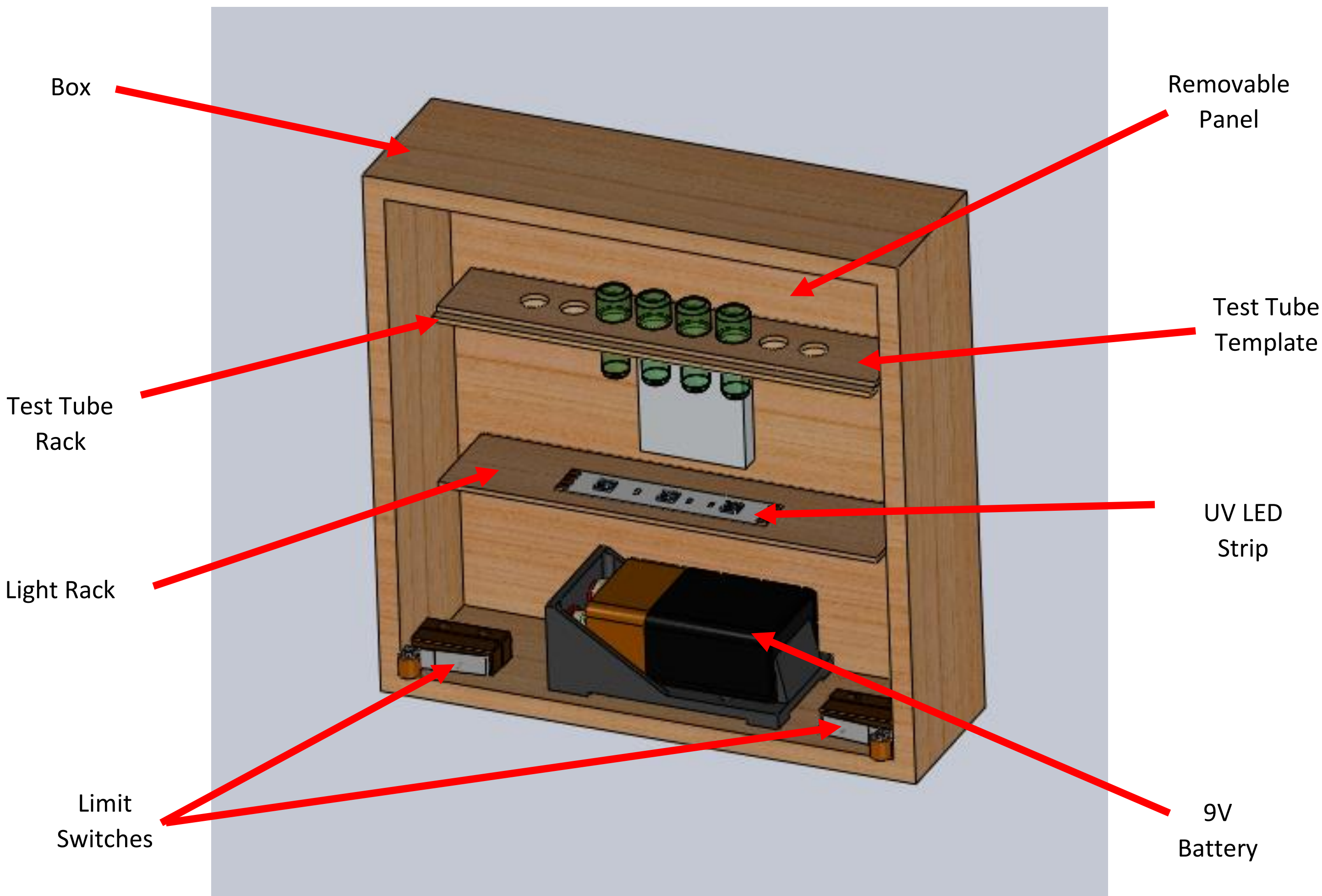


Figure 34. Inner Layout of Electrical System.

All of the electric circuit components in the circuit are attached by adhesive strips or double-sided tape to a cardboard panel that can be placed directly inside the box and removed when necessary. This is done so the electrical circuit can be modular; if the sheath or box become damaged, the electrical circuit can be removed and reused in a new illuminator. This improves the recyclability of the entire device. The removable panel also has a slot cut out for the battery switch, and the battery holder is positioned over this slot with the switch.

The racks to hold the test tubes and the LED strip, shown in Figures 35 and 36, are also attached to the removable panel. The test tube rack is positioned above the light strip rack, and the heater is positioned between the two. The racks are made out of paper that is cut in a 4.1" × 1.3" rectangle and folded at a 90˚ angle. The LED strips have an adhesive backing, which will be stuck directly on the lighting rack.

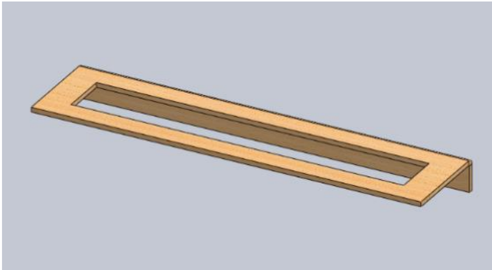


Figure 35. Test Tube Rack.

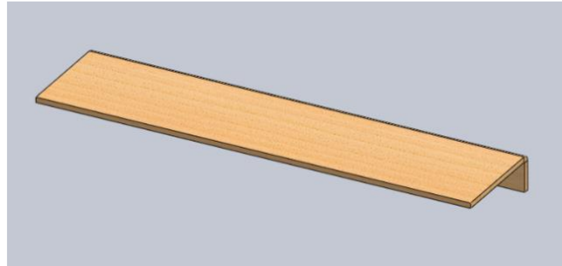
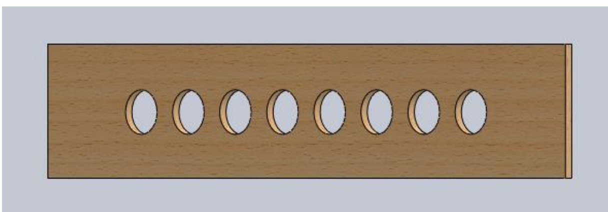
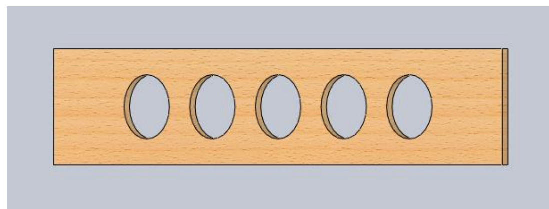


Figure 36. Lighting Rack.

The test tube rack has a 3.5” × 0.5” rectangular slot cut out so the test tubes can be nestled in after being inserted into a test tube template. The two test tube templates, shown in Figure 37 are made out of paper cut into 4.1” × 0.75” rectangles with a pattern of holes to hold test tube sizes of 0.6 mL and 2 mL. The templates rest on top of the racks as the bottoms of the test tubes sit in the rectangular slot cut out of the rack.



a) 0.6 mL Test Tube Template



b) 2 mL Test Tube Template

Figure 37. Test Tube Templates for Two Sizes.

5.2 Post-CDR Final Design Modifications

After the Critical Design Review, our team decided to make modifications to the illuminator’s final design in order to simplify the manufacturing and assembly processes. The design concept of the sheath and box remains the same; however, the removable panel is no longer necessary, and the box and sheath can hold their shape without any additional fastening methods. Modifications to the test tube stands, filter holder, and electrical circuit also included simplifications. The new illuminator design is less bulky than the previously proposed solution and uses less electrical components; the full assembly for the modified final design is shown in Figure 38, and the entire drawing package for the final design is in Appendix H.

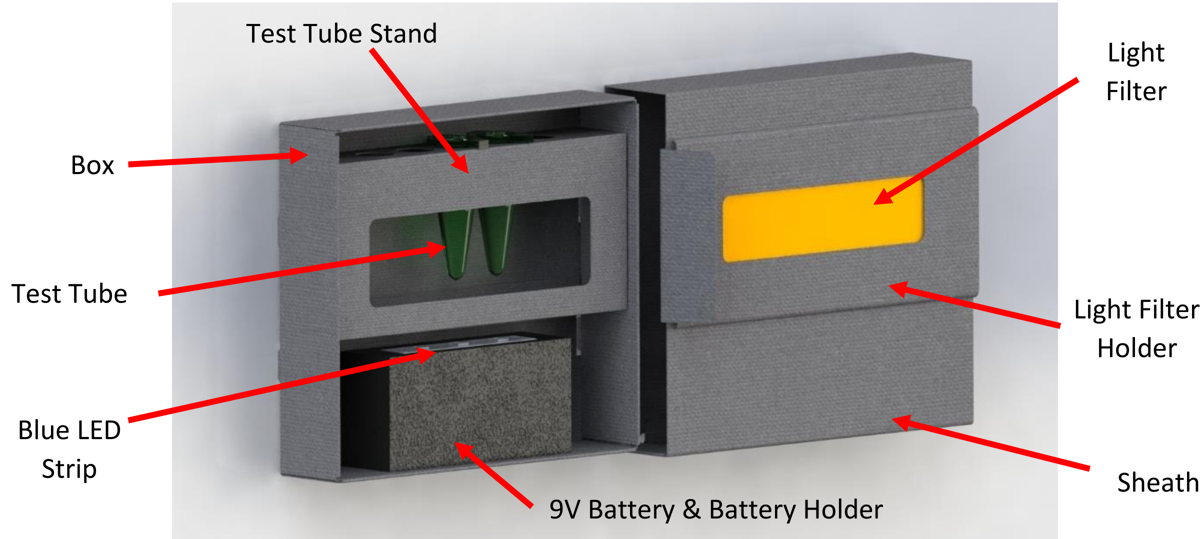
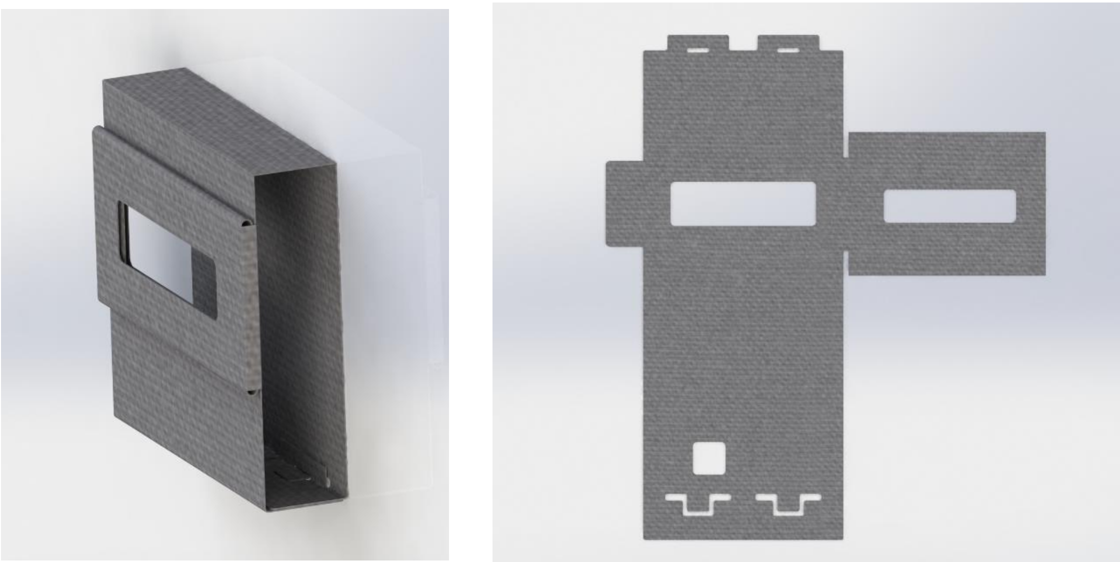


Figure 38. New Illuminator Final Design Full Assembly.

5.2.1 Sheath and Box Modifications

The sheath modifications consisted of consolidating the sheath's dimensions, adding the filter holder mechanism, and including self-locking tabs for the sheath to hold its shape. The modified dimensions of the sheath are 4.55" × 4.12" × 1.14", a reduction of 25.95 in^3 from the previous design.

The sheath's unfolded and folded isometric views in Figure 39 display the filter holder mechanism and the self-locking tabs. These were both implemented in order to reduce the use of adhesives like tape, glue, or Velcro dots to form the sheath. To assemble the sheath using the self-locking tabs, the sheath is folded at the designated lines, and the tabs on the top are inserted into the slits cut out at the bottom.



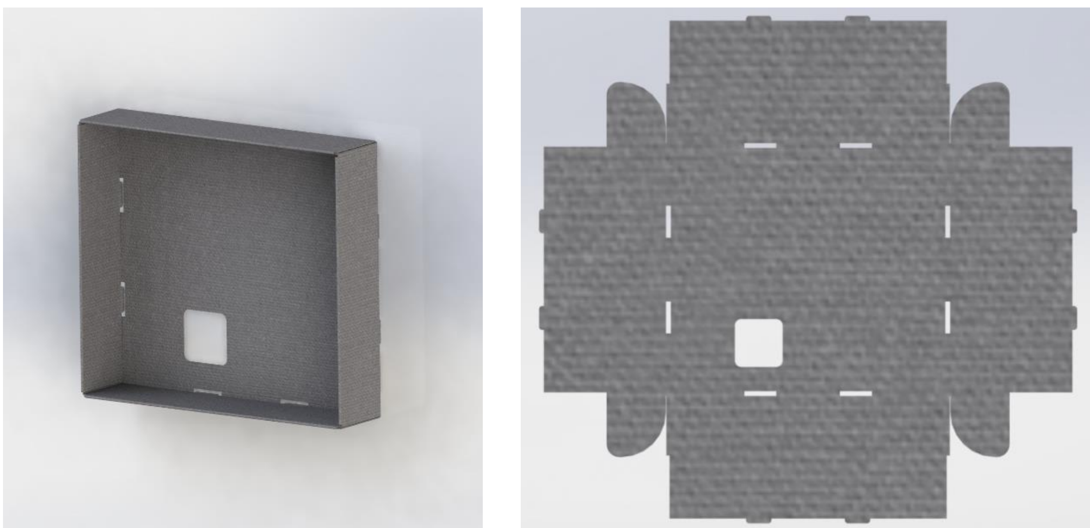
(a) Folded *(b) Unfolded*

Figure 39. Final Sheath Design.

The filter holder mechanism added onto the sheath acts as a pocket for the acrylic panel to be inserted in. A tab on the right inserts into the flaps folded down at the top and bottom to form the pocket, and the acrylic filter sits between the front of the filter holder mechanism and the front of the sheath's viewing window. Thus, the filter can be inserted and removed without using any adhesive attachments and effectively filters out the light to view the fluorescent glow. The filter was changed from amber (orange) acrylic to yellow acrylic due to better viewing of the fluorescence with the yellow filter.

The box modifications consisted of reducing the box's dimensions, simplifying the box's flat pattern, and including tabs to hold the walls of the box up when assembled. The box's dimensions are reduced to 4.5" × 4" × 1", which is a change of 19.5 in^3 from the previous design. This change occurred because the box did not need to be as thick or wide to accommodate all of the necessary components.

The box's flat pattern, shown in Figure 40, has less folds and complex tabs than the previous design; the folded view is also shown in Figure 40. The previous design took a long time to assemble and was not intuitive to users, requiring more complicated instructions.



(a) Folded *(b) Unfolded*

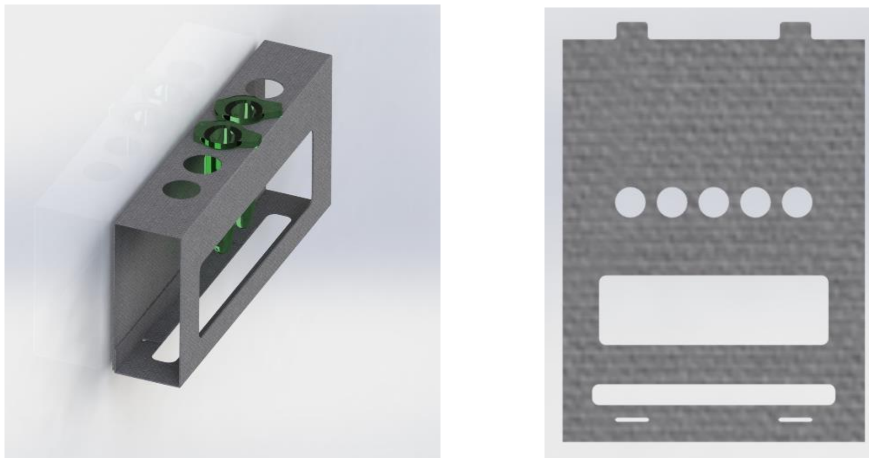
Figure 40. Final Box Design.

The new flat pattern has tabs along the on each of the four panels that form the sides of the box that insert into slits cut on the main, center panel of the box. These tabs help keep the walls of the box upright and also give the box's walls a double layer of material for added strength. The panels along the width of the box have tabs sticking out to the side that fold under the panels along the length of the box to stabilize the side walls.

Both sheath and box still have a cut-out squares on the back in order to make the on/off power switch accessible to the user. The battery pack still sits at the bottom of the box and is attached using Velcro dots.

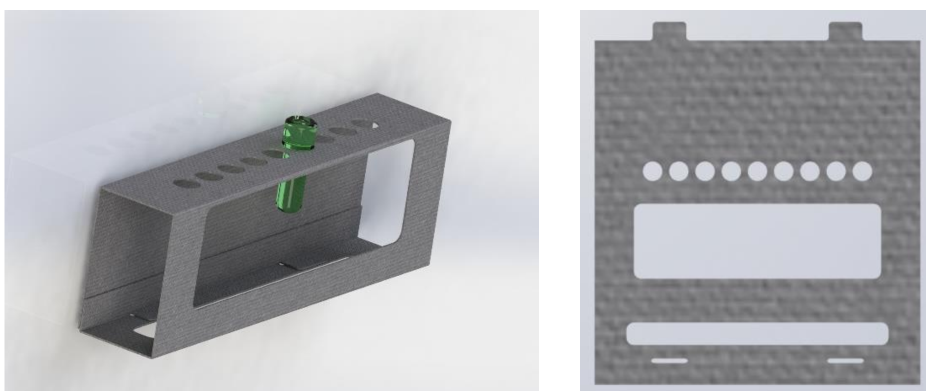
5.2.2 Test Tube Stand Modifications

The new design eliminates the need for test tube and lighting racks. Instead, new test tube stands were designed to hold the samples. They hold the samples in pre-cut holes and are able to act as test tube stands when outside of the box. The LED strips, which come with an adhesive backing, can easily be stuck onto the top of the battery pack and positioned directly under the test tube stands to provide light to the samples. The test tube stands still have two different versions; one to accommodate 2.0 mL tubes and another to accommodate 0.6 mL tubes. The unfolded and folded views of both stands are shown in Figures 41 and 42.



(a) Folded *(b) Unfolded*

Figure 41. Large Test Tube Stand (2.0 mL).



(a) Folded *(b) Unfolded*

Figure 42. Small Test Tube Stand (0.6 mL).

The length and width for both test tube stands are 8 inches and 4.3 inches, respectively. The test tube stand for the 0.6 mL tubes has a height of 1.3 inches and a pattern of 9 holes for the tubes. The test tube stand for the 2 mL tubes has a height of 1.9 inches and a pattern of 5 holes for the tubes.

The stands are folded from their flat pattern into a small box that locks with tabs that insert into slits at the bottom. It also has a viewing window, similar to the sheath. The holes for the test tubes are located on the top face of the box, while the viewing window is located on the front face. Another smaller window is at the bottom of the box, where the LED light can shine through to hit the samples. When the test tubes are placed in the stand, the bottom of the tubes (where the samples are) can be viewed by the user through the viewing window.

5.2.3 Electrical Circuit Modifications

The electrical circuit was simplified due to the discovery that UV LED lights were not sufficient enough to produce the fluorescent glow; its appropriate wavelength was too high. After some preliminary tests, our team found that blue LED lights were able to excite the necessary fluorescent glow and had a nominal wavelength closer to the excitation wavelength for the samples. Since blue LED lights can be used, there is no risk of UV radiation exposure. This eliminates the need for limit switches to make sure the LEDs would not be on when the box is in the sheath.

Another circuit modification included making the lighting and heating systems independent of each other. Our team determined that the actions of lighting and heating did not need to occur at the same time and be part of the same circuit. A USB heater was substituted for the polyimide heater, so the heating action could be performed independently by plugging the heating element into a computer USB port or wall outlet. Also, the heating element was moved from inside the box to the sheath, on the panel opposite of the filter. Therefore, in order to heat samples, the sheath can be slid with the heater side over the box opening so the heater faces the samples.

The resulting electric circuit for the lighting system only consists of the 9V battery and a 3-inch blue LED strip. A switch on the 9V battery holder cuts off the flow of current from to the LEDs. The heater, as mentioned previously, forms its own independent circuit with the power source that the USB plugs into. The lighting circuit is shown in Figure 43.

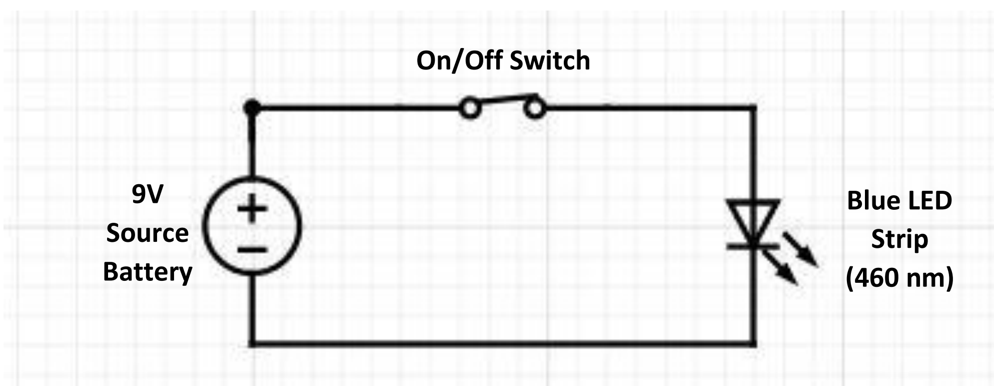


Figure 43. Final Electric Circuit Diagram.

5.3 Alignment with Sponsor Requirements

Dr. Oza's main specifications for the illuminator regarded portability, accessibility, and recyclability. The design of the device had to be collapsible, easily disposable, and in a small form factor. The cost of the device had to be around $10 and less than other existing products. Another specification included incorporating a heating element in the device to speed up the chemical reaction in the tested samples. Most importantly, to function as an illuminator, the device also had to provide ultraviolet lighting at the correct wavelength to excite the fluorescent glow of the test vials.

The size of the illuminator has a direct correlation with its portability. In order to meet Dr. Oza's specifications, the illuminator must be within dimensions of 15" × 15" when stored (flattened) and 7" ×

4.5” × 1.5” when assembled. The flattened pattern of the sheath and box are within the projected dimensions, as are the folded dimensions of the sheath, the outermost component. The flat pattern of the sheath has maximum dimensions of 11.35” × 9.85”, and the flat pattern of the box has maximum dimensions of 8.45” × 7.95”. The assembled dimensions of the sheath are 4.55” × 4.12” × 1.14”, well within the projected dimensions.

Our device includes the components to perform the same functions as a typical illuminator. It has blue LED lights that illuminate the samples, a place to hold the test tubes, a heating element that speeds up the chemical reaction, and a light filter to view the fluorescence. Despite our initial choice to include UV LEDs, our team determined with comparisons between UV LEDs that we purchased and the blue LEDs that came with the P51 that UV LEDs were not at the appropriate wavelength to produce the necessary fluorescent glow. As a preliminary test to prove the selected blue LEDs would work with our device, our team held samples provided by Dr. Oza up to the light source and viewed the glow through a light filter. The image in Figure 44 shows that the light wavelength of 460 nm from our selected LEDs will be appropriate to produce the necessary fluorescent glow.

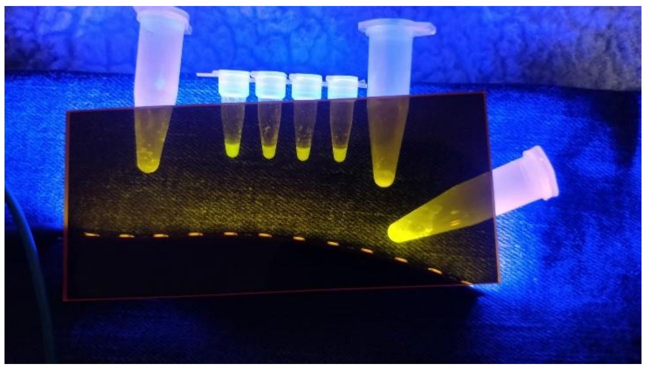


Figure 44. Fluorescent Output Signal using Waveform Lighting 460 nm Blue LEDs.

The electrical circuit allows our device to function as an illuminator, so it is important to ensure that an appropriate amount of voltage and power is supplied to each component. Although the LED lights are rated for 12 volts of DC voltage, they are still able to operate with a 9-volt battery. The USB heater was also tested with a glass thermometer to ensure it could reach the 35-40 °C necessary to speed up the reaction rate of the samples. The test showed that it was able to reach that temperature both when plugged into a computer and wall outlet. When plugged into a wall outlet, the output temperature was even higher, around 45 °C.

Our device is mostly recyclable due to the paper and cardboard materials used to form the sheath, box, and removable panel. The only non-recyclable parts include the electrical components such as the battery, heating element, wires, and LED strip. However, the electrical components are modular because they are attached to the removable panel. Even if the sheath or box becomes ripped or damaged, the electrical components can be removed easily. The damaged part can be replaced with a new part made from the templates.

It is also necessary to evaluate the functions and performance of our device with the existing competition, the P51 Molecular Fluorescence Illuminator. In comparison to the P51, our design incorporates a heating element to speed up the chemical reaction and a battery. Our design is thinner, less bulky, and costs $20 less for all of its components. It also incorporates a 9-volt battery into its cost, unlike the P51.

5.4 Safety, Maintenance, and Repair

The Failure Modes and Effect Analysis (FMEA) in Appendix I outlines the various failure modes of the illuminator and ranks the priority of each failure mode. It also provides corrective actions to any failure mode with a priority above 40. Originally, the main concerns for user safety regarding the illuminator were the ultraviolet lighting and the electrical heater that would be used to warm the samples. As stated previously, it is best for the user to not look at the UV light directly without some sort of protection like the light filter. However, with the design modification to use blue LED lights, the issue of UV radiation is no longer a user safety issue. The switch on the battery pack is incorporated into the electrical circuit in order to keep the light off when the box is not in the sheath. The original heater used to speed up the chemical reaction had the potential to burn the user or the cardboard housing if it got too hot at too high of a voltage. However, after some preliminary tests, our team found that the new USB heater is well-insulated and will not be hot enough to cause the illuminator to catch fire. Thus, the team believes that burning will not be a hindering failure mode.

The maintenance and repair of the illuminator is easily accomplished through the use of recyclable paper materials for the sheath, box, and test tube stands. Also, the use of the Cricut Maker machine to cut the paper materials significantly reduces the time needed to re-manufacture an entire illuminator. If any of the paper material parts rips or tears, they can easily be individually cut using the machine and replaced. Furthermore, the electric circuit has parts that can be easily replaced. When the blue LED strip burns out, it can be pulled off of the battery pack through its adhesive backing and replaced with another cut strip from the main reel. The LED strip can then be re-inserted into the LED strip to wire connector to complete the circuit. The light filter can also be easily reused.

5.5 Bill of Materials and Cost Analysis

The indented bill of materials (iBOM) in Appendix J contains all the parts, divided by specific subassembly, needed to make an illuminator. The cost and the source for each part are also documented. The illuminator is divided into three main sections: sheath and box materials, the electrical circuit, and the attachments. The electrical circuit requires the most parts (5) because of the various connections and components that need to be incorporated.

One of Dr. Oza's requirements for the illuminator is that it is accessible to many people, which includes the cost of the entire device. Our goal was to make the illuminator cost less, or around, $11. By buying the parts to make the illuminator in bulk, our team is able to save cost on components and produce many prototypes. The most expensive part is the USB heater, costing $3.98 per unit, and the cheapest part is the Velcro dots at $0.03 per pair. The total cost of the illuminator is $9.56, which is slightly below the requirement. In order to save cost while producing illuminator prototypes, our team's goal is to purchase material in bulk, with sets of five or more of various components.

The illuminator could be produced at an even cheaper rate with the elimination of one component. The cost of one individual illuminator with a heating element is equivalent to $9.56; however, if the device does not have the heating function, the individual cost decreases to $5.58. While the heating element is a beneficial feature for the illuminator to have, it was not one of Dr. Oza's requirements for the device. Since the heating element and lighting system are two independent circuits, it is possible to manufacture an illuminator without the USB heater and significantly decrease the cost.

6. MANUFACTURING PLAN

The manufacturing plan for the portable fluorescence illuminator details the materials and manufacturing operations necessary to build the illuminator. Since the device is meant to be assembled at the point of use, the manufacturing plan also provides the illuminator's assembly instructions.

6.1 Procurement of Materials

The specification sheets for all procured materials are in Appendix K. These sheets provide the dimensions, features, and manufacturers of the part. They also include the Cricut manufacturing materials and tools needed to cut the illuminator. The indented bill of materials (Appendix J) also contains each part needed for the illuminator along with its cost and other descriptions. The materials necessary to make the illuminator include 4-ply paperboard, adhesive attachments, amber acrylic plastic, and various electric circuit components. The paperboard and adhesive attachments (Velcro dots) used for the main housing of the illuminator will all be sourced from sellers on Amazon.

The light filter will be made from yellow acrylic plastic 1/8" thick that will be bought in bulk from Amazon. Our team discovered that the type of acrylic is important in the effectiveness of the filter. Translucent acrylic is ineffective and diffracts the light, making the fluorescence difficult to see when used with the LED lights. The correct acrylic type is transparent, which filters the light and also clearly shows the fluorescent glow.

The 9 Volt battery, battery holder, and wire to LED strip connectors for the illuminator will all be sourced from Amazon sellers. The batteries, battery holder, and LED to wire connector parts will be ordered in packs of five or more to save on cost.

The 460-nanometer, blue LED light strip will be purchased from Waveform Lighting in a 5-meter spool. The lights have a power rating of 4.8 Watts per foot at 12 volts of power. At increments of 1 inch, the reel can be cut into smaller strips. The heating element, the USB heater, is sourced from an eBay seller and sold in single quantity. It is rated at 5 volts and has a carbon fiber resistive heater with dimensions of 3.74" × 2.56".

The materials for the final prototype were purchased in bulk, enough to make 80 identical kits consisting of the paperboard illuminator components (sheath, box, test tube stands), acrylic filter, battery, battery holder, blue LED light strip, LED strip to wire connector, USB heater, and Velcro dots for attachments. Table 3 displays the purchased components, their cost, and the number of illuminators that can be manufactured from purchasing a single quantity from each vendor. As mentioned previously, the most expensive component per illuminator is the heating element, which is optional. The heating element can only be purchased in single quantity. A single blue LED spool 16.4 feet long is able to supply the enough LED strips for 64 illuminators, and 50 illuminators can be made from a single pack of paperboard. These two materials are the most cost-efficient and allow many illuminator kits to be produced.

Table 3. Number of Illuminators Available with Purchase of Materials.

Item	Description of Use	Unit Cost	# of illuminators
490 nm Blue LEDs (Waveform Lighting)	16.4 ft (5 m) spool of blue LED strip, use 3-inch strips for 1 LED	$130.69	64
9V batteries (Amazon Brand)	8 pk, for illuminator power	$10.99	8
9V battery holder (LAMPVPATH)	5 pk, to hold batteries	$8.99	5
4-ply, 22” x 28” paperboard (Railroad Board)	25 pk, paperboard material. 2 illuminators per sheet	$11.92	50
USB Heater (Ebay seller)	1 pk, heating element for incubation. 1	$3.89	1
Yellow Acrylic (AcrylandUSA)	12" x 12" x 1/8" yellow acrylic sheet. 4"x2" filter needed for 1 illuminator.	$10.99	18
Velcro Dots (Strenco)	500 pk, 2 pairs of Velcro dots per illuminator.	$11.48	250
LED to Wire Connectors (Qijie)	10pk, 1 connector per illuminator.	$8.98	10

The cost breakdown in Appendix L displays the expenditures from the Baker-Koob grant award to purchase all of the bulk materials for the final prototype, all purchased on May 5, 2020. It also shows the purchases for materials needed to make preliminary prototypes for the preliminary and critical design reviews. The total spent amount was $1979.80, resulting in an excess of $71.14.

6.2 Manufacturing

A description of all the processes required to manufacture the illuminator are compiled in Appendix M, the manufacturing plan. The sheath, box, and two test tube stands need to be cut out by the Cricut Maker machine from 4-ply paperboard using the Cricut Deep Cut Blade and Scoring Wheel. The Cricut design file layout includes the templates for all of the different components on the same file laid out on a 12” by 24” workspace, needing only one run through the machine to print a full illuminator.

The electrical circuit and light filter also need to be modified from purchased parts to The LED strip must be connected to the battery holder via the LED strip to wire connectors. The connectors have simple instructions that involve inserting the wires on one side and pinching the LED strip leads into the connector’s pins. The LED strips also need to be cut from the full reel in 3-inch strips. Finally, the light filter will be cut from a sheet of yellow acrylic into 4” x 2” rectangles using a saw.

6.3 Assembly and Operation

The assembly of the illuminator in the matchbox configuration will be accomplished by the user. The user is provided with a kit containing all of the necessary components to make one functioning portable fluorescence illuminator, which includes the unfolded paperboard pieces for the sheath, box, and two test tube stands as well as the acrylic light filter, USB heater, and electrical components. Only the electrical circuit will be pre-assembled; the kit will come with the blue LED light strip already connected to the wires of the battery pack via the LED strip to wire connector. The user will only have to connect the battery to make the electrical circuit for the lights to work.

Therefore, the instruction set provided to the user will describe the steps to fold the illuminator into shape and attach the electrical circuit to the box. The instructions will also include a user guide that explains how to use and operate the illuminator. The instructions to manufacture, assemble, and operate the illuminator are compiled in Appendix N, the operations manual, complete with drawings.

7. DESIGN VERIFICATION PLAN

In order to meet all specifications set forth by our sponsor (refer to Table 1), each specification with regard to the final illuminator design must be thoroughly verified through analysis and engineering tests. The specifications regarding dimensions and weight will be easily measured with appropriate length and weight apparatuses, and the recyclability of the entire device will be determined by the recyclability and reusability of the individual components. Production cost will be analyzed by adding up the material cost and external operations needed to manufacture each component of one illuminator. However, the luminosity, assembly time, deformation under force, and maximum drop height specifications each require designed tests to verify they meet the sponsor's needs. The test parameters and start/completion dates for each specification's test are compiled in the Design Verification Plan in Appendix O.

7.1 Engineering Tests and Test Equipment

The tests to verify the specifications of luminosity and assembly time both concern the usability of the device. The luminosity of the illuminator will be evaluated using the imageJ application, which is an image processing app that can identify the intensity of pixels in a picture. A picture will be taken of the illuminator as the it is operating, and the image will be processed in the application. The assembly time of the illuminator will be assessed through user assembly tests. Dr. Oza, his student lab assistants, and other Cal Poly students will be timed as they assemble the full illuminator while following instructions written by our team. With the target time set at 10 minutes or less, analysis of the resulting assembly times and user surveys will allow our team to determine whether our instructions are adequate and easy-to-follow. It will also allow our team to determine whether the illuminator's design is too complicated for users to easily assemble.

Furthermore, the tests concerning deformation force and drop height will evaluate the mechanical failure modes of the illuminator. The deformation force test will consist of directly subjecting the illuminator and its components to a force of 10 pounds from a weight. The drop height test will consist of dropping the illuminator from various heights and analyzing the deformation and damage of the illuminator. Both tests will require multiple trials. After each trial, the illuminator must still hold its shape and function to be successful and meet the sponsor's requirements. If the illuminator's pieces are either damaged or torn, the device will have failed the tests.

7.2 Engineering Test Results

Due to the outbreak of COVID-19, some tests were unable to be completed, such as the deformation, drop height, and luminosity test. In-person user testing and access to testing equipment were limited. Simple tests for weight and dimensions could be carried out at home. The weight of the device was 0.6 pounds, and the assembled dimensions of the device were 4.55" × 4.12" × 1.14". These measurements fall within the specifications for the device laid out by Dr. Oza.

Our group was able to complete an assembly test with Dr. Oza and eight of his students with their consent. The test consisted of providing the nine subjects with the instruction set to assemble all illuminator components and an illuminator kit. Each member of our team timed and observed them in a video conferencing call as they assembled the device, providing assistance if only absolutely necessary. At the end of the assembly, the participants were asked to fill out a survey regarding their experience, satisfaction with the instructions, suggestions for improvement, and satisfaction with the device. The survey questions and anonymous responses are documented in Appendix P.

From the results, the average assembly time fell around 20-25 minutes for the paperboard illuminator components. The subjects were also timed when assembling the electrical circuit components of LED strip, battery pack, battery, and LED strip to wire connector. The combined assembly time for the entire device took most an hour or more to complete. This occurred because many struggled on the electrical circuit assembly and connecting the LED strip and battery pack through the connector. The connector, once clamped shut, was difficult to reopen for all users and took time to force back open. Furthermore, some were unable to establish a good connection between the LED strip and connector on the first try, resulting in time-consuming reopening of the connector to restart.

The feedback concerning the instructions mainly concerned some of the images provided and the wording of some of the steps. Many of the subjects expressed their difficulties viewing some of the pictures present in the manual that displayed confusing orientations and did not exactly show what was being written about in the instructions. Overall, the subjects mostly considered the images provided helpful but confusing at some steps. Furthermore, the subjects suggested that some steps could be broken into smaller steps to improve understanding.

Some of the major improvements made to the instruction manual from the subjects' feedback included changing the orientation in a few images for clarity, mainly in the sheath assembly, and providing more explicit detail on how to insert the battery and connect the LED strip and wires to the connector. Furthermore, in addition to an instruction manual, our team created an assembly video tutorial for users to view as they assemble the device. This video will most likely improve assembly times as the user can follow along with the instructions on the screen and not rely on static pictures as a reference. Our team determined that it would be best if the electrical circuit was assembled and properly working before being put into the kit and given to the user to assemble. This would also save assembly time and not be a frustrating experience for users.

The most important feedback from the test was that most of the users were very satisfied with the design of the device and certain that it could perform the functions of an illuminator. Most believed that the device was easy to carry and portable. Furthermore, many positively commented that they believed the device would be able to perform the necessary functions.

8. PROJECT MANAGEMENT

The entire design project was carried out over the course of a year, with each quarter dedicated to a specific step in the engineering design process. Key project deliverables were due throughout each quarter, and design reviews were conducted to evaluate progress on the project at the end of each quarter. The culmination of the project at the end of the year was a senior project exposition and final design review, where the final prototype was presented.

8.1 Quarterly Project Timeline

Fall Quarter

With the Scope of Work, Preliminary Design Review, and concept ideation completed, our team performed a benchmark comparison and began preliminary analysis for appropriate materials and electrical components for our design.

The team completed an application for the Baker-Koob Endowment, requesting a total of $2055.94 for manufacturing materials and electrical components, and the grant was awarded in late December. The grant will fund the benchmarking costs as well as the material and manufacturing costs of the illuminator prototypes during the manufacturing and test phases. It will also fund the materials to create the final prototypes of the illuminator in spring quarter.

After conferring with our sponsor and purchasing the product, benchmark comparison was conducted with the currently existing miniPCR P51 Molecular Fluorescent Viewer, our project's main competitor. This determined the features our design should improve or implement to meet our sponsor's needs, which included size, cost, and user safety. A list of specific criteria and our QFD specifications was used as the standard to determine the success of the P51 in meeting our sponsor's needs.

Our team performed research regarding recyclable material for the outside of the illuminator and appropriate electrical components for batteries, wiring, and LED lighting. Our team began a bill of materials (BOM) of possible components, considering the cost and quantity of each component needed to manufacture a single illuminator.

Winter Quarter

The project focus was on prototyping and manufacturing. The final design of the illuminator in the matchbox configuration was refined from the concept design. The CAD model was slightly altered with changes to the box shape, the test tube racks, and the inclusion of a removable panel. All of the materials needed to make an illuminator were compiled into a bill of materials (BOM), and some components were purchased to make a structural prototype for the Critical Design Review (CDR). Our team created a manufacturing plan to build a prototype of the illuminator, which includes instructions to make the sheath and box. The instructions also detail the configuration of the circuit and lighting orientation on the removable panel.

After CDR, our team continued to refine our design and conduct tests with the structural prototype. We contacted the Cal Poly Packaging Lab in order to gain insight on our design and decided to shift our design to include interlocking tabs for the sheath and box in place. To ease the manufacturing process, a Cricut Maker was purchased to automatically cut the prototypes instead of cutting them by hand. Furthermore, after a few preliminary tests, our team decided to modify our design's lighting and heating systems to simplify the electrical circuitry and eliminate the need for safety switches. Our team prepared a preliminary prototype for Dr. Oza to show to his colleague for possible patenting.

Spring Quarter

Due to the outbreak of COVID-19, our team was unable to work on the project in person with one another. However, our team decided to fulfill the project to our best efforts and continued to make small modifications to the design. The focus was on interfacing the design from SOLIDWORKS with the Cricut software and perfecting a design template that could be used by future users. The materials for the project were purchased in bulk using the Baker-Koob grant, enough to make 80 prototypes. Our group worked on assembling a few final prototypes with the purchased materials and conducting some preliminary tests for assembly time, weight, and deformation. The Final Design Review (FDR) report documented the entire project process from ideation to the final prototype. Our team also documented the project for the Senior Project Exposition online on the Cal Poly Digital Commons.

Project Deliverables

The deliverables displayed in Table 3 are replicated on a timeline by the Gantt charts in Appendix Q, highlighting deliverables, key due dates, and project milestones for the whole year. The Gantt charts display all the steps taken by the team to complete the project and the major project milestones.

Table 4. Senior Project Deliverables and Dates.

DATE	DELIVERABLE
10/18/19	Submit Scope of Work (SOW) to Sponsor
11/12/19	Preliminary Design Review (PDR) Presentations in Lab
11/15/19	Submit PDR to Sponsor
1/16/20	Interim Design Review in Lab
2/4/20	Critical Design Review (CDR) Presentations in Lab
2/7/20	Submit CDR to Sponsor
3/12/20	Manufacturing and Test Review in Lab
5/19/20	DVPR Sign-Off
5/26/20	Expo Poster / Final Design Review (FDR)
5/29/20	Senior Project Expo

9. CONCLUSION AND RECOMMENDATIONS

This Final Design Review report establishes the final design of the illuminator in the matchbox configuration and the design changes since the Critical Design Review. The report also restates the objectives and goals that the portable ultraviolet fluorescence illuminator project must meet to satisfy Dr. Oza's and his lab assistants' requirements. These requirements specifically relate to the increased portability, accessibility, and luminosity of the device with a lowered overall cost. The background and initial research into existing ultraviolet transilluminators indicate many useful applications for a portable product in biology research and development. The report also outlines the various features of the device, including the three main subassemblies of the sheath, box, and electrical circuit. The illuminator is able to meet Dr. Oza's specifications of portability, recyclability, and cost; it performs the expected function of an illuminator in a compact form factor. The manufacturing plan for the illuminator prototypes contains the materials needed to be purchased and modified to make the illuminator, as well as how the full illuminator will be assembled. The operations manual includes the manufacturing, assembly, and use operations for the illuminator in full detail. Furthermore, the design verification plan for the illuminator outlines the various tests, such as weight and assembly time, that were performed on the illuminator to meet Dr. Oza's specifications.

The portable fluorescence illuminator was a successful project, despite the outbreak of COVID-19 that hindered our team from working in-person together. Our team was able to continue with our planned objective of creating final working prototypes for Dr. Oza and purchase all of the materials we needed to produce 80 prototypes.

If our team were to attempt this project again, we would improve our processes for developing the final design, manufacturing preliminary prototypes, and choosing materials. First, our team made many design iterations of the illuminator. The design changes between PDR and CDR overly complicated our design and resulted in a bulky product that had many unnecessary electrical components and a long assembly time. It was not until after CDR that our team was able to reevaluate the objectives of our project and refocus the design on producing a simple easy-to-use product. Second, our team struggled with manufacturing the preliminary prototypes; we used to cut out and fold the paper by hand from printed SolidWorks drawings. Once we obtained the Cricut Maker in late winter quarter, the time spent cutting and assembling prototypes decreased and the time spent refining the design increased. Lastly, our team purchased materials that were not the right type for our project, resulting in many repurchases and returns. The UV LEDs were not the correct wavelength of light for our project, and the initial orange acrylic sheet that we purchased in bulk was translucent and could not filter the LED light properly. These mistakes could have been easily avoided with simple tests with the lights and filters prior to purchasing; however, in the case of the light filters, our team could not be together to perform the test.

Some future recommendations for the project would be to use 6-ply paperboard in future prototypes for the sheath, box, and test tube components because it is thicker and more durable for the same cost as 4-ply paperboard. The Cricut file is already modified in order perform the cutting operations twice with the deep cut blade to effectively cut through the thicker paperboard. Furthermore, the assembly test should be carried out with a wider range of subjects to obtain a wider variety of subjects' age, experience, and opinion on the instruction set. Finally, it would also be beneficial to test the device with different colors of LED lights and light filter colors with different biological proteins and fluorescent reagents. This allows for the device to become more modular, broadening the already numerous applications and implications the portable fluorescence illuminator could have for the future.

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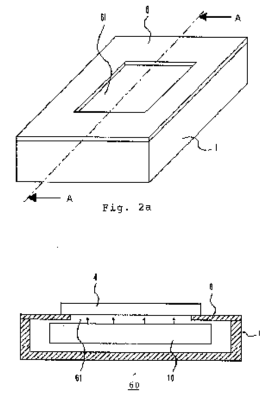
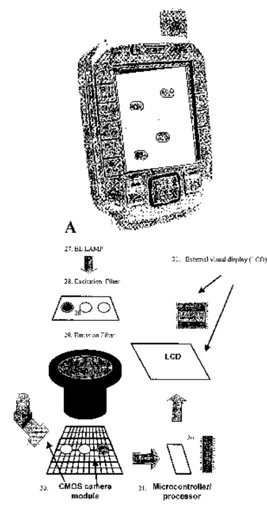
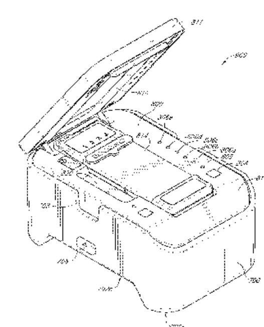
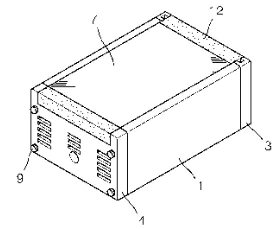
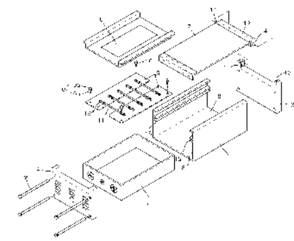
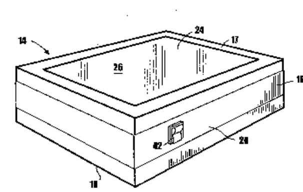
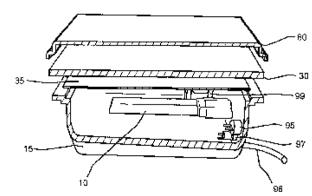
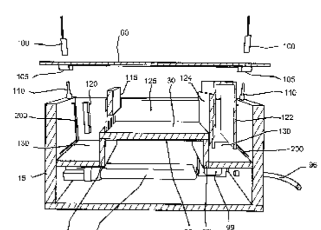
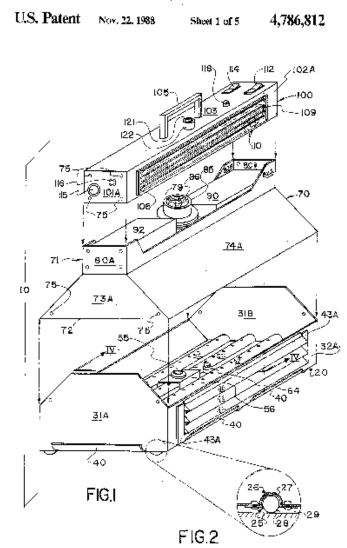
APPENDIX A: RELEVANT PATENTS

PATENT NO.	PATENT NAME	DESCRIPTION	IMAGE
US6774382B2	Fluorescent transilluminator requiring no visible light-cutting filter	A fluorescent transmitter that uses an ultraviolet source and a housing case. The transmission window passes ultraviolet rays toward an object to be irradiated. A visible light-cutting filter is not installed. The ultraviolet source is activated by gadolinium and emits a peak emission wavelength of 313 nanometers (Samsung Electronics Co., Ltd).	 Fig. 2a Fig. 2b
US20100105035A1	Electroluminescent-based fluorescence detection device	The device uses an electroluminescent light source to measure fluorescence in biological samples. It is an economical, battery powered and hand-held device for detecting fluorescent light from reporter molecules in DNA, RNA, proteins, or other biological samples (Michigan State University).	
US8562802B1	Transilluminator base and scanner for imaging fluorescent gels, charging devices and portable electrophoresis systems	This cassette electrophoresis system contains a visible light transillumination system to view a pattern of fluorescence. It includes a base power supply that houses a light source (LIFE Tech Ltd).	 FIG. 18A

PATENT NO.	PATENT NAME	DESCRIPTION	IMAGE
KR20080110041A	UV trans-illuminator	The UV transilluminator consists of an outer case that holds a UV protection window, an ultraviolet ray lamp, and a UV permeable filter. The front and rear cover slide onto the main body and are attached with bolts (Park).	 
US20060237658A1	Transilluminator with ultraviolet light emitting diode array	This apparatus is used in genomic or proteomic research to visualize fluorescent DNA, RNA, or protein samples. The radiation source is comprised of an array of UV LEDs (Waluszko).	
US6914250B2	Fluorometric detection using visible light	This system includes a lights source that emits visible light through two separate optical filters. The first filter transmits light at a wavelength that excites fluorophores in fluorescently stained biological material, and the second filter blocks the rest of the light from the source to amplify the fluorescence (Clare Chemical Research, Inc).	  FIG. 10

PATENT NO.	PATENT NAME	DESCRIPTION	IMAGE
CN108226109A	Simple gel imaging device	This gel imaging device utilizes a tabletop UV transilluminator and black light isolating shell that is placed over the transilluminator. With a hole made in the isolating shell, a camera lens can be used to take photos or view the fluorescence from the illuminator after gel electrophoresis has occurred (Anhui Normal University).	N/A
US 4786812A	Portable germicidal ultraviolet lamp	This portable germ-killing machine has many ultraviolet light bulbs in a protective housing with air passageways. A fan draws air in, and the lightbulbs kill any germs entering the housing (Dora DiCamillo 1988 Trust).	

APPENDIX B: QUALITY FUNCTION DEPLOYMENT

Correlations	
Positive	+
Negative	–
No Correlation	

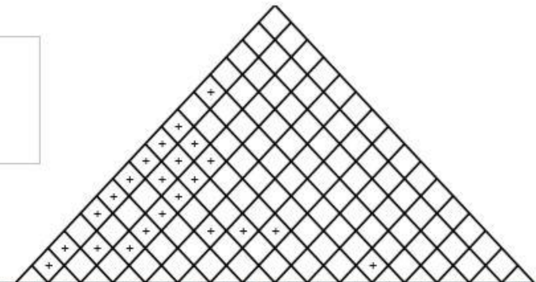
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: Portable Fluorescence Illuminator

Revision Date: 10/13/19



								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
	WHO: Customers							Direction of Improvement	▼	▼	▼	▲	▼	▼	▼	▼	▼	▼	◇	◇	▲				NOW: Curr. Products					
Row #	Weight Chart	Relative Weight	Dr. Oza	Lab/Field Researchers	Students		Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Weight	Cost	Assembly Time	Luminosity	Assembled Size, Length	Assembled Size, Width	Assembled Size, Height	Stored Size, Length	Stored Size, Width	Stored Size, Height	Drop Height	Stiffness/Deformation	Recyclable				P51 Fluorescent Viewer	UV Benchtop Transillumin.	UV Handheld Lamp	3D-Printed Transilluminator	Biotek Cytation 5	Row #
1		8%	10	8	7		9	portable	●	○	▽		○	○	○	●	●	●		▽					5	0	5	5	0	1
2		9%	10	10	8		9	UV lighting	○	●	○	●	○	○	○	○	○	○			●				5	5	5	5	5	2
3		6%	7	7	4		9	low cost production	○	●		●	▽	▽	▽	▽	▽	▽			○				1	2	4	0	0	3
4		6%	6	6	5		9	durable	○	○			▽	▽	▽	▽	▽	▽	●	●	▽				3	3	3	4	2	4
5		7%	7	6	8		9	easy to assemble	○		●		○	○	○	○	○	○		▽					5	0	2	3	0	5
6		6%	8	6	4			heating element																	3	5	0	0	5	6
7		6%	7	5	5		9	disposable/recyclable				○								▽	●				5	2	2	2	1	7
8		9%	10	10	8		9	visualize UV glow		○		●													5	5	3	5	5	8
9		9%	10	10	7		9	fits standard test vials					●	●	●	▽	▽	▽							5	5	0	5	5	9
10		6%	7	7	5		9	collapsible					○	○	○	●	●	●							4	0	0	0	0	10
11		8%	9	8	8		9	small form factor	○	○	▽		●	●	●	●	●	●							4	2	3	5	0	11
12		8%	10	8	6		9	accessible to many people	○	●	●	●				▽	▽	▽			○				5	2	4	2	0	12
13		10%	10	10	10		9	easily usable	○		●	○													5	2	4	4	0	13
14		0%																												14
15		0%																												15
16		0%																												16

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	x < 5 lbs	x < 5 minutes	x< $10	max. signal output with diff. filters	x < 7 inches	x < 4.5 inches	x < 1.5 inches	12 < x < 15 inches	12 < x < 15 inches	0.25 < x < 1 inches	sustain fall from x = 4 feet	sustain x < 10 lbf	x > 90% recyclable waste			
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9			
	Technical Importance Rating	240.8	306.9	274.2	343.5	263.7	263.7	263.7	287.9	287.9	287.9	51.69	73.01	184.1	0	0	0
	Relative Weight	8%	10%	9%	11%	8%	8%	8%	9%	9%	9%	2%	2%	6%	0%	0%	0%
Curr. Products	P51 Fluorescent Viewer	5	4	0	4	5	5	0	2	2	2	4	3	2			
	UV Benchtop Transillumin.	0	3	0	1	0	0	0	5	5	0	0	4	0			
	UV Handheld Lamp	5	0	5	5	0	5	1	5	5	0	4	3	0			
	3D-Printed Transilluminator	5	3	0	4	5	5	2	5	5	0	4	4	0			
	Biotek Cytation 5	0	0	0	1	0	0	0	0	0	0	0	5	0			
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

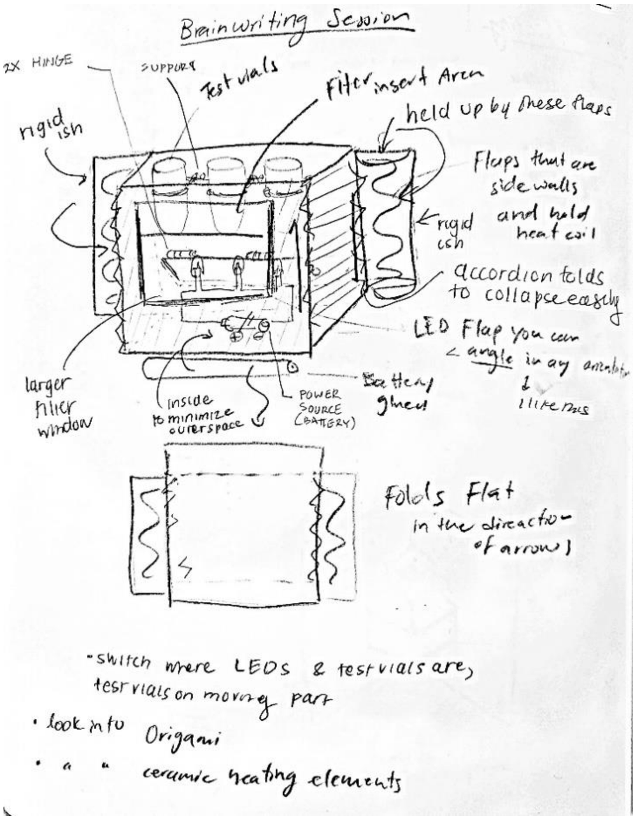
APPENDIX C: IDEATION CONCEPTS

Function Tree Ideas

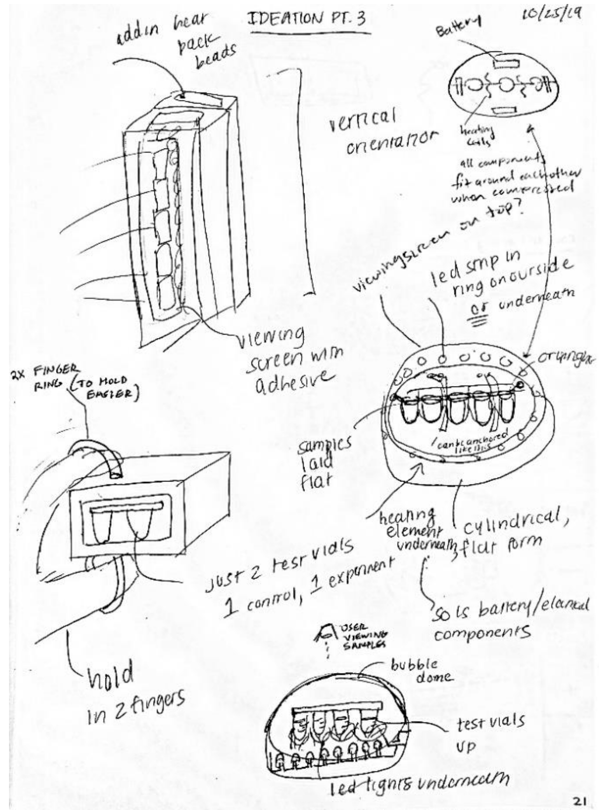
SUB- FUNCTIONS	IDEA
quantify glow output	human eyes
	animal eyes
	phone application
create dark environment	turn off the lights
	black/dark background
	light filters
	blanket over head/device
	operate only at night
filter light	sunglasses for user
	adhesive filter
	shutter filter with multiple filter types
	replaceable filter slides
	magnetic filter
	corner holder for filters
heat samples	internal hotplate
	hold samples in hand
	Salon Pas/IcyHot activation beads
	metal enclosure + body heat
	put on a boiler/stovetop
	heating coil
	LED that emits UV light and heat
	fire
provide light/use lighting system	UV individual LEDs
	UV flashlight
	UV light strip
	external lighting system
	sunlight
provide light/power LEDs	electric generator
	potato circuit
	electrical circuit
	battery pack
	solar power
	watch batteries
be portable/reduce weight	lightweight materials
	sponge as material
	reduce number of materials used
	make electrical system external
be portable/carry illuminator	neck strap
	fanny pack
	wristwatch
	hat
	pocket device
	attach to user’s hand
	carry test vial individually

SUB- FUNCTIONS	IDEA
be portable/disassemble illuminator	telescoping tube
	fold into a box
	accordion
	springs
	roll up
	individual parts
	crumple and throw away
	origami folding
	edible material
fit standard test vials	test vial cap holders
	test tube rack
	hinged single test tube holder
	big vial for small vials
lower cost	cheap manufacturing
	cheap materials
	use commercially standard parts
	reduce number of parts & components
lower assembly time	already fully assembled when purchased
	pop-up components
	modular parts
make simple to use	include easy-to-follow instructions
	have children assemble the product

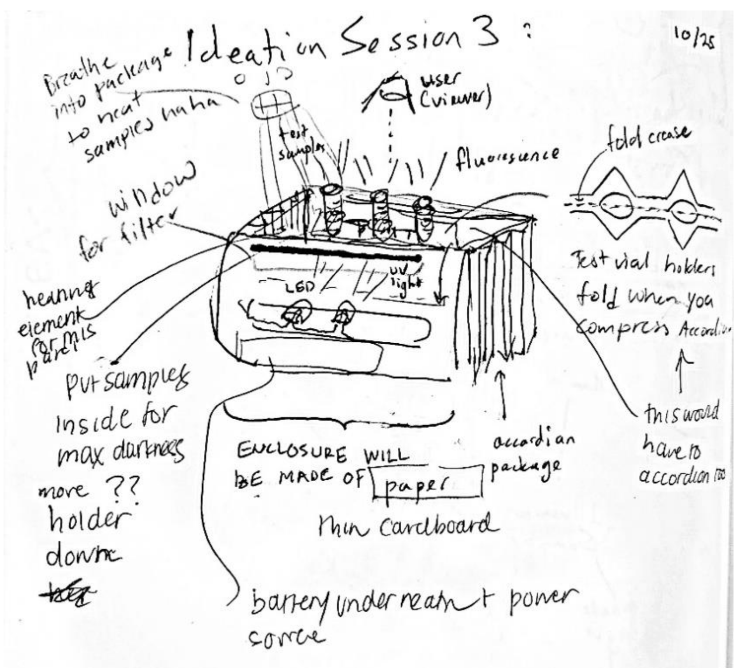
<u>Brainsketching Ideas</u>



Emran's Brainsketching

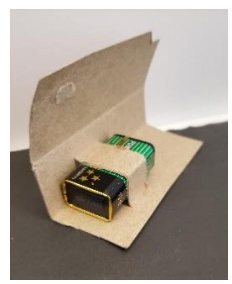


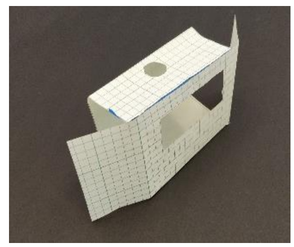
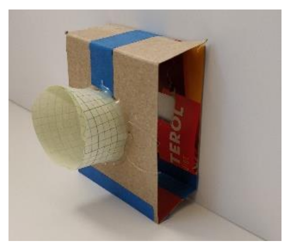
Katherine's Brainsketching



Emmett's Brainsketching

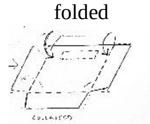
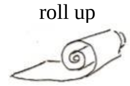
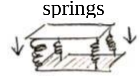
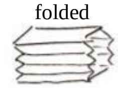
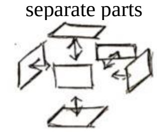
APPENDIX D: FUNCTION CONCEPT PROTOTYPES

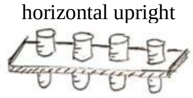
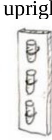
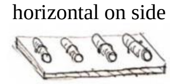
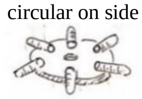
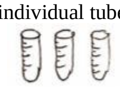
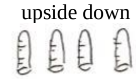
CONCEPT	DESCRIPTION	IMAGE
cylindrical outer shape and test tube configuration	The cylindrical orientation of the illuminator would allow for the LED lighting to be positioned around the inner circumference and the battery to be positioned underneath the inner shelf.	
adhesive filter	The adhesive filter sticks on to the back of the cutout window for easy installation.	
accordion side folds	The accordion side folds allow for the illuminator to be collapsed easily for storage by pressing down on the top.	
negative-space battery holder	The battery for the power system is held by using a strip cut out from the back of the illuminator with a folded edge. The outside light is blocked out by the battery, and the strip restricts the battery from shifting.	
test tube rack holder	The test tube rack holder uses a clamp to hold up the test tube flap in order to prevent the rack from sinking due to the weight of the test tubes.	
vertical test tube rack	The test tubes are placed individually in their own singular flap holders in a vertical orientation. This orientation allows for a thinner outer shape to be used.	

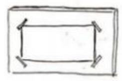
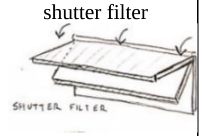
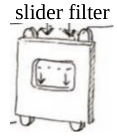
CONCEPT	DESCRIPTION	IMAGE
mini illuminator with finger holder	The mini illuminator will only fit 1-2 test vials and can be held by the user with the finger holder, like a handle.	
shutter filter	The shutter filter consists of 3-4 different light filter types attached to a hinge-type center. The filters can simply be flipped over the window to view the samples and alternated with the other filter types.	
collapsible box with outer flaps	The box can be collapsed through folding; the outer flaps on the side help the box hold its shape when assembled.	
sliding filter	This filter has 3-4 different filter types on a sliding mechanism placed one after the other. The user can choose which filter to slide over the viewing window.	
flashlight illumination method	A flashlight will be entered into the hole in order to illuminate the samples on the inside of the device.	

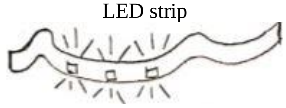
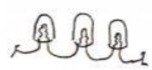
APPENDIX E: PUGH MATRICES

SHAPE	horizontal, rectangular box 	vertical, rectangular box 	cylinder 
manufacturability	DATUM	S	-
allows for most test tubes		-	-
blocks outside light		S	S
easy to hold by user		S	+
least folds		S	+
disassembled shape for storage		S	-
TOTAL	0	-1	-1

COLLAPSIBLE FORM	folded 	roll up 	springs 	accordion folded 	separate parts 
number of parts/adhesives	DATUM	-	-	-	-
material wear		-	-	-	+
disassembly time		-	+	+	-
storage		-	S	+	-
manufacturability		+	-	-	-
TOTAL	0	-3	-2	-1	-3

TEST TUBE ORIENTATION	horizontal upright 	vertical upright 	horizontal on side 	circular on side 	individual tubes 	upside down 
view glow well	DATUM	S	-	S	S	-
easy to orient with lights		S	-	S	-	-
easy fixture to install		-	-	-	-	+
least space		S	S	-	+	S
least deflection of material		S	+	+	+	-
TOTAL	0	-1	-2	-1	0	-2

FILTER HOLDER	corner filter holder 	shutter filter 	slider filter 	adhesive filter 	bubble filter 
replaceability	DATUM	-	-	-	-
use of multiple filters		+	+	S	-
low cost		-	-	S	-
easy to position to show glow		S	S	-	+
blocks outside light		S	S	S	S
TOTAL	0	-1	-1	-2	-2

UV LIGHTING SYSTEM	LED strip 	individual LED lights 	incandescent bulb 	LED flashlight 
cost	DATUM	S	-	-
power demand		S	-	-
light intensity		-	+	+
ease of use & integration		S	-	S
availability at 400 nm		S	S	S
TOTAL	0	-1	-2	-1

APPENDIX F: WEIGHTED DECISION MATRIX

Criteria	Weight	Concept 1		Concept 2		Concept 3		Concept 4		Concept 5		Concept 6		Concept 7	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Portable	5	4.5	22.5	4	20	3	15	4	20	4	20	3	15	4	20
UV lighting	4.5	5	22.5	2	9	2	9	2	9	3	13.5	4.5	20.25	5	22.5
Low Cost	3.5	4	14	2	7	3	10.5	3	10.5	3	10.5	3	10.5	4	14
Durable	3	3	9	3	9	4	12	4	12	3	9	4	12	2.5	7.5
Easy Assembly	3.5	4	14	3.5	12.25	2	7	2	7	3	10.5	2.5	8.75	3	10.5
Heating Element	3	2	6	3	9	3	9	3	9	3	9	3	9	2	6
Disposable/Recyclable	3	3	9	3	9	3	9	3	9	3	9	3	9	3	9
Visualize UV Glow	4.5	4	18	2	9	2	9	3.5	15.75	2.5	11.25	2	9	4	18
Fits Standard Test Vials	4	4	16	3	12	2	8	4	16	3.5	14	3	12	4	16
Collapsible	4	5	20	4	16	4	16	3	12	4	16	2.5	10	3	12
Small Form Factor	4	5	20	3	12	4	16	4	16	4	16	3	12	3	12
Easily Usable	5	5	25	5	25	5	25	4	20	5	25	3	15	5	25
	Total	196		149.25		145.5		156.25		163.75		142.5		172.5	

APPENDIX G: DESIGN HAZARD CHECKLIST

DESIGN HAZARD CHECKLIST

Team: 51, Portable Fluorescence Illuminator Faculty Coach: Harding

Y	N	
☐	☒	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	☒	2. Can any part of the design undergo high accelerations/decelerations?
☐	☒	3. Will the system have any large moving masses or large forces?
☐	☒	4. Will the system produce a projectile?
☐	☒	5. Would it be possible for the system to fall under gravity creating injury?
☐	☒	6. Will a user be exposed to overhanging weights as part of the design?
☐	☒	7. Will the system have any sharp edges?
☐	☒	8. Will any part of the electrical systems not be grounded?
☐	☒	9. Will there be any large batteries or electrical voltage in the system above 40 V?
☒	☐	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	☒	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☐	☒	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☒	☐	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☒	14. Can the system generate high levels of noise?
☐	☒	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
☒	☐	16. Is it possible for the system to be used in an unsafe manner?
☒	☐	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Battery-Powered System	The batteries utilized will be grounded and less than 15 V in output. The battery will be anchored to the outer casing in order to prevent falling out.	1/25/20	1/25/20
Ultraviolet Lighting	Testing will be performed with various light filters and PPE to reduce exposure to ultraviolet radiation. A method such as a switch will be incorporated into the device so the user does not turn on the ultraviolet lighting without fully closing the device and protecting themselves from radiation. The ultraviolet lighting was switched out for blue LED lights that achieved better fluorescence, so ultraviolet radiation is no longer a concern.	1/25/20	1/30/20
Flammable Material and Heating Element	The device must incorporate a heating element and be made of a disposable material, which may be flammable. In order to avoid fire or burn hazard in the operation of the illuminator, insulating material could surround the heating element to protect the device and user. Alternatively, the chosen heating element could also have low-power, low-heat output that does not produce a flammability risk. Gas fire should not be used in the operation of the illuminator.	1/30/20	1/31/20

APPENDIX H: FINAL DESIGN DRAWING PACKAGE

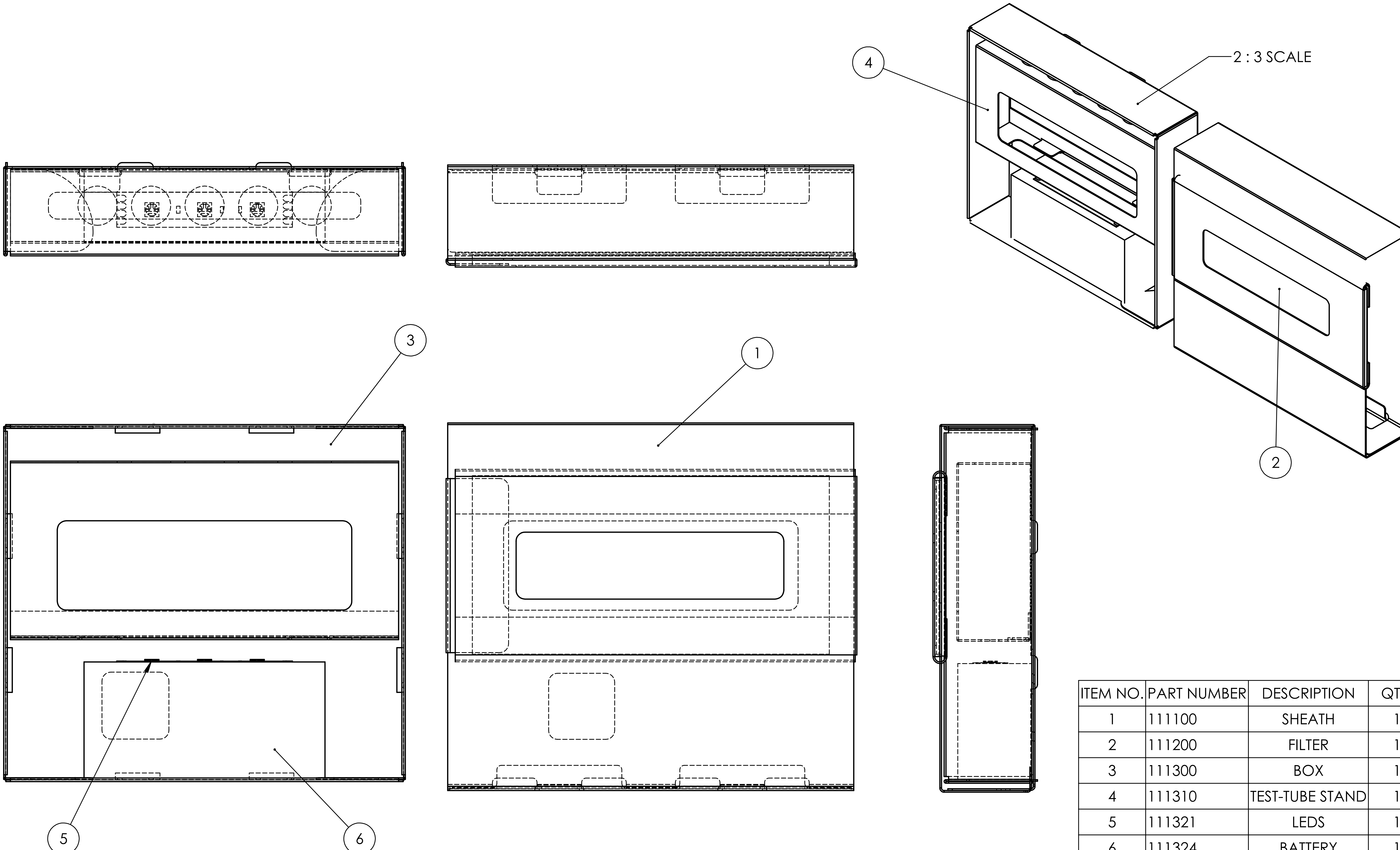
[1] Full Assembly

[2] Exploded Full Assembly

[3] Sheath

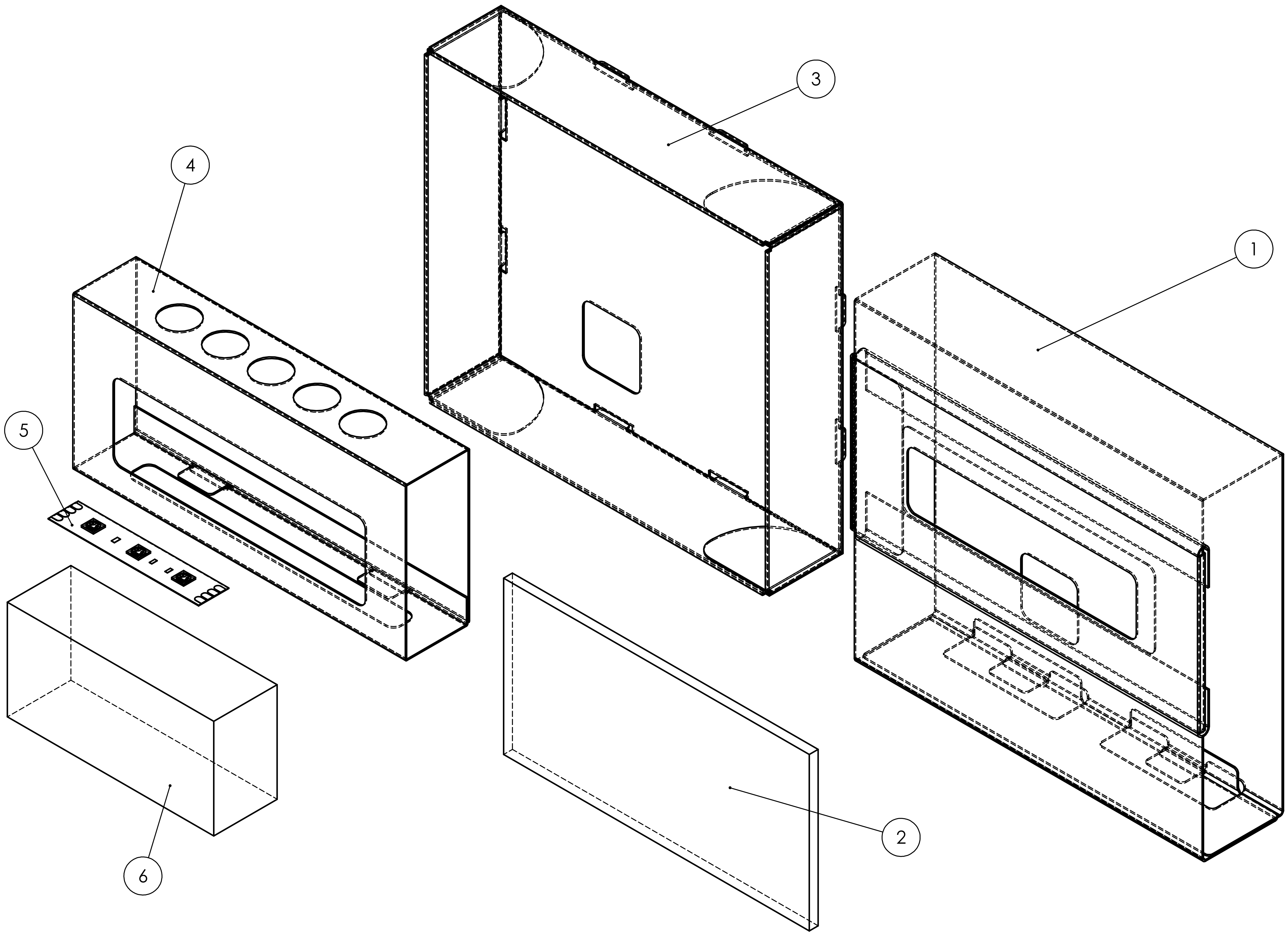
[4] Box

[5] Test Tube Stands



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	111100	SHEATH	1
2	111200	FILTER	1
3	111300	BOX	1
4	111310	TEST-TUBE STAND	1
5	111321	LEDS	1
6	111324	BATTERY	1

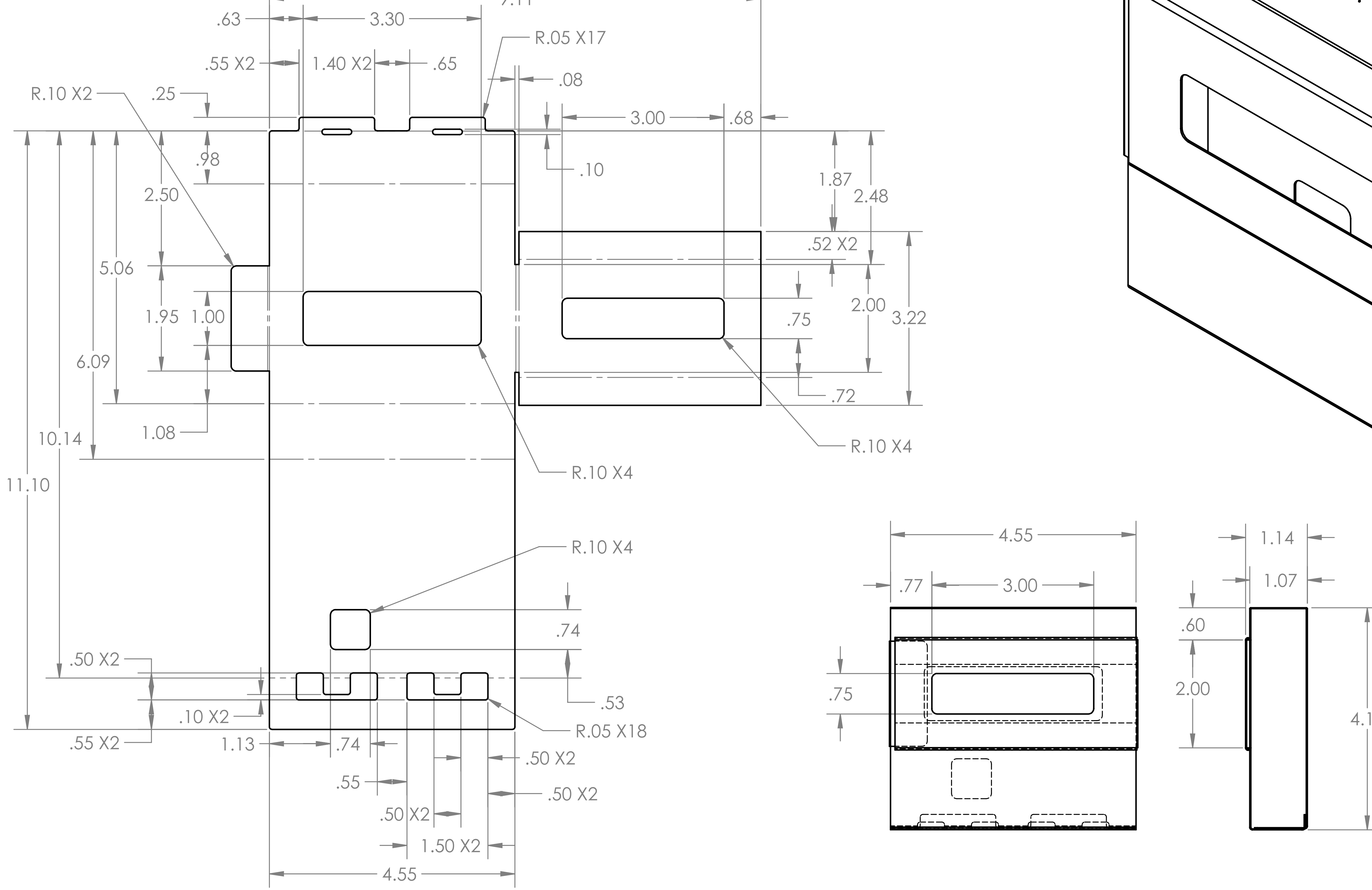
Cal Poly Mechanical Engineering	PN 100000	Title: ILLUMINATOR ASSEMBLY		Drwn. By: EMRAN BARYAL
ME 430 - SPRING 20	Dwg. #: 1	Date: 5/28/2020	Scale:1:1	Chkd. By: ME STAFF

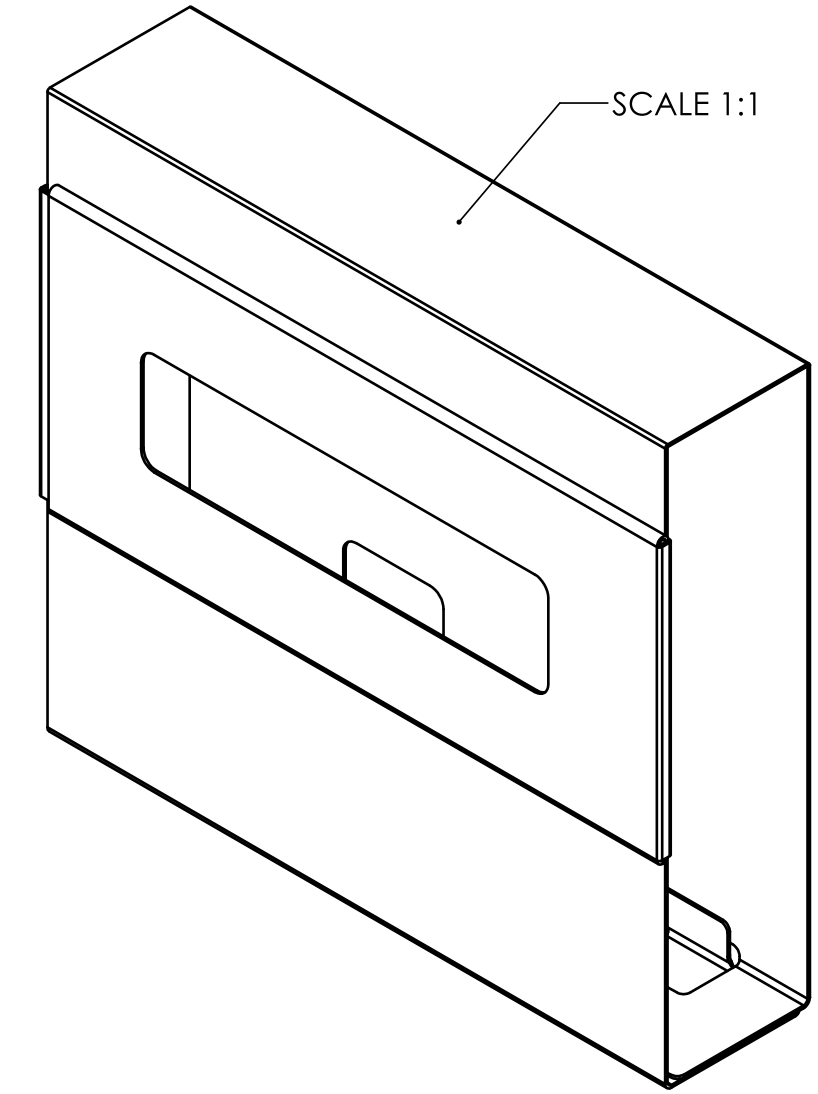


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	111100	SHEATH	1
2	111200	FILTER	1
3	111300	BOX	1
4	111310	TEST-TUBE STAND	1
5	111321	LEDS	1
6	111324	BATTERY	1

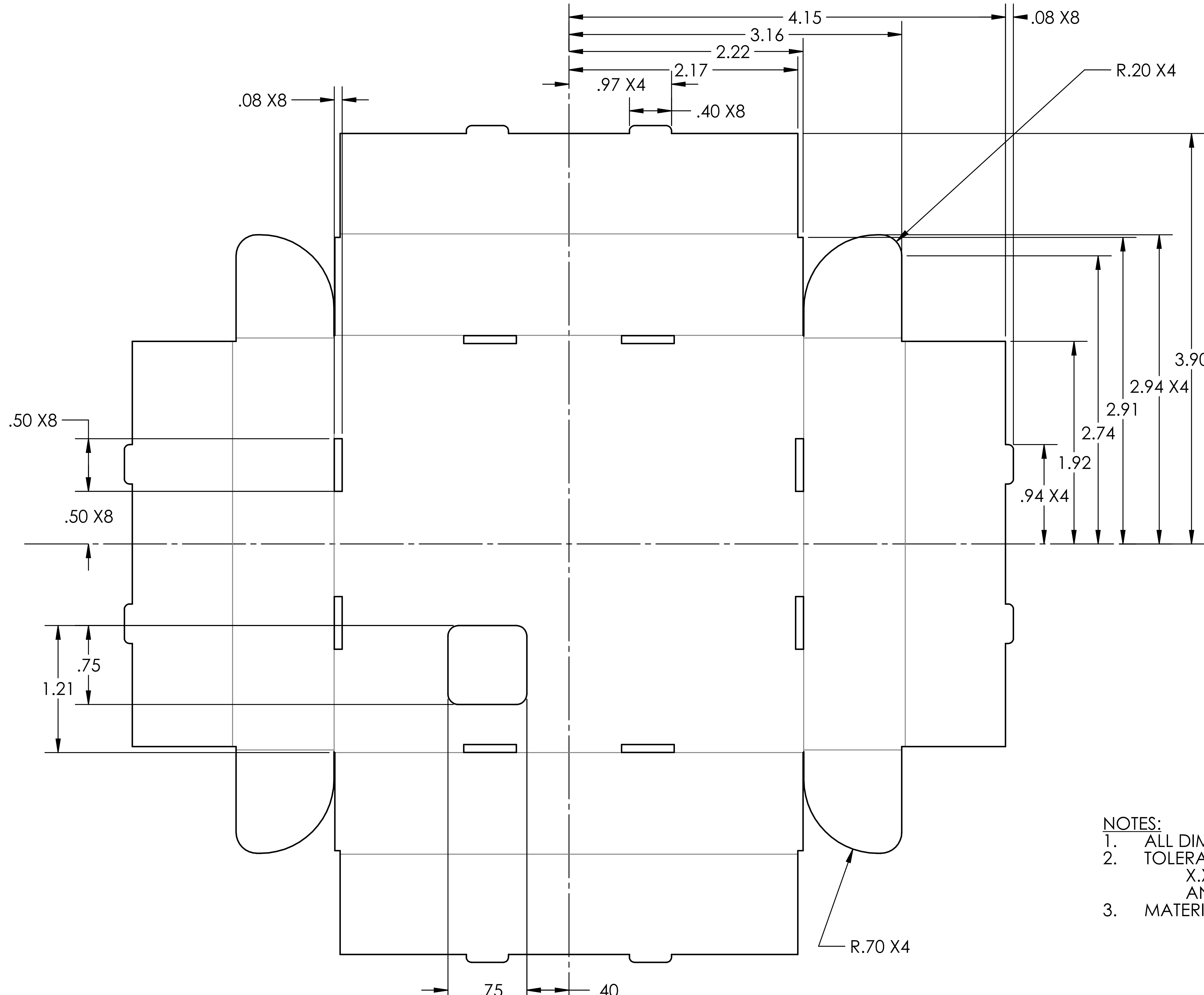
Cal Poly Mechanical Engineering	PN 100000	Title: ILLUMINATOR ASSEMBLY		Drwn. By: EMRAN BARYAL
ME 430 - SPRING 20	Dwg. #: 2	Date: 5/28/2020	Scale:1:1	Chkd. By: ME STAFF

NOTES:
1. ALL DIMS. IN INCHES
2. TOLERANCES:
   X.XX= ±0.01
   ANGLES: ±1°
3. MATERIAL: 6-PLY PAPERBOARD



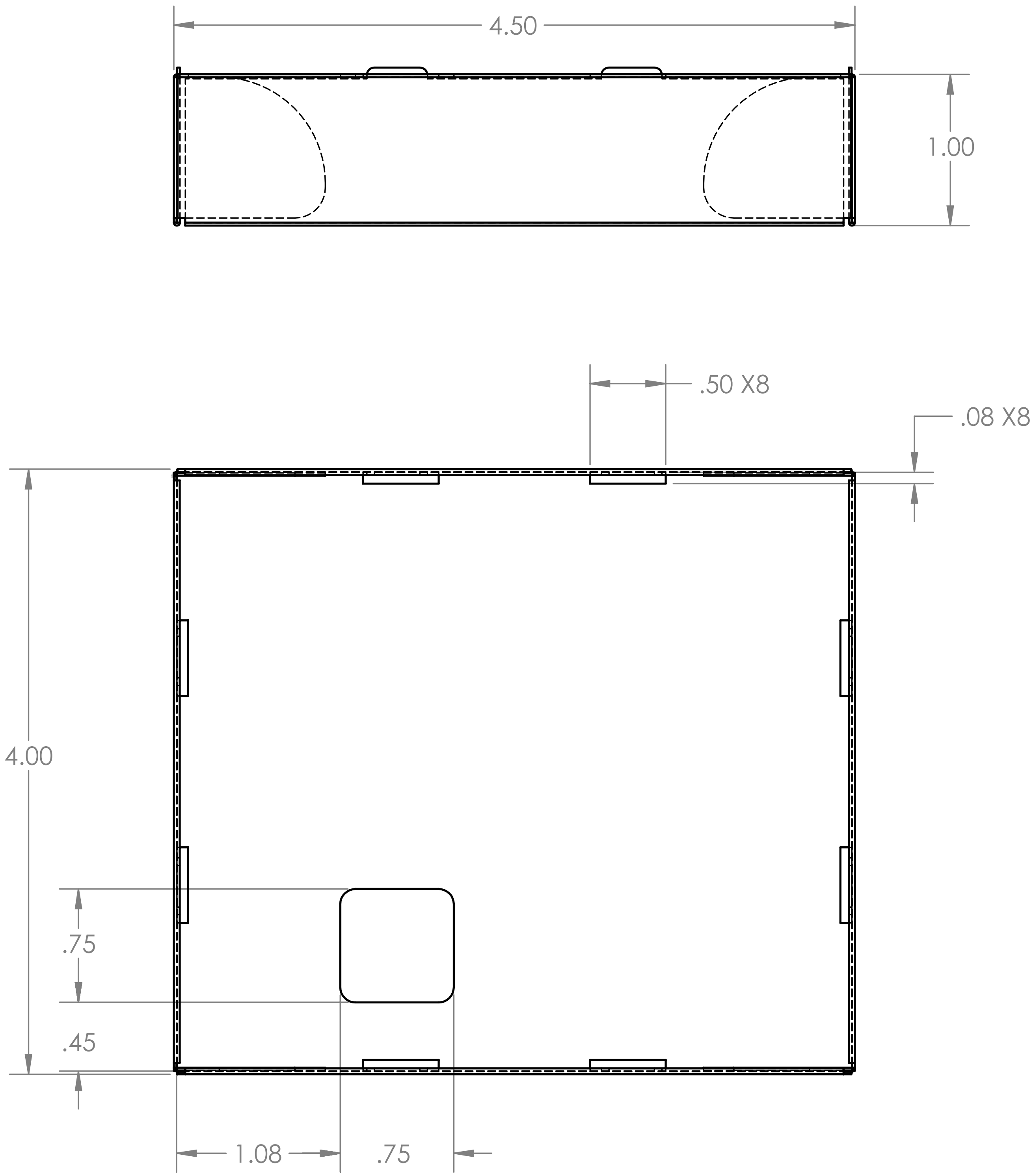


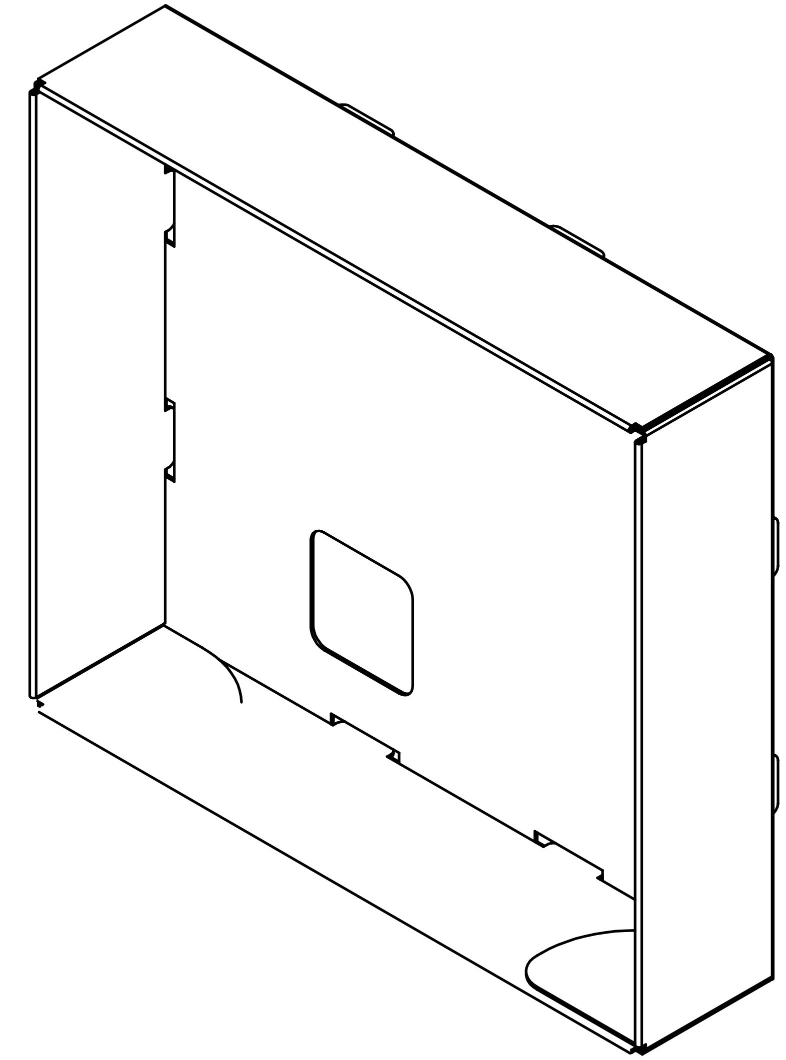
Cal Poly Mechanical Engineering	PN 111100	Title: ILLUMINATOR SHEATH		Drwn. By: EMRAN BARYAL
ME 430 - SPRING 20	Dwg. #: 3	Date: 5/28/2020	Scale:1:2	Chkd. By: ME STAFF



NOTES:
1. ALL DIMS. IN INCHES
2. TOLERANCES:
X.XX= ±0.01
ANGLES: ±1°
3. MATERIAL: 6-PLY PAPERBOARD

Cal Poly Mechanical Engineering	PN 111300	Title: ILLUMINATOR BOX		Drwn. By: EMRAN BARYAL
ME 430 - SPRING 20	Dwg. #: 4	Date: 5/28/2020	Scale:1:1	Chkd. By: ME STAFF

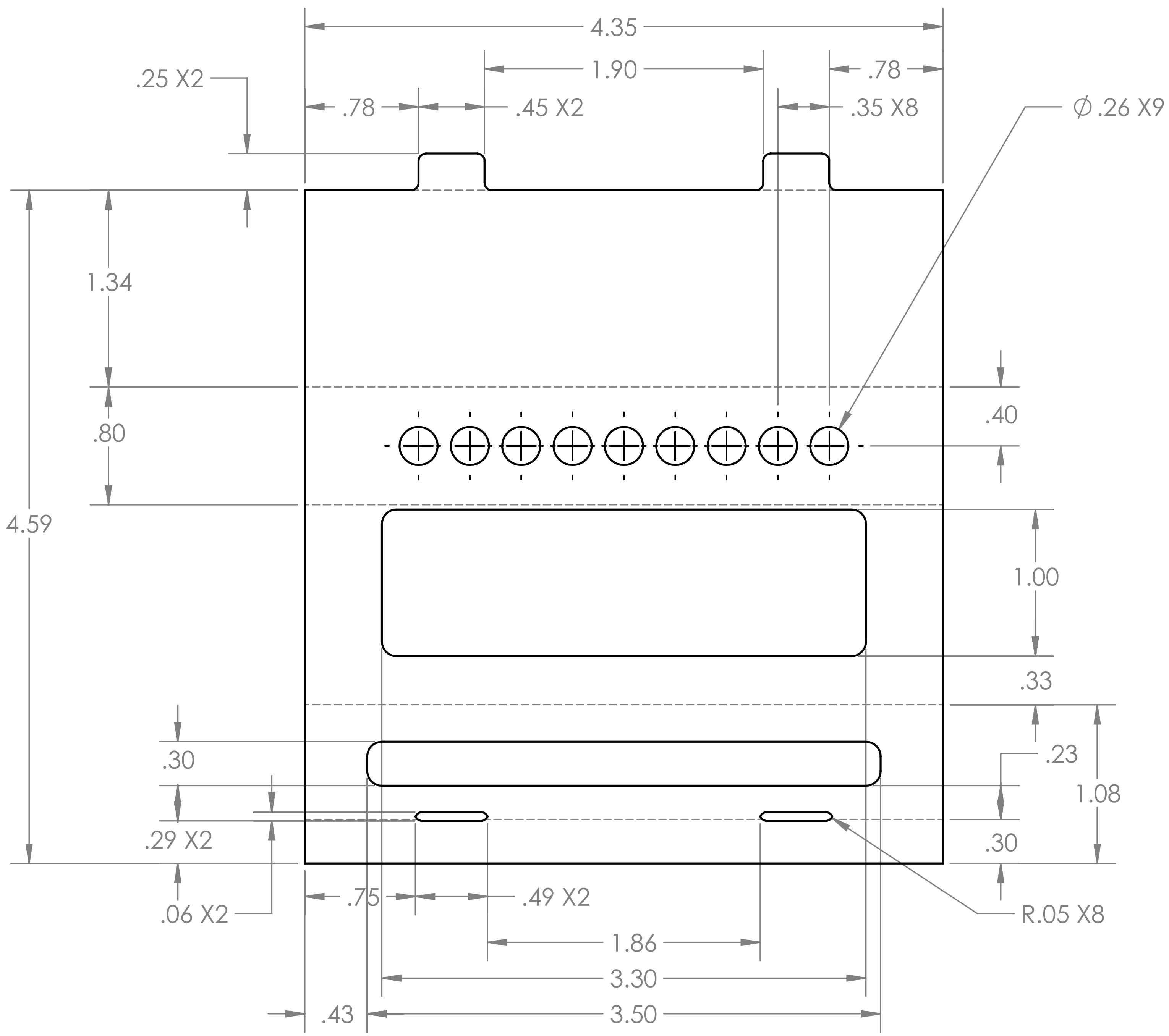




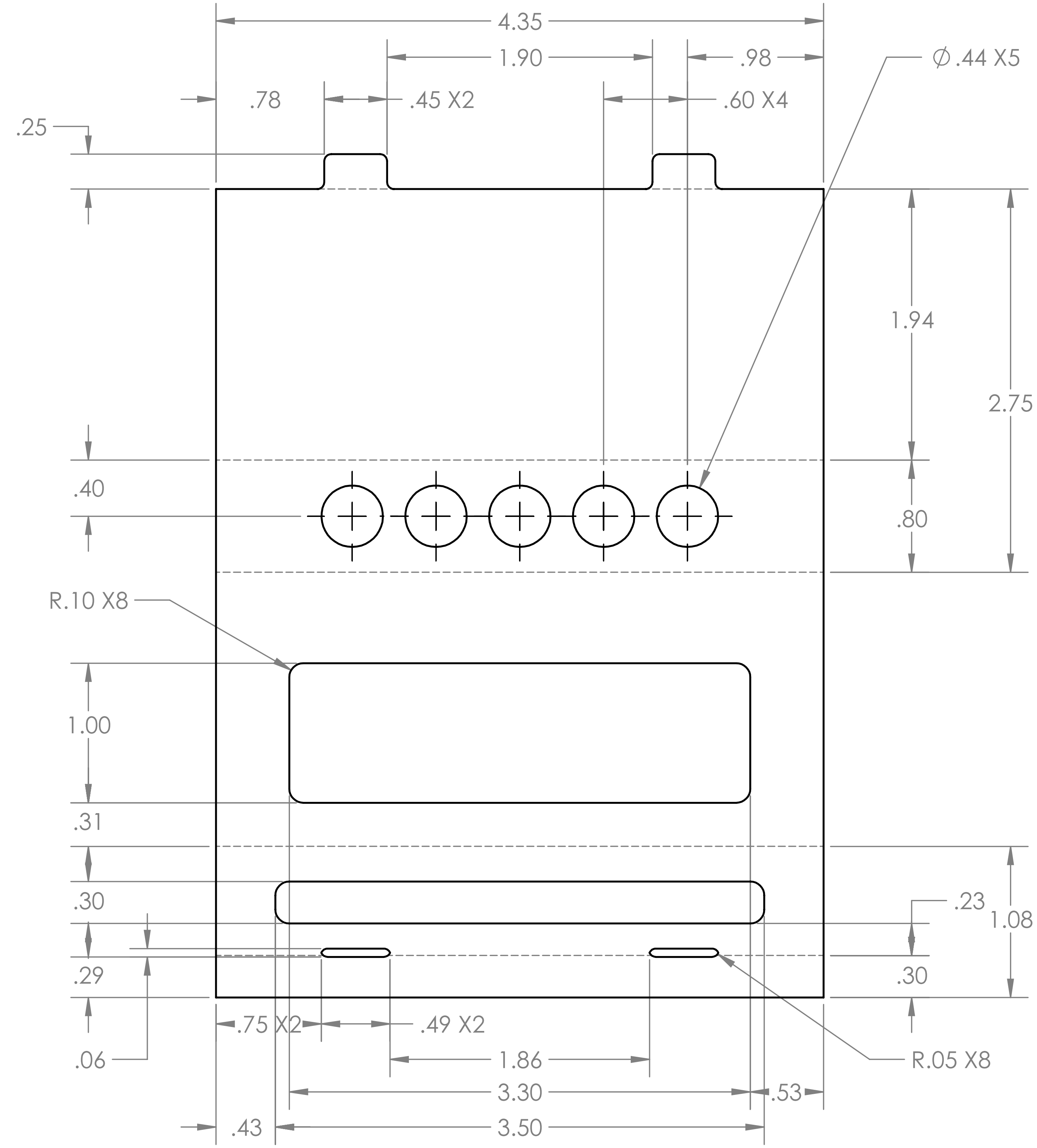
<u>NOTES:</u>
1. ALL DIMS. IN INCHES
2. TOLERANCES:
   X.XX= ±0.01
   ANGLES: ±1°
3. MATERIAL: 6-PLY PAPERBOARD

Cal Poly Mechanical Engineering	PN 111300	Title: ILLUMINATOR BOX		Drwn. By: EMRAN BARYAL
ME 430 - SPRING 20	Dwg. #: 4	Date: 5/28/20	Scale: 1:1	Chkd. By: ME STAFF

NOTES:
1. ALL DIMS. IN INCHES
2. TOLERANCES:
   X.XX= ±0.01
   ANGLES: ±1°
3. MATERIAL: 6-PLY PAPERBOARD



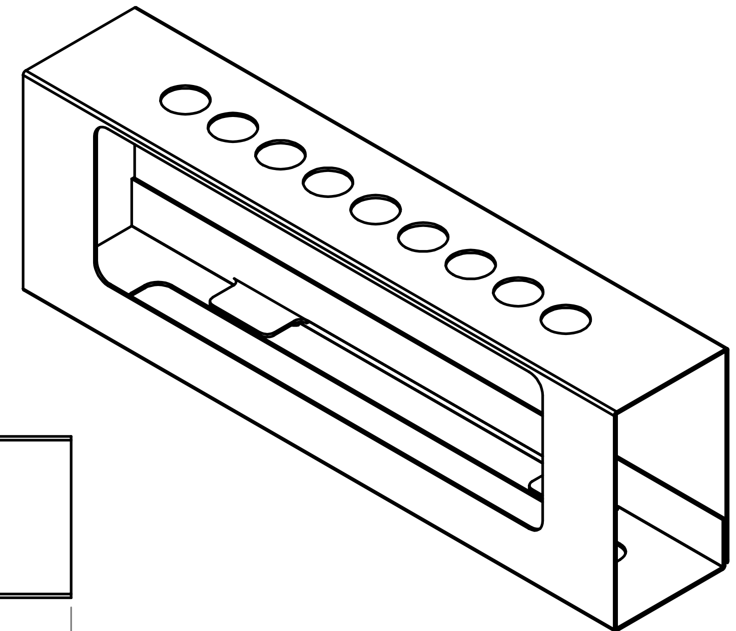
0.6 MILLILITER TEST TUBE STAND FLAT-PATTERN
PN 111311

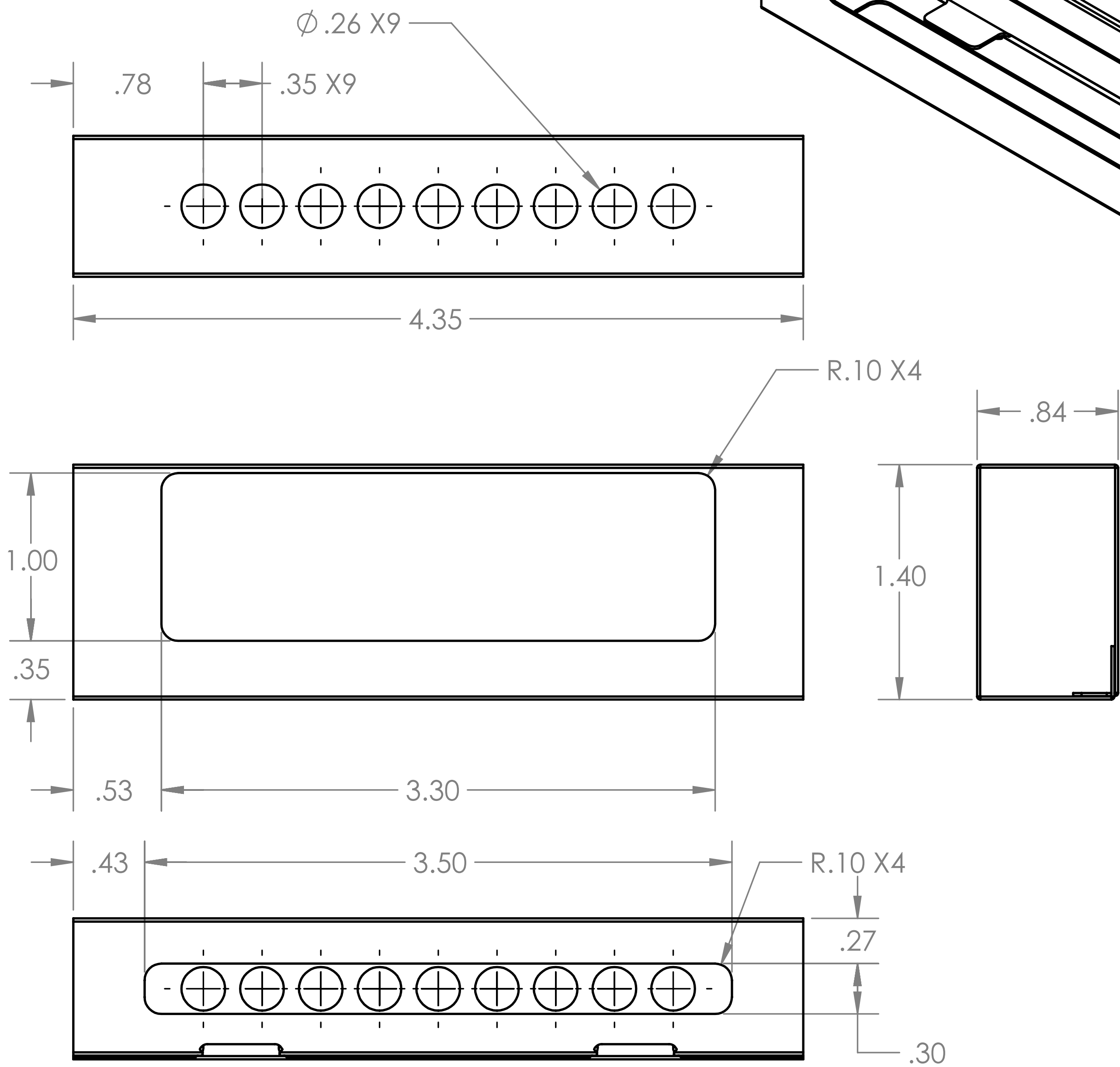


2 MILLILITER TEST TUBE STAND FLAT-PATTERN
PN 111312

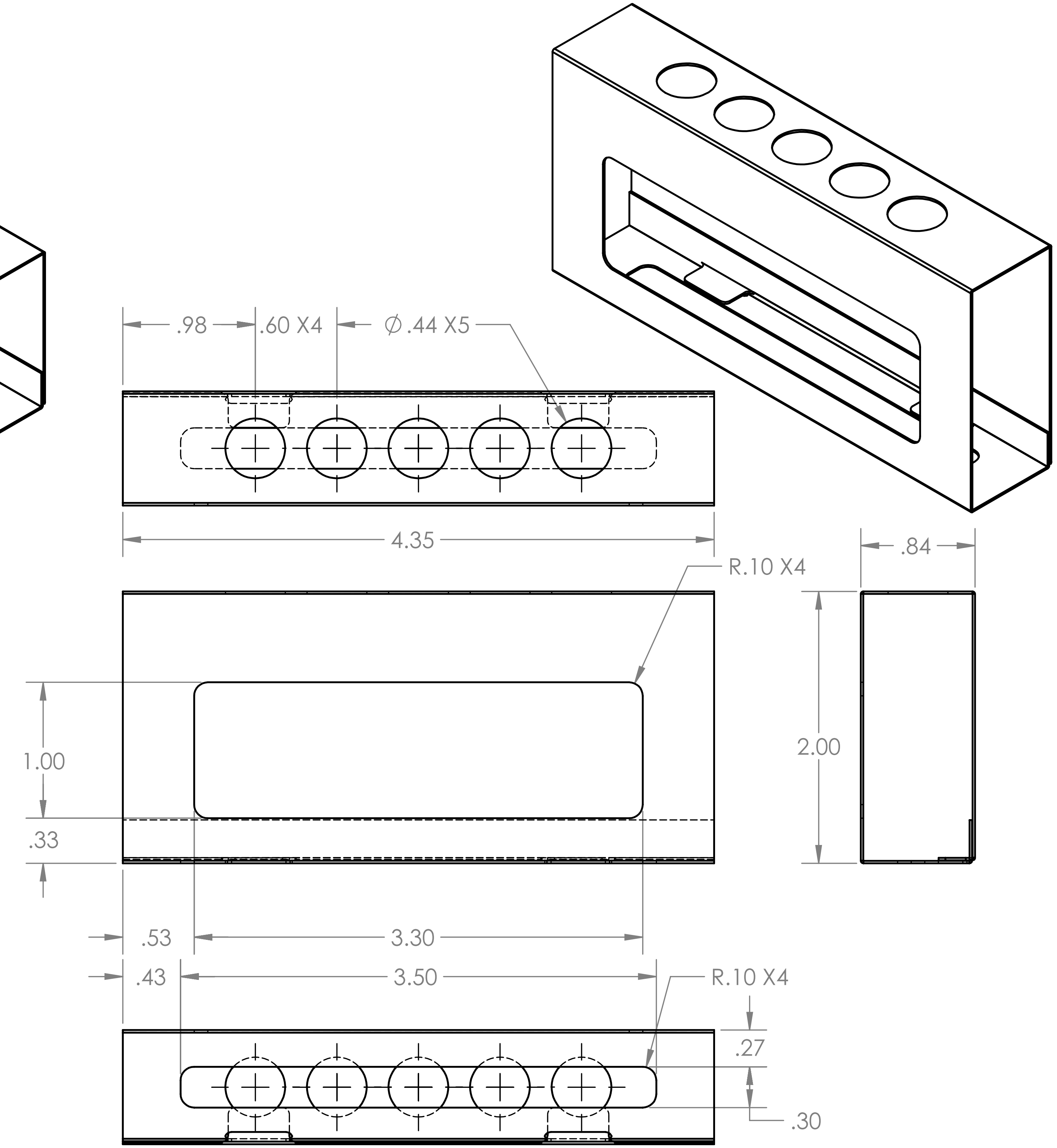
Cal Poly Mechanical Engineering	PN 111310	Title: ILLUMINATOR TEST TUBE STANDS		Drwn. By: EMRAN BARYAL
ME 430 - SPRING 20	Dwg. #: 5	Date: 5/28/2020	Scale:1:1	Chkd. By: ME STAFF

NOTES:
1. ALL DIMS. IN INCHES
2. TOLERANCES:
   X.XX= ±0.01
   ANGLES: ±1°
3. MATERIAL: 6-PLY PAPERBOARD





0.6 MILLILITER TEST TUBE STAND
PN 111311



2 MILLILITER TEST TUBE STAND
PN 111312

Cal Poly Mechanical Engineering	PN 111310	Title: ILLUMINATOR TEST TUBE STANDS		Drwn. By: EMRAN BARYAL
ME 430 - SPRING 20	Dwg. #: 5	Date: 5/28/20	Scale: 1:1	Chkd. By: ME STAFF

APPENDIX I: FAILURE MODES AND EFFECTS ANALYSIS

												Action Results			
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**Priority**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**
Lighting / Light Filter	filter falls off / gets lost	a) light is not filtered b) user's eyes are exposed to light	5	1) filter is dropped 2) filter is lost before assembly	1) secure filter with adhesive 2) secure filter with corner holder 3) rest filter on bottom of illuminator	5	user can see when filter is in place	2	50	secure filter with adhesive or other material inside the device to ensure it does not fall out	1/31/20	Filter secured with sturdy, double-sided tape	3	2	
Lighting / Illuminate Samples	light turns on when not in use	a) user's eyes are exposed to light/radiation b) battery runs out quickly c) user's eyes are impaired for a short while	4	1) light switch accidentally toggled 2) battery is installed with switch on 3) user wants to test lights	1) light switch connected to battery 2) light filter over lights	2	user can see when light is on/off	2	16						
	electrical components short out	device can no longer illuminate/use UV lighting system	4	1) overuse 2) power supplied cannot be handled by electrical components 3) inappropriate power source, not enough power	1) electrical power analysis 2) on-off switch to control power usage	4	electrical components do not work	6	96	design method to break circuit and not light up system until device is fully closed	1/31/20	two limit switches triggered by contact with door and on/off switch must all be engaged for lights to turn on, sheath must be in place	2	2	
	electrical components fall out	a) device can no longer illuminate/use UV lighting system b) electrical shock/user injury	5	1) tilting or dropping illuminator 2) components insecurely installed	1) "negative space" battery holder to anchor battery to device	4	battery is or is not in designated slot	2	40	secure electrical components with adhesives or other materials to prevent components falling out	1/25/20	electrical components secured by double-sided tape to removable panel, could also be super-glued if necessary	2	2	
Lighting / Quantify Glow Output	weak or no glowing signal	user cannot quantify any data	4	1) inappropriate LED UV wavelength 2) filter is too dark or too light to view glow appropriately 3) outside light is not blocked out enough	1) quantification with imageJ app 2) view signal with eyes	1	imageJ app	4	16						
Outer Casing / Collapsing	casing tears / deforms	a) the device cannot block out outside light b) sharp cuts c) device cannot be used to light or hold test vials	4	1) casing is stepped on 2) casing has been squished by heavy object 3) user tears by accident 4) casing is dropped 5) overuse	1) robust material 2) material deformation analysis	3	visual detection of tears	2	24						
Outer Casing / Folding	folds without tearing/rips	device falls apart, short device lifespan	4	1) user folds vigorously 2) consistent folding/unfolding of tabs/flaps 3) user tears by accident	1) robust material 2) slightly perforated lines at folding points	1	visual detection/ observation of device folding	5	20						

												Action Results			
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
	casing does not hold shape	a) device cannot block outside light b) results cannot be quantified	3	1) casing is stepped on 2) casing has been squished by heavy object 3) tabs to not fit 4) too many inner components to properly close device	1) tabs to hold shape	1	visual detection if illuminator is in full shape, if tabs are fully inserted	1	3						
Outer Casing / Hold Test Tubes	test tubes do not fit in device	a) no experiment can occur b) test tubes could fall out c) biomaterial spilling	3	1) incorrect hole size to hold test tubes 2) test tubes are wrong size to use with illuminator	1) holes for test tube rack that fit tube size 2) test tube rack connected to illuminator casing	1	fit test tubes in slot to check sizing	1	3						
Outer Casing / Assembly	casing too bulky to hold	a) user cannot hold device easily b) no portability	4	1) outer form is too fat and clunky 2) entire device is too heavy	1) minimization of device size 2) user testing	1	user testing, holding device to evaluate comfort	3	12						
	casing takes too long to assemble	a) user may find entire process unmanageable b) no experiments/tests conducted	2	1) casing has too many components 2) casing has confusing or unclear instructions 3) the material and components are missing	1) user testing	1	quick assembly tests	5	10						
Heating element / Heat Samples	device catches on fire	a) user is burned b) device is burned c) device cannot be used	9	1) heating element is left on for long period of time 2) heating element is in contact with flammable material 3) heating element is on when device is not used	1) electrical power analysis 2) on-off switch to control power usage 3) non-flammable material 4) keep heating element internalized	2	none	5	90	utiltize insulatory material with device around heating coil, use flame-retardant material	1/31/20	polyimide heater is resistive and small, will 9V supplied, the heater is not hot to the touch	3	2	
	reaction does not occur	a) no quantifyable data b) device is ineffective	4	1) heating element is not in contact or near test vials 2) heating element temperature change is insufficient	none	1	none	2	8						
	heating element turns on when not in use	a) device becomes fire hazard b) user gets burned c) electrical power wasted	7	1) power switch is accidentally toggled 2) negligent user 3) faulty heating element/switch	1) electrical power analysis 2) on-off switch to control power usage	4	none	3	84	design method to break circuit and not light up system until device is fully closed	1/31/20	two limit switches triggered by contact with door and on/off switch must all be engaged for lights to turn on, sheath must be in place	3	2	

APPENDIX J: INDENTED BILL OF MATERIALS

Portable Fluorescence Illuminator

Indented Bill of Material (iBOM)

Assembly Level	Part Number	Description	Qty	Cost	Ttl Cost	Source	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4					
0	100000	Final Assy				------	
1	111000	Outer Assembly				------	
2	111100	Sheath	1	0.13	0.13	Custom	Paperboard, cut from 11"x 24"
2	111200	Orange Light Filter	1	0.64	0.64	Amazon	Yellow Acrylic, 1/8" thick, 4" x 2"
2	111300	Box	1	0.08	0.08	Custom	Paperboard, 11"x 24"
3	111310	Test Tube Stand				------	
4	111311	Small Test Tube Stand	1	0.03	0.03	Custom	Paperboard, 11"x 24"
4	111312	Large Test Tube Stand	1	0.03	0.03	Custom	Paperboard, 11"x 24"
3	111320	Electrical Components				------	
4	111321	Blue LED light strip	1	1.45	1.45	Waveform Lighting	Blue LED light strip, 10 mm width, 3 inch length
4	111322	USB Heater	1	3.98	3.98	Ebay	5V, carbon fiber, 3.74" × 2.56"
4	111323	Battery	1	1.38	1.38	Amazon	9V
4	111324	Battery Housing	1	0.85	0.85	Amazon	9V snap connection with switch
4	111325	LED to Wire Connector	1	0.90	0.90	Amazon	10 mm LED strip, plastic
2	111400	Attachments				------	
3	111410	Velcro Dots (pair)	3	0.03	0.09	Amazon	0.75" diameter Velcro dots
	Total Parts		**13**		**9.56**		

APPENDIX K: PART SPECIFICATION SHEETS

[1] Waveform Blue LED Lights

[2] 4-Ply Black Railroad Board

[3] USB Heater Pad

[4] LED Strip to Wire Connectors

[5] 9-Volt Battery Holder

[6] Yellow Acrylic Light Filter

[7] Velcro Dots

[8] Cricut Materials

- a. Cricut Maker with Starter Package
- b. Cricut StandardGrip Machine Mat, 12” × 24”
- c. Cricut Deep Cut Blade and Housing

[1] Waveform Blue LED Lights

waveform lighting

PN: 7041

SimpleColor™ 12V LED Strip

SimpleColor™ LED strip lights are professional-grade lights that feature high light output in a fixed, single color. Available in a wide range of colors – violet, blue, green, amber, red – the LED strips do not require any controllers or dimmer systems to operate. Simply connect a 12V power supply (sold separately) and get just the color you need.

Premium color LEDs are mounted in a high density configuration of 36 per foot, providing 3x the brightness compared to RGB LED strips. The back side of the LED strip includes pre-applied 3M VHB® double-sided tape, which provides a simple but extremely strong adhesive mounting method for all of your projects.

The LED strips are 16.4 feet (5.0 meters) in length, and are conveniently reeled for quick and easy application, and can be cut to length every 1 inch (25 mm) with just a pair of scissors.

FEATURES

- Available in violet, blue, green, amber and red
- High brightness, single fixed color
- Plug and play ready with DC connector pre-mounted
- Runs on 12V constant voltage, power supply sold separately
- 4.5 W/ft (14.4 W/m)
- 4 oz copper circuitry for reduced voltage drop
- For indoor use only

PHOTOMETRIC SPECIFICATIONS

	Violet	Blue	Green	Amber	Red
Lumens per ft:	6 lm	88 lm	321 lm	185 lm	161 lm
Wavelength (peak):	415 nm	460 nm	525 nm	592 nm	630 nm
Wavelength (dominant):	430 nm	465 nm	530 nm	590 nm	623 nm
FWHM:	16.5 nm	19.5 nm	30 nm	15.5 nm	15.5 nm
CIE xy:	(0.1698, 0.0101)	(0.1391, 0.0490)	(0.1683, 0.7494)	(0.5811, 0.4181)	(0.6962, 0.3037)
WPE:	22%	33%	15%	9%	17%

Download full photometric reports at https://www.waveformlighting.com/photometrics

ELECTRICAL SPECIFICATIONS

Input type:	Constant Voltage
Input voltage:	12V DC
Current draw per ft:	365 mA @ 12V DC
Current draw per reel:	6.0 A @ 12V DC
Power draw per ft:	4.5 W @ 12V DC
Power draw per reel:	72 W @ 12V DC
Max run:	16.4 ft (5 meters)

MECHANICAL SPECIFICATIONS

Length:	16.43 ft (5008 mm)
Width:	0.394 in (10 mm)
Height:	0.067 in (1.7 mm)
LED spacing (OC):	0.327 in (8.3 mm)
Cut-line spacing:	0.984 in (25 mm)
PCB copper thickness:	2 oz
DC Connector (both ends):	18 AWG

POWER SUPPLY SELECTION

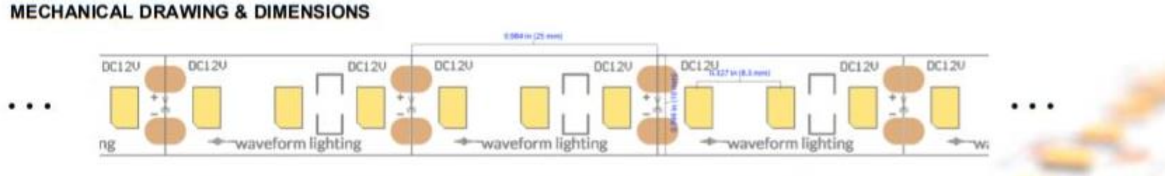
Compatible with Waveform Lighting PN 3091 or third-party 12V DC constant voltage power supply.

If you choose to utilize a third-party power supply unit, you will need to ensure that the power capacity of the power supply is sufficient for the length of LED strip being connected. Use the table below to determine if the power supply is sufficient for your project.

Length	Minimum Power Supply Capacity
1 ft:	400 mA / 5.3 W
3 ft:	1.3 A / 16 W
6 ft:	2.6 A / 32 W
9 ft:	4.0 A / 47 W
12 ft	5.3 A / 63 W
16.4 ft	7.2 A / 86 W

Length	Minimum Power Supply Capacity
0.5 m:	720 mA / 8.6 W
1.0 m:	1.4 A / 17 W
2.0 m:	2.9 A / 35 W
3.0 m:	4.3 A / 52 W
4.0 m:	5.8 A / 69 W
5.0 m:	7.2 A / 86 W

MECHANICAL DRAWING & DIMENSIONS



(This drawing is an excerpt that shows just three complete, cuttable sections. Each reel consists of 200 of these sections).

PART NUMBERS AND ORDERING

Violet:	7041.415	**Amber:**	7041.592
Blue:	7041.460	**Red:**	7041.630
Green:	7041.525		

Document Number: CS7041
Rev Version 1.0 / 10-23-2018

www.waveformlighting.com

This datasheet is subject to change without notice.

Source: https://www.waveformlighting.com/datasheets/CS_7021.pdf

[2] 4-Ply Black Railroad Board

School Smart 1485728 Railroad Board, 4-ply Thickness, 22" x 28", Black (Pack of 25)

by School Smart

9 ratings

Amazon's Choice for "black poster paper"

Price: $17.76 prime & FREE Returns

Product description

Size:**22 x 28 Inches**

School Smart 4 Ply Railroad Boards are black and measure 22 x 28 inches. It is the ideal choice for any creative project. The boards are black on both sides with a smooth uniform finish. They are perfect for construction, art projects, mats, mounting, block printing, painting, markers, stenciling and posters. Sold as 25 per pack.

Product information

Size:**22 x 28 Inches**

Technical Details

Manufacturer	ROSELLE PAPER INC
Brand Name	School Smart
Item Weight	4.5 ounces
Product Dimensions	28 x 22 x 0.03 inches
Item model number	1485728
Color	Black
Material Type	Paper
Number of Items	25
Size	22 x 28 Inches
Manufacturer Part Number	1485728

Additional Information

ASIN	B00PEFCCJ8
Customer Reviews	9 ratings 4.4 out of 5 stars
Best Sellers Rank	#11,934 in Office Products (See Top 100 in Office Products) #19 in Poster Boards
Date First Available	November 2, 2014

Warranty & Support

Product Warranty: For warranty information about this product, please click here

Feedback

If you are a seller for this product, would you like to **suggest updates through seller support**?
Would you like to **tell us about a lower price**?

Source: https://www.amazon.com/School-Smart-1485728-Railroad-Thickness/dp/B00PEFCCJ8/ref=sr_1_8?dchild=1&keywords=black+pac5460+4-ply+railroad+board%2C+white%2C+22%22+x+28%22%2C+100+sheets&qid=1587504770&sr=8-8

[3] USB Heater Pad

5V Portable USB Heating Heater Winter Warm Plate For DIY Shoes Gloves Pad Mat

Condition: **New**

Quantity: 1 More than 10 available / 96 sold

Price: **US $3.89**

Buy It Now

Add to cart

Add to Watchlist

3-year protection plan from SquareTrade - $1.99

Shop with confidence

eBay Money Back Guarantee
Get the item you ordered or get your money back. Learn more

Seller information
surprise-7 (50142 ★)
99.1% Positive feedback

Save this Seller
Contact seller
Visit store
See other items

5V Portable USB Heating Heater Winter Warm Plate For Shoes Gloves Pad Mat DIY

Description:

- Features:
  Plug and play: easy and convenient to use. you can put it in your shoes, gloves, mouse pad and so on.
  Lightweight and portable, convenient to take with for outdoor camping or other activities on winters.
  Also applicable to the people who are afraid of coldness, and they will do not fear of winter any more with it.
  Note: This product is Plug and Play, without switch.
  USB Heating Plate only, other accessories demo in the picture is not included.
- Specification:
  Input voltage: 5V
  Surface Temperature: 40~45 Celsius / 104~114 Fahrenheit
  Material: Carbon Fiber
  Size: app.9.5x6.5cm/3.74x2.56in
  Cable Length: app.103cm/40.55in
  Color: As the picture shown
  Quantity: 1 Pc
- Note:
  No retail package.
  Please allow 0-1cm error due to manual measurement. pls make sure you do not mind before you bid.
  Due to the difference between different monitors, the picture may not reflect the actual color of the item.
  Thank you!

Package includes:

- 1 x USB Heating Plate

Source: https://www.ebay.com/itm/5V-Portable-USB-Heating-Heater-Winter-Warm-Plate-For-DIY-Shoes-Gloves-Pad-Mat/173788708266?hash=item28769d3daa:g:LGEAAOSwl7pcYTlB

[4] LED Strip to Wire Connector

QIJIE 10mm 5050 LED Strip Connector 2 Pin for Non-waterproof Single Color Tape Light, Snap Splicer for Board-To-Wire (22,20,18 Gauge), Pack of 10 (No Wire)

by QIJIE

16 ratings

Price: $8.98 prime & FREE Returns

Get $70 off instantly: Pay $0.00 ~~$8.98~~ upon approval for the Amazon Prime Rewards Visa Card. No annual fee.

Color: **10mm 2 Pin, Strip to Wire**

Size: **For Both IP20 and Silicon Waterproof IP65**

For Both IP20 and Silicon Waterproof IP65 | For Epoxy/PU Waterproof IP65 Only

- This 10mm 5050 LED Strip Connector has 2 end, one end for strip light and another end for extension wire (22,20,and 18 AWG), easily DIY lead connector wire or strip-to-strip-bridge (jumper) with any length.No need stripping wire insulation before connection (pierce-to-contact), easily connect your led strip to power or dimmer without any soldering, just a pliers needed
- Widely applicable for IP20 Non-waterproof tape light like 10mm SMD5050 /5630 /2835 /5730 in different LED density ranging 30~90 LEDs per meter
- Clear Cap that will not mask light of first SMD thus hardly see dark area in your lighting space. Make lighting effect more uniform
- Powerful with as much as total 5A current supported, allow you to connect longer LED strip by one connector,reducing cost and connection work
- The pin will go through PCB from BACK of strip, which can grip strip light tightly and wire-end blade go through insulation to contact conductor inside cable, you never worry strip light or wire moving out of connector. Even workable to strip light with 3M VHB red foam adhesive tape

Product description

Color:**10mm 2 Pin, Strip to Wire** | Size:**For Both IP20 and Silicon Waterproof IP65**

A 2 pin solderless 5050 flexible strip light connector terminal mainly designed to link no-waterproof strip light to 2 conductor extension wire. No need stripping wire insulation and you can determine wire gauge and length as you want in linear lighting project with this connector.Powerful,reliable,safe and easy to use. Free you from difficult and dangerous soldering iron operation.

1)LED Strip Type It Can Work With

1. Normal **10mm single color LED strip** like SMD5050 /5630 /2835 /5730 ranging 30~90 diodes per meter
2. Other **IP20 rated LED tape light 10mm with 2 solder pad**
3. **Ultra slim PURE SILICON COATING waterproof strip light (Total Height<2.7mm):** no need stripping glue layer before connection, same operation as non-waterproof strip light but with bigger pressure to cap

2)Package Include

5050 LED Strip Connector 10mm 2 Pin IP20:10 PCS

Kindly Note: this package does not include any wire, you can purchase wire via below link

Black-Red 6 Meter 20AWG with fixing clips: http://www.amazon.com/dp/B01L3DYWCE

3)Tools Needed

A pliers
A scissor will make work more efficient. (cut wire and strip light)

4)Technical Data

Working Voltage:Below 24V
Max Current of Pin: 5A
Pin Quantity: 2 pin
Workable Wire Gauge: 22~18AWG / 0.34~0.78 ㎜2
Workable Strip Light Width: 10mm
Workable PCB Thickness:0.2~0.35 mm
Working Ambient TEMP.: -20~50℃
Heat Resistance:105℃
Connector Dimension: 24.3*14.6*7.7 mm

Source: https://www.amazon.com/gp/product/B01MT50ZCZ/ref=ppx_yo_dt_b_asin_title_o02_s00?ie=UTF8&psc=1

[5] 9-Volt Battery Holder

LAMPVPATH (Pack of 5) 9v Battery Holder, 9 Volt Battery Holder with Switch, 9v Battery Case with Switch

by LampVPath

64 ratings

Amazon's Choice for "9v battery holder with switch"

Price: $8.99 ✓prime FREE Same-Day & FREE Returns

Get $70 off instantly: Pay $0.00 ~~$8.99~~ upon approval for the Amazon Prime Rewards Visa Card. No annual fee.

Free Amazon product support included

- Battery Holder Type: 9v battery holder with switch, 9v battery holder with on off switch
- Battery Holder Voltage Output: 9V, 1 x 9v battery holder= 9 volt battery holder with leads; Battery Holder Switch Function: ON/OFF switch on 9 volt battery case holder
- 9 Volt Battery Holder Dimensions: (L*W*H)/2.657" x 1.299" x 0.835"/6.75cm x 3.30cm x 2.12cm
- Wire Leads: 9v battery holder with leads, tinned wire end; Wire Length: 5.8"/14.8cm; Cable Diameter(count in the PVC isolation around the wire): 0.0433"/1.1mm; Cable Color: red and black
- One 9v Battery Holder and One Screw Weight: 0.674oz/19.1g; Package Contents: 5Pcs battery holder 9v, 5Pcs screws for 9 volt battery holder with switch

Product description

Brand Name: LAMPVPATH

Specification:
<1>Battery Type: 9v battery holder with switch, 9v battery holder with on off switch
<2>Battery Holder Voltage Output: 9V, 1 x 9v battery holder= 9 volt battery holder with leads
<3>9v Battery Holder Switch Function: ON/OFF switch on 9 volt battery case holder
<4>9 volt Battery Holder with Leads: 9v battery holder with leads, tinned wire end
<5>Wire Length of 9v Battery Holder: 5.8"/14.8cm
<6>Cable Diameter(count in the PVC isolation around the wire): 0.0433"/1.1mm
<7>Battery Holder Cable Color: red and black
<8>Dimensions of 9 Volt Battery Holder with Switch:(L*W*H)/2.657" x 1.299" x 0.835"/6.75cm x 3.30cm x 2.12cm
<9>Weight of 9v Battery Case with Switch: 0.674oz/19.1g (one 9v battery holder and one screw weight)
<10>Box Color of 9v Battery Holder with Switch: black
<11>Material of 9 volt Battery Case Holder: Plastic ABS
<12>Screw Size: 0.303" x 0.0787"/7.7mm x 2.0mm(Length*Diameter)

Package Contents:
5x 9v battery holder with on off switch
5x screw for 9 volt battery holder

Source: https://www.amazon.com/LAMPVPATH-Pack-Battery-Holder-Switch/dp/B07BXBS93X/ref=sr_1_2_sspa?keywords=9V+battery+holder&qid=1581012970&sr=8-2-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzQzYyR0FPQjQ2TFVIJmVuY3J5cHRlZElkPUEwNzU3MjMzM0hDVlBKTEFTQzVITCZlbmNyeXB0ZWRBZElkPUEwMjcxMjczMlVDSDdLNVBPTElSNiZ3aWRnZXROYW1lPXNwX2F0ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU=

[6] Yellow Acrylic Light Filter

Brand: acrylandUSA

Cast Acrylic Sheet - .118" Thick, TP Yellow, 12" x 12" Nominal

11 ratings | 6 answered questions

Price: $11.55 FREE Shipping on orders over $25.00 shipped by Amazon or get **Fast, Free Shipping** with Amazon Prime

New (3) from $11.55 & FREE Shipping on orders over $25.00

Specifications for this item

Brand Name	acrylandUSA
Item Shape	Square
Item Thickness	0.118 inches inches
Material	Acrylic
Measurement System	Inch
Specification Met	
UNSPSC Code	60120000

See more product details

Share

$11.55

FREE Shipping on orders over $25.00 shipped by Amazon or get **Fast, Free Shipping** with Amazon Prime

Want it Friday, May 22? Choose **Two-Day Shipping** at checkout. Details

In Stock.

Qty: 1

Add to Cart

Buy Now

Your transaction is secure

Sold by acrylandUSA and Fulfilled by Amazon.

Product features

- The linear dimensions of our sheets are nominal and they have a tolerance of +-1/8" in each direction (length and width). Therefore the dimensions you request will be within the tolerance stated

Product description

Acrylic sheet offers superb optical clarity and optimum performance that cannot be matched at any price. Cast from premium materials, these cell cast acrylic sheets allow precision manufacturing applications to meet a wide range of specifications. Whether it's cutting, drilling, routing, cementing, polishing or thermoforming, Acrylic is a tough product to rival. The advanced technology also assures superior resistance to weathering and crazing.

Product details

Product Dimensions: 12 x 12 x 0.1 inches
Shipping Weight: 12 ounces (View shipping rates and policies)
ASIN: B006FLYKF4
Customer Reviews: 11 customer ratings
Amazon Best Sellers Rank: #30,648 in Industrial & Scientific (See Top 100 in Industrial & Scientific)
#125 in Plastic Sheets

Source: https://www.amazon.com/Cast-Acrylic-Sheet-Yellow-Nominal/dp/B006FLYKF4/ref=psdc_11260350011_t1_B006FLYLKS

[7] Velcro Dots

Strenco 3/4 Inch - Pack of 500 Sets - Adhesive Hook and Loop Dots - White - 1000 PCS - 20 mm Coins

by Strenco

161 ratings | 3 answered questions

Amazon's Choice for "strenco 3/4 inch pack of 500 sets adhesive hook and loop dots"

Price: $10.25 prime FREE One-Day & FREE Returns

- 3/4 inch wide Hook and loop Dot Coins Self Adhesive by Strenco great for Fastening
- Hook and loop 500 sets (1000 pcs) of each side side. Strenco double sided hook and loop straps
- Sticks on glass, wood, plastics and other clean, flat surfaces. Great for light weight items like laminating sheets.
- Mounting tape on which is great as a office supply, organization, classroom wall art stickers, poster paper hanging, remote controls, scissors, educational printable thermal laminator sheets, and much more
- For more strength use more dots.

Source: https://www.amazon.com/Hook-Loop-Dots-White-Sets/dp/B01M5ASDBH/ref=sr_1_1_sspa?%20keywords=velcro+dots&qid=1581013042&sr=8-1-spons&psc=1&spLa=%20ZW5jcnlwdGVkUXVhbGlmaWVyPUFCQTdMR1MzT0wwTkkmZW5jcnlwdGVkSWQ9QTAwOTEyNjUyU1ZUMzRUM0RLNklOJmVuY3J5cHRlZEFkSWQ9QTA2ODQxNDlUNTNJN1YzQVVTTFEmd2lkZ2V0TmFtZT1zcF9hdGYmYWN0aW9uPWNsaWNrUmVkaXJlY3QmZG9Ob3RMb2dDbGljaz10cnVl

[8] Cricut Materials

a. Cricut Maker with Starter Pack

Cricut Maker® Machine, Champagne

$369.99 ~~$399.99~~

Description

Meet Cricut Maker, the ultimate smart cutting machine. With the ability to use more advanced tools, Cricut Maker gives you the freedom to make virtually any DIY project you can imagine, from 3D art to home decor, jewelry, iron-on, vinyl, paper projects, and so much more. It has the tools to cut hundreds of materials quickly and accurately, from the most delicate paper and fabric to the tough stuff like matboard, leather, and basswood. Use the Rotary Blade to cut fabric for a sewing project — without backing material. Switch to Knife Blade (sold separately) and cut thicker and denser materials for added dimension and depth. Or quickly switch between scoring, engraving, debossing, and other decorative effects with a variety of specialty tips (sold separately). Featuring unique cutting versatility, a huge library of design ideas, sewing patterns available instantly, and easy-to-use apps, Cricut Maker delivers professional-level cutting performance that anyone can use.

Features

- The ultimate in professional-level cutting performance and versatility
- Cuts 300+ materials, from the most delicate fabric and paper to matboard and leather
- Rotary Blade for cutting virtually any fabric without backer
- 500+ digital sewing patterns and quilt blocks available from Simplicity®, Riley Blake™, and more (sold separately)
- Compatible with Knife Blade for thicker materials up to 2.4 mm (sold separately)
- Compatible with QuickSwap™ tools to quickly switch between scoring, engraving, debossing, and other decorative effects (sold separately)
- Compatible with Washable Fabric Pen for marking pattern pieces (sold separately)
- Adaptive Tool System™ for professional-level cutting performance and expandability
- Bluetooth® wireless technology
- Fast Mode for up to 2X faster cutting and writing
- Design Space® software for iOS, Android™, Windows®, and Mac®

Included

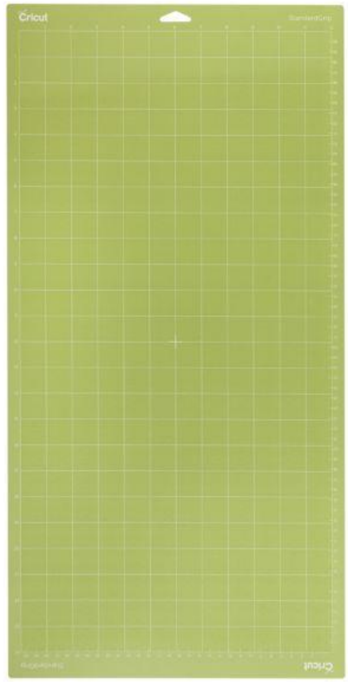
- Cricut Maker machine
- Rotary Blade + Drive Housing
- Premium Fine-Point Blade + Housing
- Fine Point Pen, Black
- FabricGrip™ Machine Mat, 12" x 12" (30.5 cm x 30.5 cm)
- LightGrip Machine Mat, 12" x 12" (30.5 cm x 30.5 cm)
- Welcome Book
- USB cable
- Power adapter
- Free trial membership to Cricut Access™ (for new subscribers)
- 50 free ready-to-make projects, including 25 sewing patterns
- Materials for a practice project

Source: https://cricut.com/en_us/machines/cricut-maker/cricut-makerr-machine-champagne.html#product_detail

b. Cricut StandardGrip Machine Mat, 12” × 24”

StandardGrip Machine Mat ,12" x 24" (2 ct)

$17.19 ~~$21.49~~



Details

Description

Perfect for heavy cardstock, patterned paper, vinyl, iron-on, and more, the StandardGrip Mat was carefully engineered for a wide range of medium-weight materials. As the interface between your material and your Cricut machine, each reusable mat holds your material in place as it's cut, and makes it easy to cleanly remove finished pieces once a cut is complete. Each mat is formulated to ensure the best possible adhesion and the longest possible life. With two mats included, you can load one in your Cricut machine for cutting as you prep the next. For use with Cricut Maker® and Cricut Explore® cutting machines.

Tips:
Keep the clear film cover on the mat when storing to keep mat free from paper scraps and dust.
Use the scraper to scrape away excess pieces and the spatula to carefully remove cut images.
To ensure best performance, use the recommended material types on the mats.

Features

- 2 reusable machine mats 12" x 24" (30.5 cm x 61 cm)
- Use to cut heavy cardstock, iron-on, vinyl, and more
- Formulated for best possible adhesion and longest life
- For Cricut Maker® and Cricut Explore® cutting machines
- Now made with water-based paint and adhesive

Source: https://cricut.com/en_us/standardgrip-machine-mat-12-x-24-2-ct.html

c. Cricut Deep Cut Blade and Housing

Cricut® Explore® Deep Cut Blade & Housing

Item # D032562S, # 10307856

★★★★★ 5.0 (4) Write A Review

$34.99

Free Shipping on your entire online order when you buy $35 or more in Cricut Accessories See Details

Cut deep with precision using the Cricut® Deep Cut Blade & Housing. The blade cuts thick materials including fabrics and poster boards with ease. It comes with a protective housing to cover when not in use. Simply slice through different materials to get accurate shapes.

Details:

- Cuts through thick material
- Compatible with Cricut® Explore
- Includes a blade with housing

Source: https://www.michaels.com/cricut-explore-deep-cut-blade-and-housing/D032562S.html?cm_mmc=PLASearch-_-google-_-MICH_Shopping_US_N_Cricut_N_Smart_N_N-_-&Kenshoo_ida=&kpid=go_cmp-9982987110_adg-98032308662_ad-433378147596_pla-62755688467_dev-c_ext-_prd-D032562S&gclid=CjwKCAjw5Ij2BRBdEiwA0Frc9cOdDpGycnvNdQKsz0349Ws-bQ8stshtLj_WoTD_0O8t5I1BxBRyQRoCbUIQAvD_BwE

APPENDIX L: TOTAL MATERIAL BUDGET AND BAKER-KOOB EXPENSES

Baker Koob Expenditures

Item Description	Cost	Qty.	Tax/Shipping	Total Cost	Purchased by	Date Purchased
Foam Core Board	$2.00	2	Included in cost	$4.00	Emran	10/27/2019
Peltier Plate Heater from Amazon	$6.63	1	Included in cost	$6.63	Emran	1/28/2020
Kapton Heaters	$19.69	1	Included in cost	$19.69	Emran	1/31/2020
Waveform UV Light Strips, 3 ft	$37.54	1	Included in cost	$37.54	Emran	1/27/2020
Waveform 460nm Blue LEDs	$130.69	1	Included in cost	$130.69	Emran	2/12/2020
USB Heating Plate Heater Winter Warm Plate	$6.02	1	Included in cost	$6.02	Emran	2/13/2020
Project Board	$7.53	1	Included in cost	$7.53	Emmett	2/17/2020
Cricut Machine + tools	$425.60	1	Included in cost	$425.60	Emmett	3/6/2020
Poster Board Assorted and Masking Tape	$4.99	1	Included in cost	$4.99	Emmett	3/6/2020
Cricut Deep Cut Blade, Black	$27.84	1	$10.06	$37.90	ME Dept.	5/5/2020
Cricut Scoring Stylus	$17.98	1	$8.08	$26.06	ME Dept.	5/5/2020
Cricut 12x24in Mat (3pack)	$17.99	1	$8.23	$26.22	ME Dept.	5/5/2020
490nm Blue LED strip	$95.00	1	$28.80	$123.80	ME Dept.	5/5/2020
9V batteries (Amazon Brand)	$10.99	10	$7.22	$182.10	ME Dept.	5/5/2020
9V battery holder (LAMPVPATH)	$8.99	16	$7.07	$256.96	ME Dept.	5/5/2020
4ply (22"x28") Railroad Board (25pack)	$11.92	4	$6.21	$72.52	ME Dept.	5/5/2020
USB heaters	$3.89	80	$0.30	$335.20	ME Dept.	5/5/2020
Filter Sheets	$10.99	7	$7.47	$129.22	ME Dept.	5/5/2020
Velcro Dots	$11.48	1	$7.25	$18.73	ME Dept.	5/5/2020
LED to Wire Connectors	$8.98	8	$7.07	$128.40	ME Dept.	5/5/2020

Total	$1,979.80
Grant Remaining	$71.14

APPENDIX M: MANUFACTURING PLAN

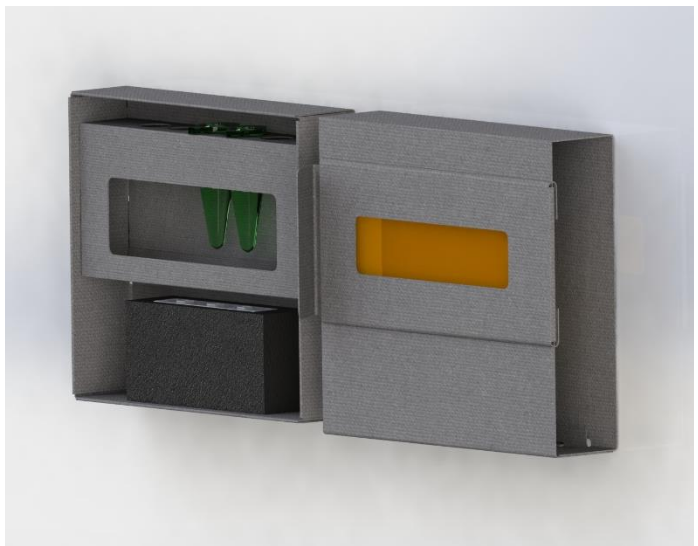
Manufacturing Plan: Portable Fluorescence Illuminator				
Step	**Components**	**Purchased or Made from Scratch**	**Operation**	**Operation Limitations**
1	Paperboard	Purchased	Use Cricut Maker to cut pieces using Cricut Design file for sheath, box, and test tube stands with the Cricut Deep Cut Blade and Scoring Pen	Done by user/machine, only one at a time
2	Blue LED Strips	Modified from purchase	Cut to appropriate size and connecting to LED strip-to-wire connectors	No limitations
3	9V Battery	Purchased	Place in battery holder	No limitations
4	9V Battery Holder	Modified from purchase	Connect to LED strip-to wire connectors, attach case to Velcro dots	No limitations
5	LED Strip to Wire Connector	Purchased	Connect to LED strip and to wires from 9V battery holder	No limitations
6	Heating Element	Purchased	Attach to Velcro dots	No limitations
7	Light Filter	Modified from Purchase	Cut acrylic sheets into 4” × 2” rectangles	Need chop saw

APPENDIX N: ILLUMINATOR OPERATIONS MANUAL

Sections:

1. Manufacturing
2. Assembly
3. Operations

PORTABLE FLUORESCENCE ILLUMINATOR OPERATIONS MANUAL



June 4, 2020

The Illuminators

Emran Baryal

Katherine Hui

Emmett Lambert

For Dr. Javin Oza, Cal Poly Department of Chemistry and Biochemistry

Table of Contents

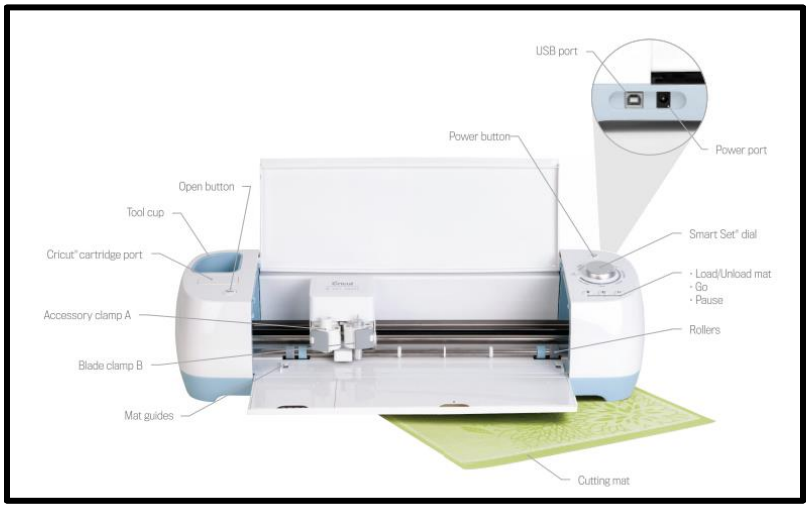
Manufacturing Instructions

Tools/Materials:

Sheath/Box/Test Tube Stands	Electrical Components
Cricut Maker	Blue LED light strip, 460nm”
Cricut 24” × 12” Mat	LED strip-wire connectors
Cricut Deep Point Blade	9V battery
Cricut Scoring Pen	9V battery holder
6-ply Railroad Paperboard	USB Heater
2”x4” Yellow Transparent Acrylic Filter	Velcro Dots

1. The Cricut

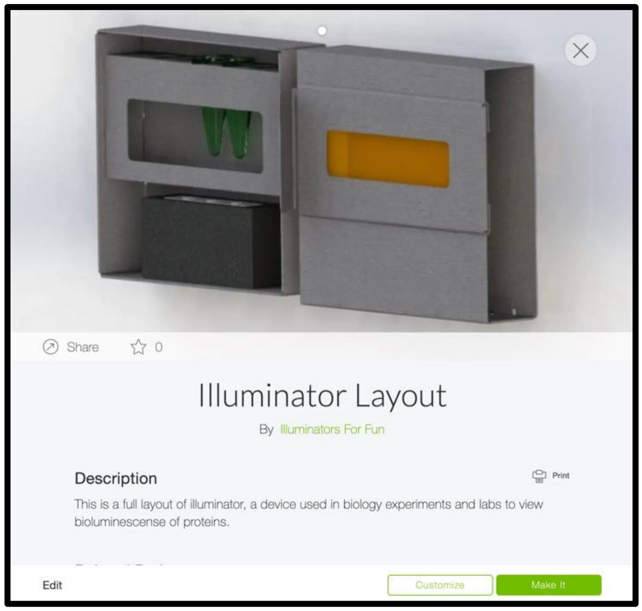
1a. Plug in the power cable to the back of the Cricut and press the Power Button to power on the Cricut.



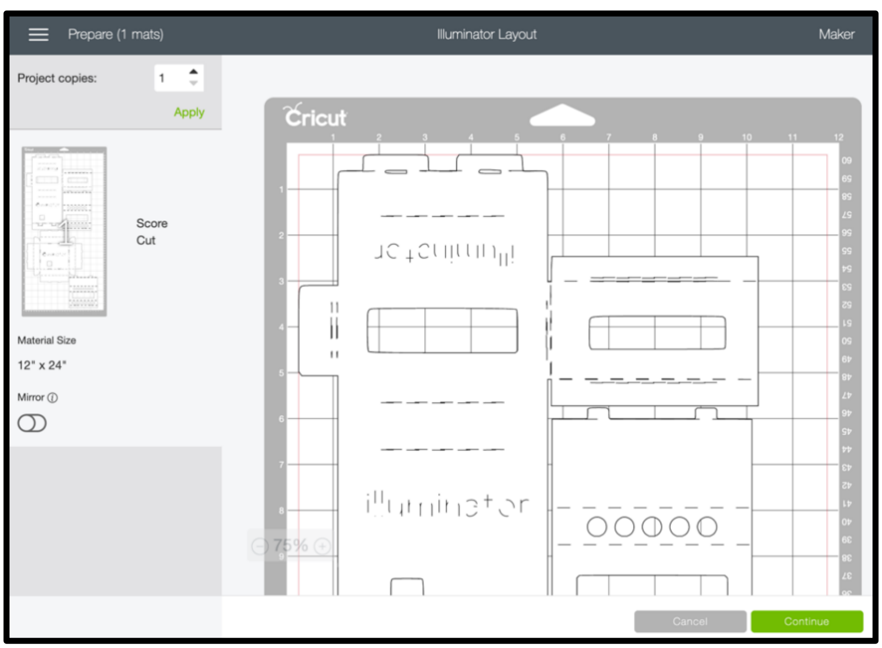
1b. On your laptop’s browser, copy and paste the following link which will direct you to download and set up the Cricut software:
https://design.cricut.com/#/launcher

1c. Once you have created an account and set up the Cricut design space on your laptop, copy and paste the following link to your browser which will direct you to the illuminator’s cutout program.
https://design.cricut.com/landing/project-detail/5ebcc051068e44021cd65a80

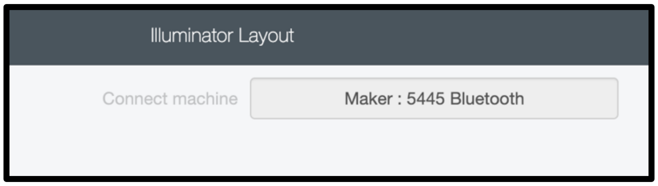
1d. You'll be taken to the Cricut design page again, this time click on open which will open the Cricut software and take you to the illuminators cutout program as shown below. Click on "Make it".



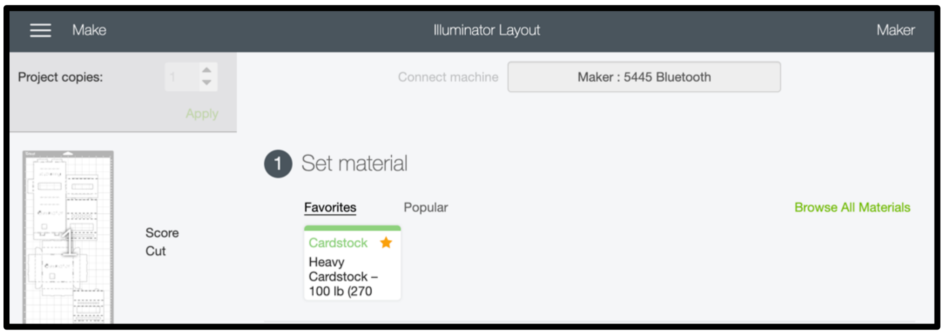
1e. The illuminator's layout on the mat will be shown. The thin red line on the mat represents the area the Cricut is able to cut/score. The area is 1cm away from all 4 borders of the Cricut mat. Click on "Continue."



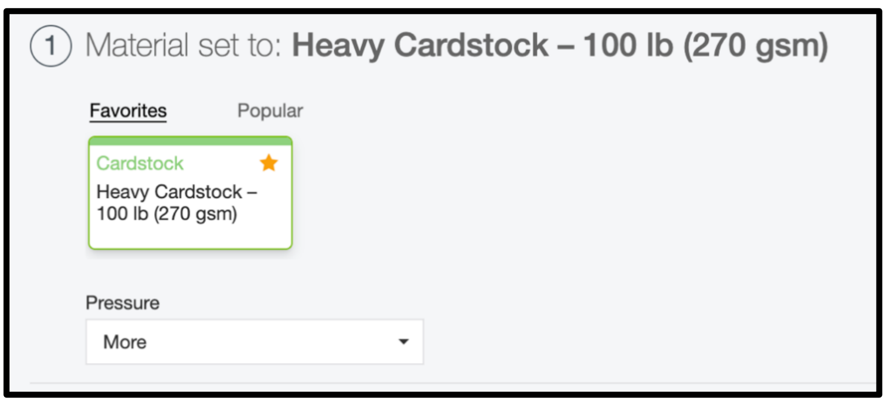
1f. Connect to your Cricut Maker through Bluetooth, by clicking the “Connect Machine” button on top. If you do not have a Bluetooth, you may also connect to the Cricut Maker through the provided USB cable. Attach the USB cable to the port at the back of the Cricut maker and also to your laptop.



1g. Once connected, click on “Browse All Materials” and under category “Cardstock,” find and select “Heavy Cardstock – 100lb”. “Heavy Cardstock” will show up under select material, click on it again.

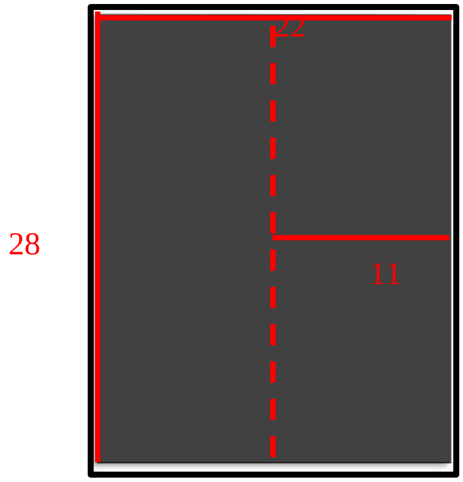


1h. A “Pressure” drop down menu will appear. Select the “More” pressure mode.

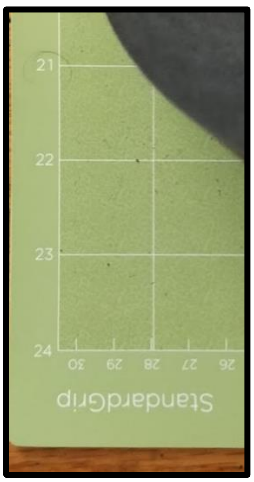


2. Prepping the Mat

2a. Cut the 22" × 28" paperboard into half along the dashed line with scissors so it is 11" × 28".



2b. Next, lay the paper onto the 24" grip-mat. Make sure to line up the top of the paper to the top horizontal border of the mat.



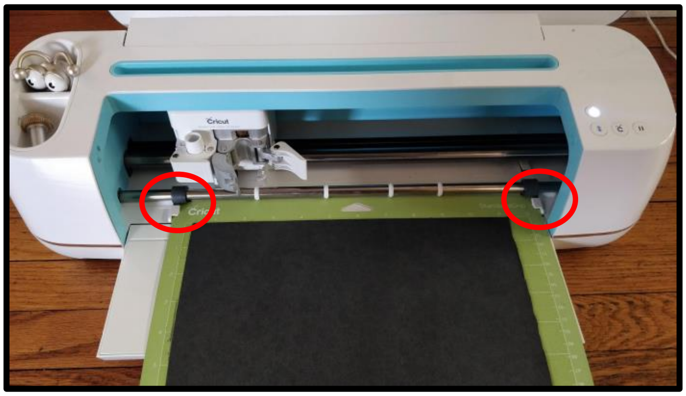
Align the left side of the paper 1 centimeter away from the right border of mat. The easiest way to do so is to align the paper vertically with the 30 cm mark denoted on the bottom of the mat.

Why the weird alignment? We do this to be able to cut 2 illuminators from one sheet of paper. Also, the Cricut does not cut/use any paper left of the 30 cm mark.

If the grip on the mat is not strong, make sure to tape the edges of the paper onto the mat. This ensures it does not come off during the cutting process.

3. Scoring and Cutting Processes

3a. Load the prepared mat into the Cricut. Make sure to feed the mat under the mat guide notches (circled).

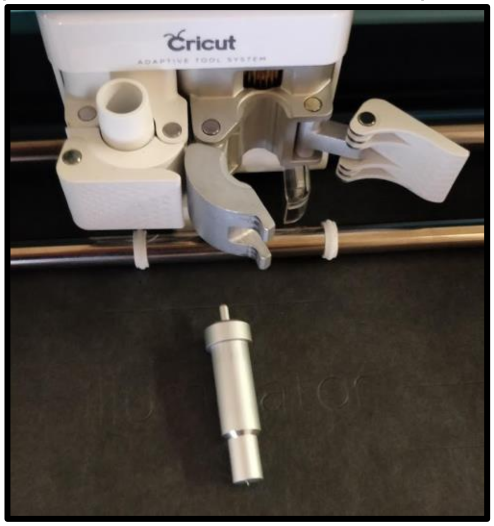


3b. Once the mat is in contact with the black rubber wheels behind the notches, press the "Load/Unload" button.

3c. Load the scoring wheel onto "Accessory Clamp B" and close the clamp.

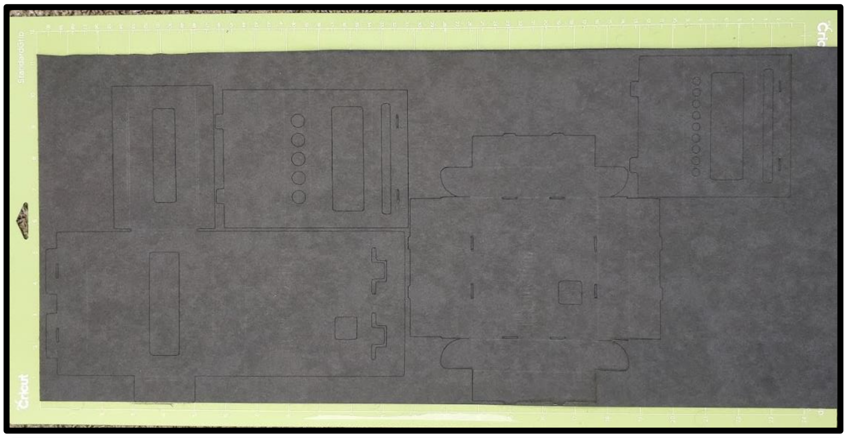
3d. Press the "Go" button on the Cricut to begin the scoring process. This should take about 7 minutes.

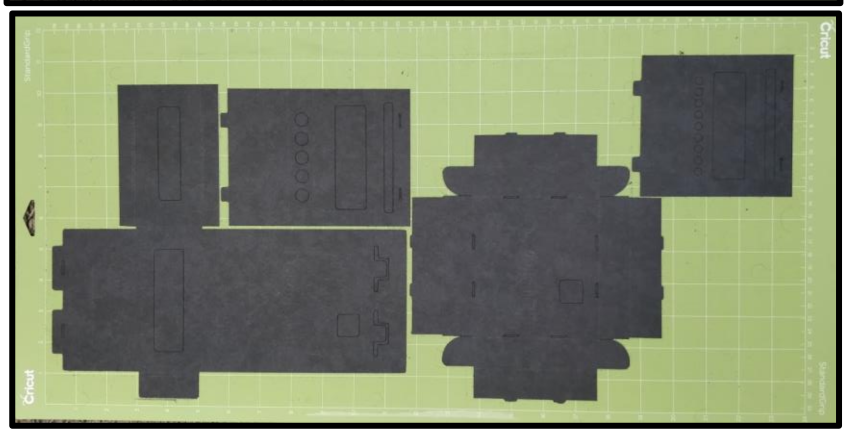
3e. Once the scoring process is complete, you'll be prompted to insert the blade into Clamp B by the Cricut Software. Both the Fine Point Blade (silver), or the Deep Point Blade (black – not pictured) will work for this process. Load the blade onto Clamp B and press the Go button.



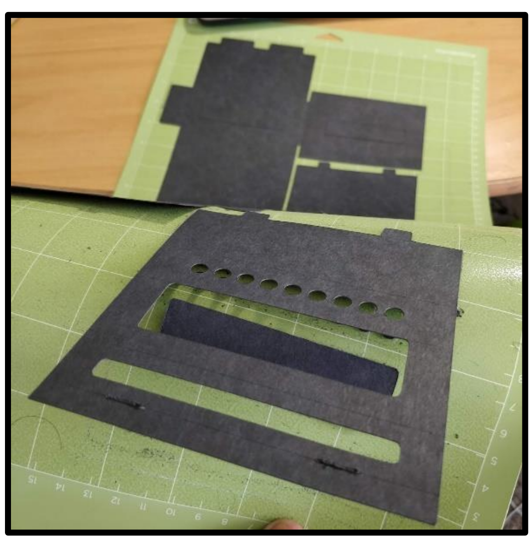
3f. The cutting process will take about (7 minutes). Once it's complete, unload the mat by pressing the "Load/Unload" button.

3g. This is what the final scored/cut product will look like. Remove/recycle the excess paper and retrieve the cutouts.



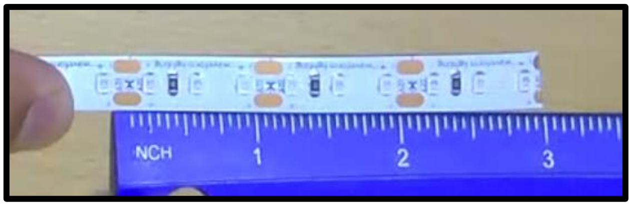


Hint: The easiest way to remove the cutouts from the mat is to bend the mat where the locations of the cutouts. The cutouts themselves will un-attach themselves from the grip-mat.

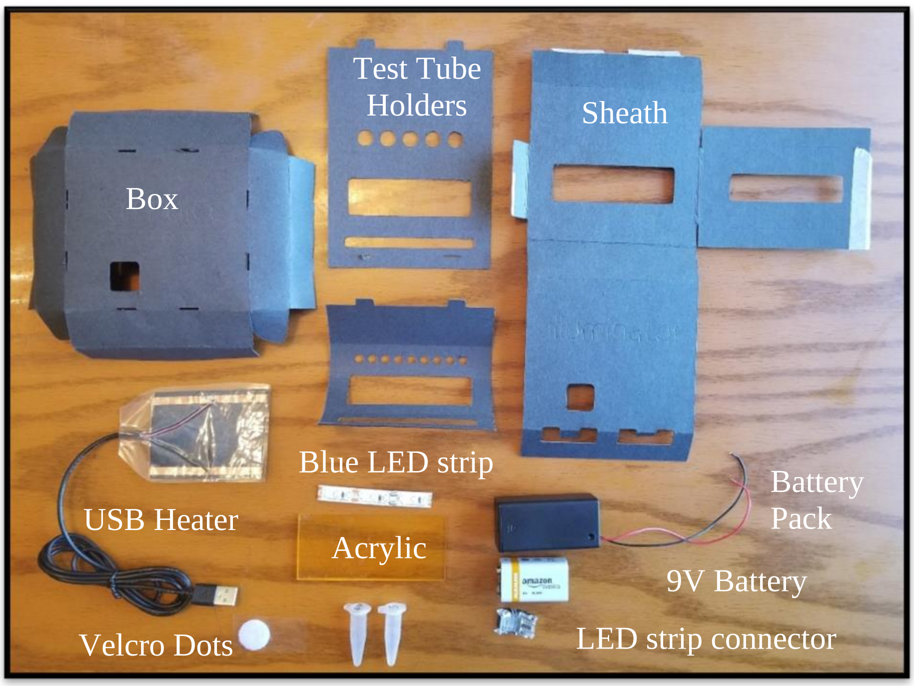


4. Kitting

4a. Grab the spool of 460nm Blue Lights and cut a 3-inch segment of it. Make sure you cut slightly left to the left of marked cutting line denoted by a scissor on the LED strip. This leaves more room for the connector during the assembly process.



4b. Grab a sheet of Velcro dots and cut off 2 pairs (2 loops, 2 hooks) for the kit. Make sure you have all the listed Illuminator components to include in the kit.



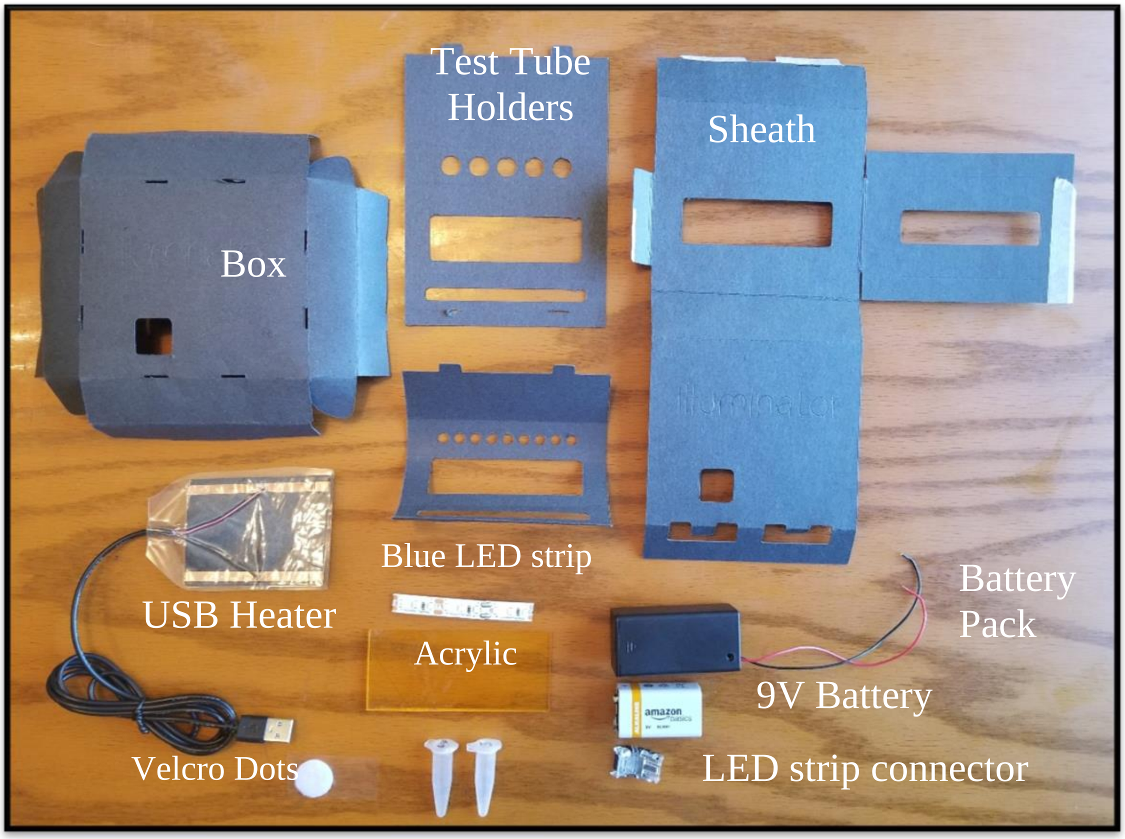
Description	Checklist
(1) Sheath Piece	
(1) Box Piece	
(1) Test Tube Holder, 0.6 mL (9-hole pattern)	
(1) Test Tube Holder, 2.0 mL (5-hold pattern)	
(1) LED Strip to Wire Connector	
(1) 4” × 2” Yellow Acrylic Filter	
(1) 9-Volt Battery	
(1) 9-Volt Battery Holder	
(1) Blue LED Light Strip	
(1) USB Heater Pad	
(2) Velcro Dot Pairs	

4c. Put all the listed components into a gallon-sized Ziplock bag to complete the kit. You may need to fold some of side flaps on the sheath and the box to make them fit inside the bag.

Illuminator Assembly Instructions

Preliminary Check

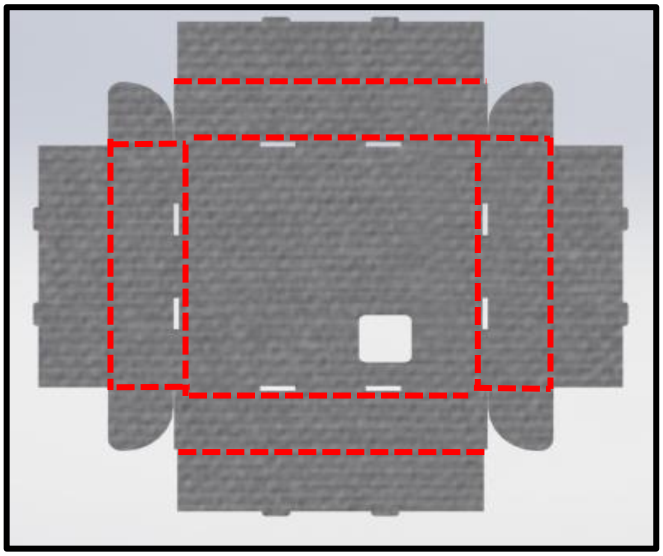
Make sure you have all the listed Illuminator components in your kit.



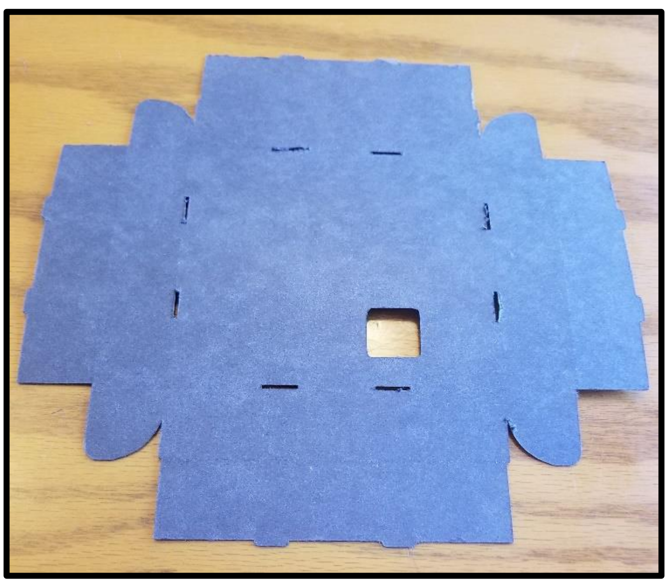
Description	Checklist
(1) Sheath Piece	
(1) Box Piece	
(1) Test Tube Holder, 0.6 mL (9-hole pattern)	
(1) Test Tube Holder, 2.0 mL (5-hold pattern)	
(1) LED Strip to Wire Connector	
(1) 4” × 2” Yellow Acrylic Filter	
(1) 9-Volt Battery	
(1) 9-Volt Battery Holder	
(1) Blue LED Light Strip	
(1) USB Heater Pad	
(2) Velcro Dot Pairs	

1. Box Instructions

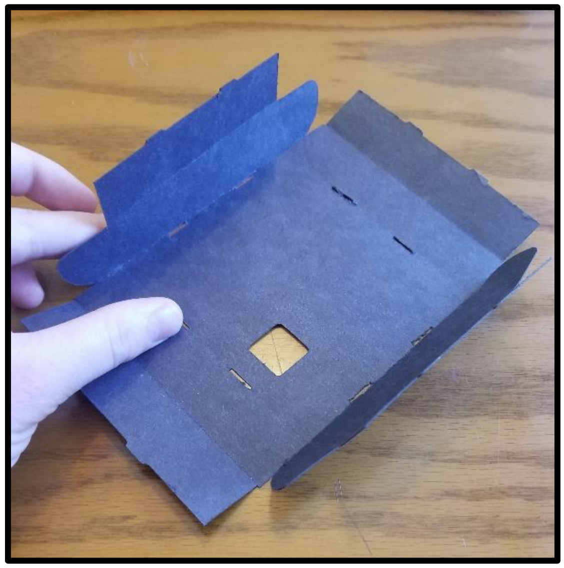
1a. Take the box piece out of the kit. With the "Illuminator" indentation facing downwards and the cut-out in the bottom right hand side as shown in the image, take a ruler or use a table or counter edge to make creases along the pre-scored lines on the paper. Crease along all of the RED lines towards you in the orientation shown.



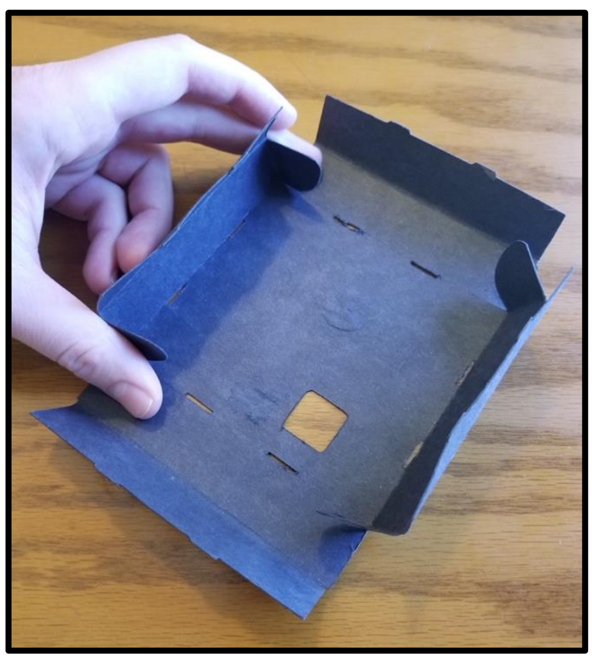
1b. Next lay the box piece flat with the side **without** the "Illuminator" indentation facing up. Orient the piece so the square cutout is on the bottom right, as shown in the image below. This orientation will be used when referencing the "top", "bottom", and "side" panels.



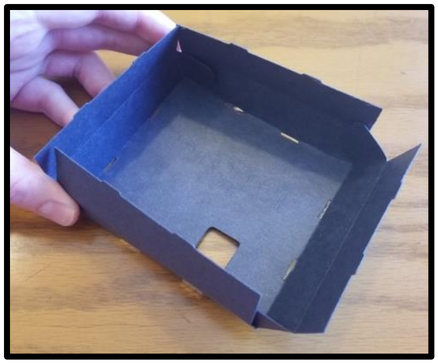
1c. Fold the left- and right-side panels along the scored lines closest to the center of the box, making the panels vertical.



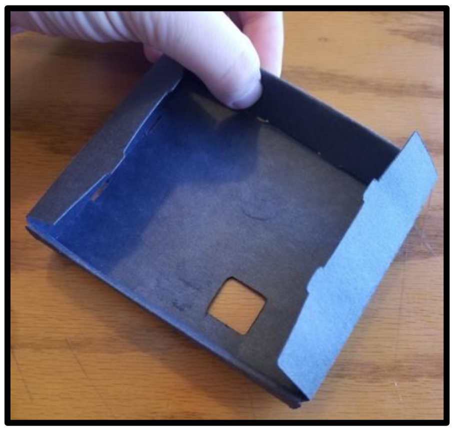
1d. Fold the rounded tabs on both side panels inward so that the tabs and side panels form a 90° angle with the panels.



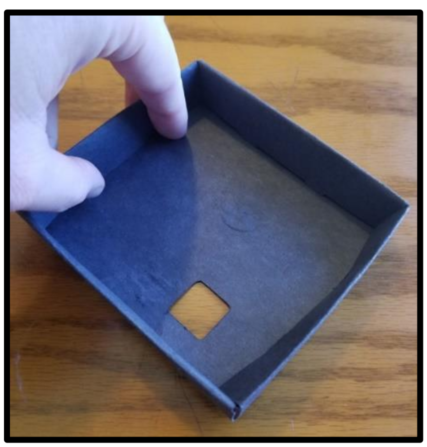
1e. Fold the top and bottom panels upward along the scored lines closest to the center of the box.



1f. Fold the top and bottom panels at the crease in the middle over the rounded tabs on the side panels, inserting the small tabs at the panel's ends into the holes in the base of the box.



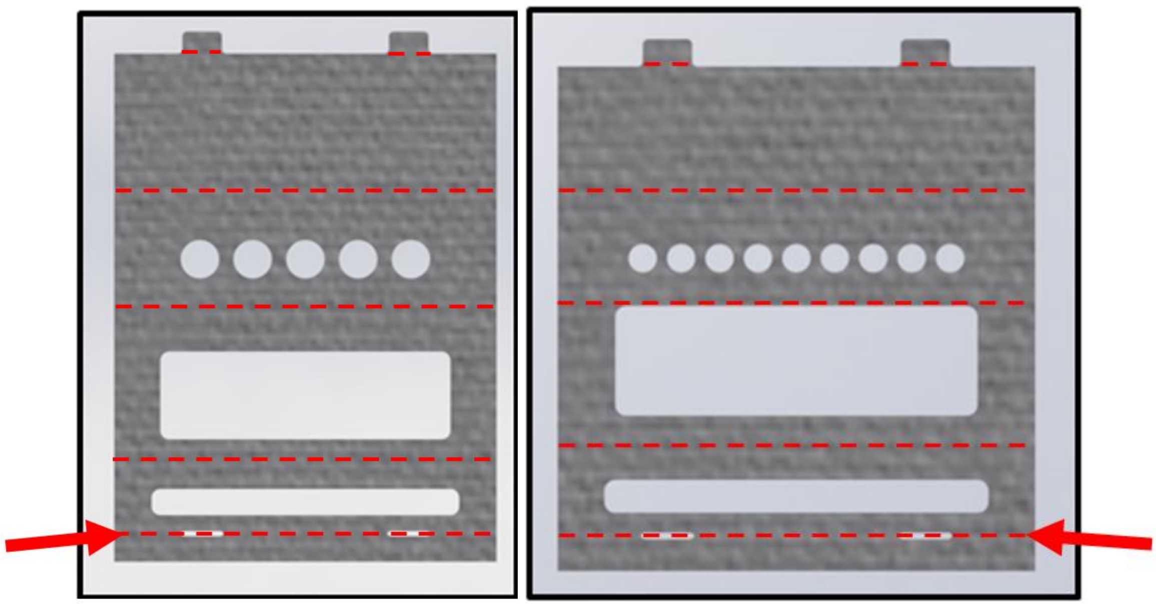
1g. Fold the left and right side panels at the crease in the middle and down, inserting the small tabs at the ends into the holes in the base of the box. The box is now complete.

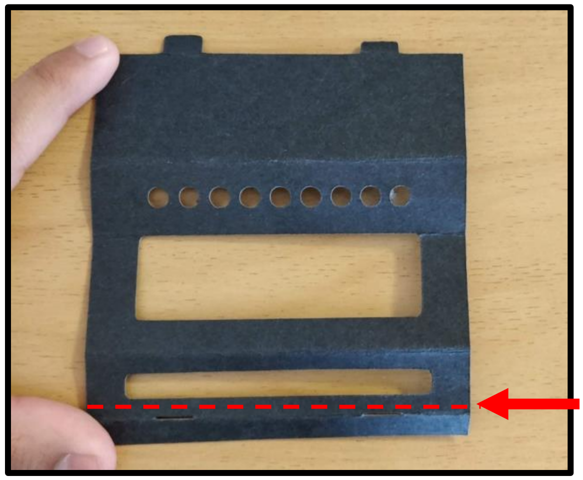


2. Test Tube Holder Instructions

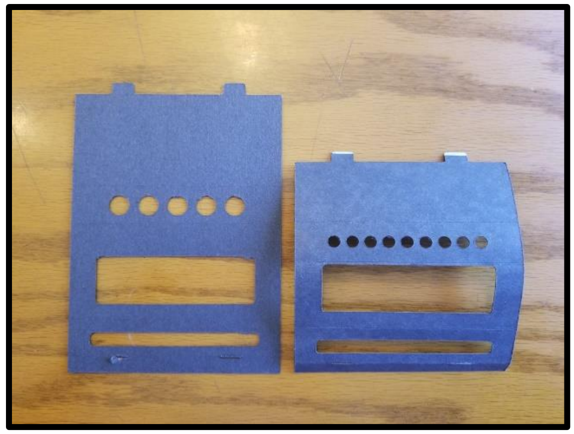
2a. Take out the small and large test tube holder pieces from the kit and orient them with the tabs pointing upwards, as shown below. Using the same method as before, crease all of the scored lines on the test tube holders inwards from the current view.

*** Be particularly careful folding along the crease with the narrow horizontal cutouts at the bottom of the holder. ***

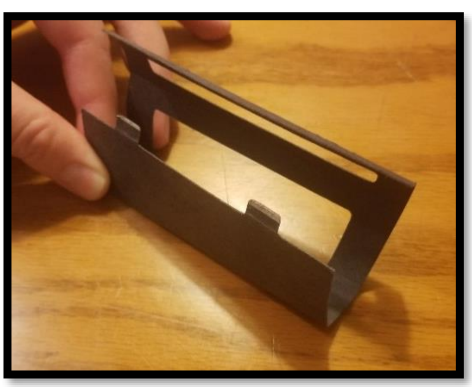


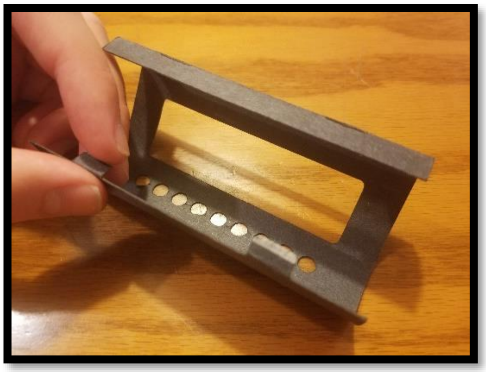


Once done, return the pieces to the orientation below, with the folds pointing away from you.

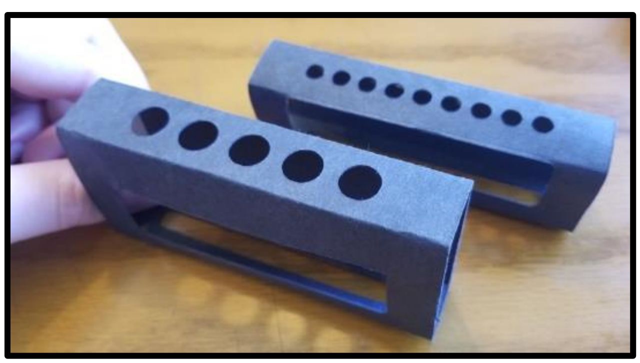


2b. Fold the test tube holder around into a rectangular prism and insert the tabs from the top panel into the narrow horizontal slits at the bottom panel. Make sure to insert the tabs firmly into the slits until they are secure.



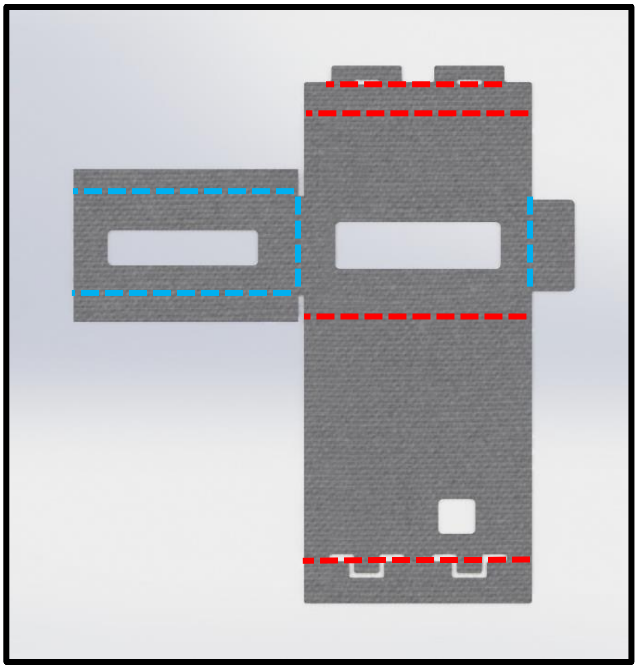



2c. Assemble the other test tube holder in a similar manner; the test tube holders should be able to stand upright and have a rectangular box prism form when complete.



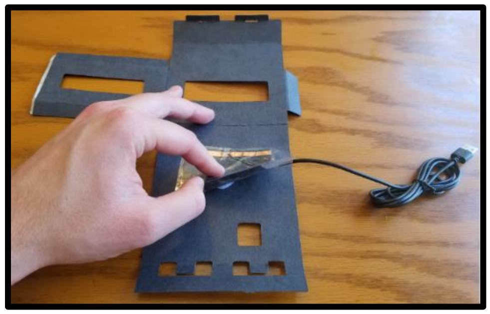
3. Sheath Instructions

3a. Take out the sheath piece from the kit. Place the sheath with the "Illuminator" indentation facing down and the light filter piece sticking out to the left, as shown in the image below. Crease along the pre-scored lines as before, folding RED lines towards you. Next, crease the BLUE lines away from you in the orientation shown.



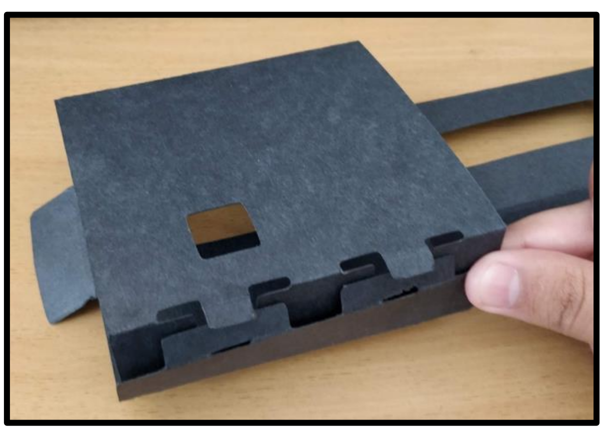
3b. To assemble the sheath, position it in the unfolded position as shown so that the indented 'Illuminator' logo is facing downward and the light filter holder sticks out to the left.

3c. Take the USB heater and Velcro dots from the kit. Attach a Velcro dot with "loops" (soft) onto the back of the USB heating element and place a Velcro dot with "hooks" (scratchy) on top of the other Velcro dot. Orient the heating element with the USB cable sticking to the right over the panel with the square cut-out, placing it slightly above the cut-out and centered on the panel.

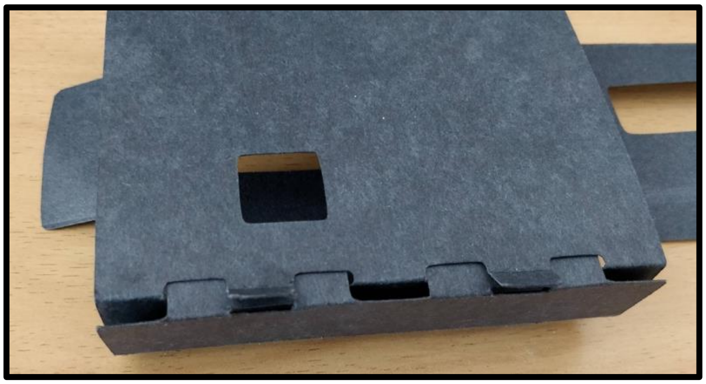


3d. Fold along the scored line adjacent to the viewing window as shown so that the window is vertical.

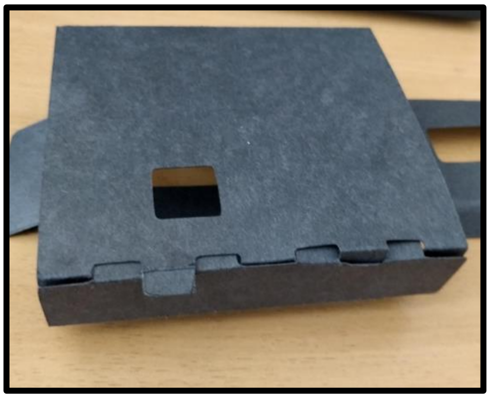
3e. Fold along the horizontal red fold lines portrayed in step 3.a so that the sheath closes with the small tabs on the base and top of the sheath close together as shown.

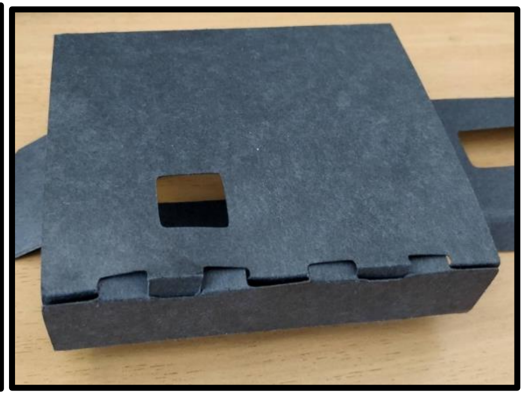


3f. Insert the wider tabs into the opening as shown below.

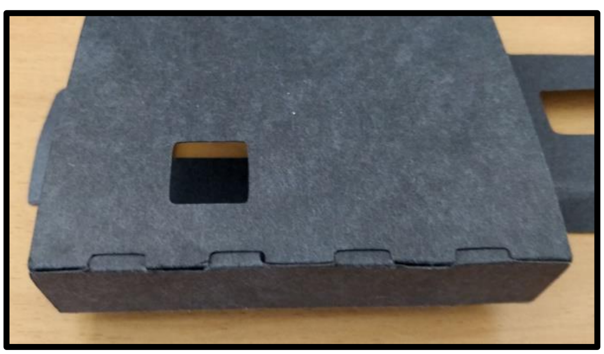


3g. Now carefully insert the smaller tabs into the opennings within the wider tabs as shown below.

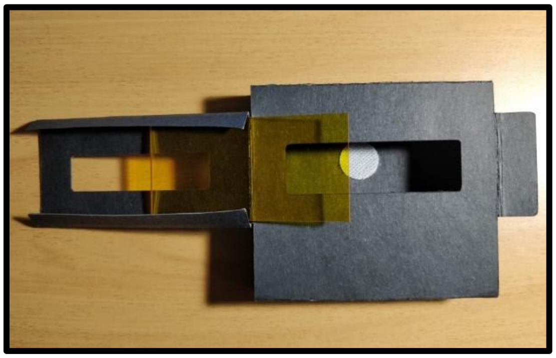




3h. Push the tabs in further until they're fully secure.

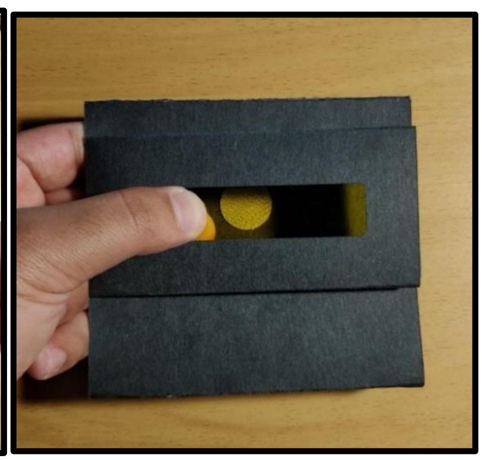


3i. With the viewing window facing upright and the filter holder out to the left, fold the top and bottom creases on the filter holder. Take the yellow acrylic from the kit and slide it underneath the new top and bottom flaps on the filter holder, as shown below.



3j. With the filter fully inserted, flip the filter holder over the viewing window, as shown in the image at lower left. Then insert the side tab into the filter holder in the space front of the acrylic.

3k. Pinch along the folds of the filter holder and push the filter further to the left until it sits firmly in place.



4. Electrical Circuit Assembly

4a. Take all remaining components out of kit, which should include the 9-Volt battery, battery pack, LED strip, LED to wire connector, and two Velcro dot pairs.

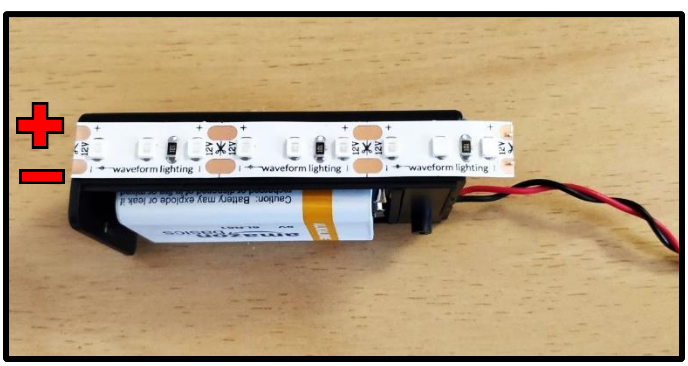
4b. Ensure the "ON/OFF" slider is on "OFF". Remove cover from battery pack, insert the 9-Volt battery with the proper terminal orientation as shown. It may take some force to snap the battery into place.

4c. Remove the red backing from the adhesive tape from underneath the LED strip.

*** Beware of the sharp corners of LED strip. ***

Orient the battery case so the power button is facing away from you and the wires are coming out of the bottom right side. Place the adhesive of the LED strip on the top of the battery pack as shown, with the positive (+) side of the LED strip aligned with the back edge of the battery case (side with the power switch) and the end of the strip aligned with the left side (side without the wires).

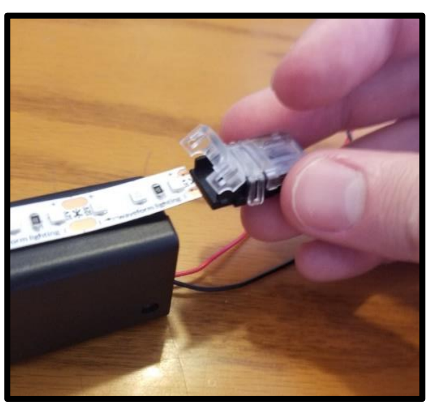
Ensure the strip does not block the removable battery lid. Once you confirm that it's not blocked, slide in the battery holder cover.



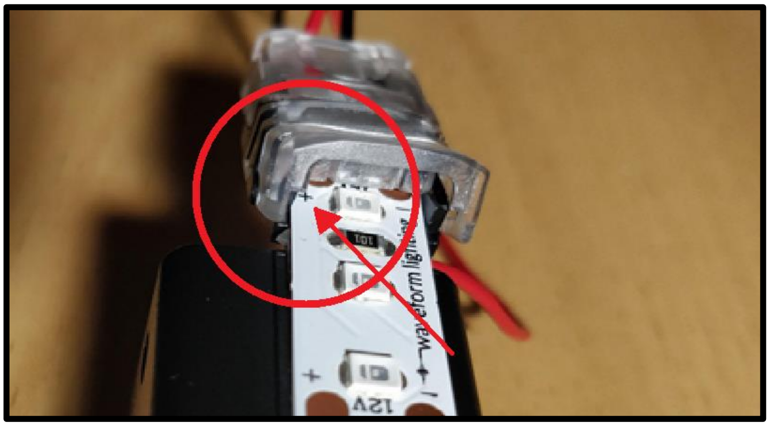
4d. Use your nails to scratch off adhesive from the hanging portion of LED strip. Remove enough of the adhesive (about 1 cm) so there isn't any under the copper leads of the strip.

4e. Flip the cap on the LED to wire connector up until you can completely see the sharp metal leads on the LED strip side. The side with two semicircular indentations in the base is for the wires, and the side with the flat base is for the LED strip, which is shown below.

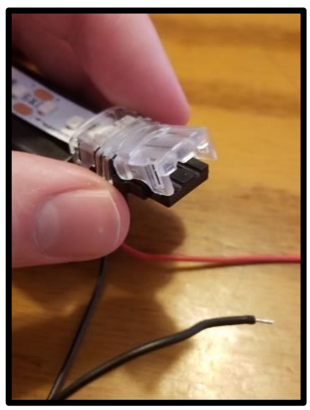
4f. Insert the hanging end of the LED strip into the connector's LED side, positioning the shiny copper terminals on the LED strip over the metal pins in the connector. This is important, as the pin and LED copper terminal connection will provide battery power to the lights. The pins in the connector should create indentations in the copper LED terminals.



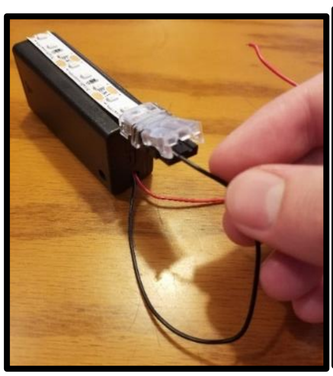
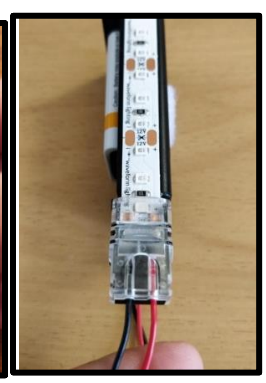
4g. Ensure that the strip is not too far into the connector and the last LED is clear of the tab on the connector cap before slowly closing the cap. Ideally, the clear cap should snap into place once closed.



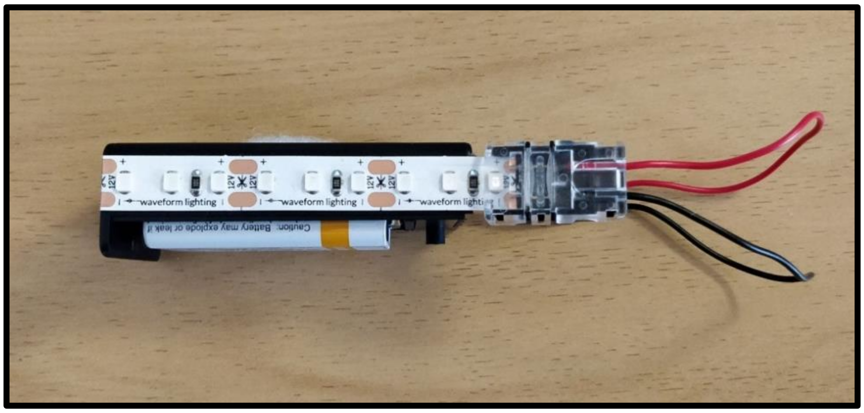
4h. Turn the opposing white cap up vertically until you see the metallic "V" of the wire connectors.



4i. Insert wires into connector opening so that they rest on the metallic "V" grooves inside the connector. Make sure that the red wire is on the same side of the LED strip that indicates a positive (+) sign (RIGHT). Similarly, the black wire should be on the side of the negative (-) sign on the LED (LEFT).

4j. Once wires are lined up within their respective grooves, close the cap until it snaps into place.



4k. Once wires are lined up within their respective channel, make sure the metal mart of the wire will come into contact with the metal in the channel, or else the lights will not work. When in place, snap the cap down over the wires.

4l. Turn on the power button at the back of the battery case to test the lighting.

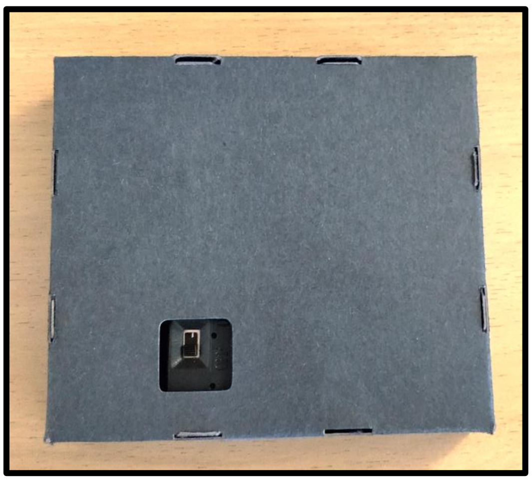
NOTE: To avoid discomfort due to bright LEDs, point the LEDs away from your eyes when turning them on.

TROUBLESHOOTING: In case the lights do not turn on, do the following

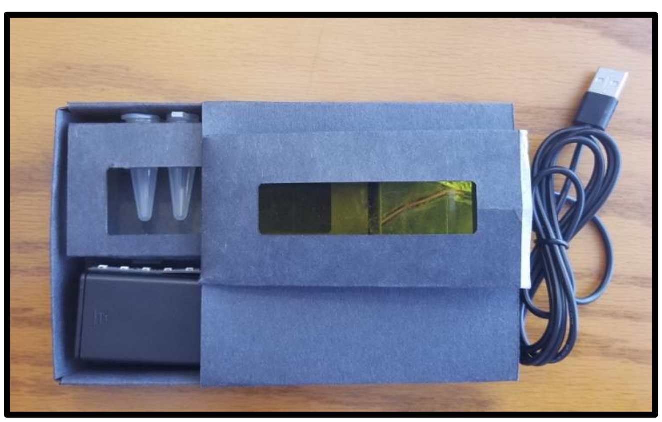
1. Redo the connection between the LED strip and Connector
2. Check the wires and LED strip polarity. Ensure that (+) lines up with the Red wire and (-) lines up with Black.
3. Check the battery connection and polarity. Ensure that the leads properly snap into the leads of the battery housing.

4m. Attach a Velcro dot with "loops" (soft) behind the switch on the side of the battery pack with the switch. Then place a Velcro dot with "hooks" (scratchy) on top of it, as shown.

4n. Line up the power switch on the battery with the cut-out hole at the bottom of the box. Then attach the battery pack and test tube rack to the inside of the box as shown.



4o. Finally, slide the box into the sheath. The Illuminator is complete!



Operation Instructions

WARNINGS:

1. Light can be bright if not covered by filter, do not stare at for long extended periods of time.
2. When not in use, to preserve battery life and protect eyes from unexpected flashes, turn off LED blue lights with battery switch or unplug heater from source.
3. DO NOT operate lights and heater at the same time.

Illumination

1. Choose appropriate test tube stand for samples; either 0.6 mL or 2 mL test tube stand. Place upright and slide tubes into holes. Place test tube stand inside of the box on top of the battery pack, making sure that the cut-out at the bottom of the test tube stand is positioned over the LED light strip.
2. Slide sheath over box with the filter side over the open face of the box, covering it entirely. Make sure that filter is securely attached and positioned over the test tube viewing slot. Also, make sure that the two cut-outs for the battery pack switch on the back of the box and sheath align with one another.
3. Toggle battery pack switch from the back cut-out to turn lights on and off and view fluorescent glow. Turn lights off before removing sheath and taking out samples.

Heating

1. Choose appropriate test tube stand for samples; either 0.6 mL or 2 mL test tube stand. Place upright and slide tubes into holes. Place test tube stand into box over the battery pack.
2. Slide sheath over box with the heater side over the open face of the box (filter side is over back of box), covering it entirely.
3. Take USB cable and plug into wall outlet (with USB-plug converter) or computer USB port to provide power to the heating element and heat the test tubes.
4. Wait until reaction is complete before unplugging USB cable and preparing for illumination viewing.

APPENDIX O: DESIGN VERIFICATION PLAN

Report Date: 1/28/20			Sponsor: Dr. Javin Oza		Component/Assembly		Portable Fluorescence Illuminator		
TEST PLAN									
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED		TIMING	
						Quantity	Type	Start date	Finish date
1	Assembly Time	Time how long assembly takes	10 minutes	Katherine, Emran, Emmett	CV	30	A	2/10/2020	5/22/2020
2	Deformation Force	Place weights on Illuminator, see deformation	10 lbs	Emran	CV	15	B	2/10/2020	N/A
3	Drop Height	Drop illuminator, see deformation	10 ft	Emmett	CV	15	B	2/10/2020	N/A
4	Luminosity	Test intensity of pixels from picture with imageJ app	maximum light intensity	Katherine	CV	10	C	2/10/2020	N/A

APPENDIX P: ASSEMBLY TEST USER SURVEY RESPONSES

Question	
How long did it take for you to assemble the illuminator? *(minutes)*	
Subject	Response
1	40
2	23
3	30
4	60
5	50
6	70
7	70
8	30
9	30

Question	
If you could not assemble the illuminator in under 10 minutes, what do you think made you unable to?	
Subject	Response
1	Instructions have too much text, which takes time to read and understand. bold/ underlines can help extract important details. (and of course, then electronics connector)
2	it took 23 minutes to assemble the box and probably 45 for the electronics for me. I think making sure all of the orientations in the pictures match was the user is seeing right in front of them will make it faster. also having a tool (or recommending one in the instructions) that helps pop the battery in and reopen the connector would speed things up! I also just didn't get that I needed to put the LED strip on top of the gold prongs for a really long time, so make that super clear! In general though, I didn't feel like it was taking a long time when I was folding it together, even though it was more than 10 minutes.
3	Couldn’t clip the connector. Some of the images for folding were in the wrong orientation, so I redid a few steps due to a bit of confusion.
4	Unable to open the clasp for the led strip and the wire connection. Folding took longer than expected as well
5	I had issues with the connector, but I know that you are aware. I think otherwise, the folding instructions could be more clear and the images could have been sharper and brighter. With better images and more clear instructions, the assembly would probably take around 10-15 minutes.
6	the circuit set up. the folding of the orange filter.
7	I got stuck at assembling the electronics.
8	It was mostly issues with the electronics
9	Some of the folds were difficult to fold and the markings were somewhat confusing. The technology was also very difficult to assemble.

Question		Question	
Overall, how easy were the instructions to follow in order to assemble the illuminator? *(1 – Not very, difficult to understand; 5 – Easy to follow, no problem understanding)*		How much do you agree with this statement: The instruction to assemble the illuminator were clear and concise. *(1 – Highly disagree; 5 – Highly agree)*	
Subject	Response	Subject	Response
1	3	1	3
2	4	2	4
3	4	3	4
4	5	4	5
5	3	5	2
6	4	6	4
7	5	7	5
8	4	8	4
9	4	9	4

Question		Question	
Overall, how helpful were the images in depicting how the illuminator should be folded? *(1 - Not helpful; 5 - very helpful)*		If there was a marking/indentation on the box to indicate where the Velcro dots should go, would it be easier for you to assemble the illuminator? *(Yes, No, Neutral)*	
Subject	Response	Subject	Response
1	5	1	No
2	5	2	Yes
3	3	3	Neutral
4	3	4	Neutral
5	2	5	Neutral
6	5	6	Yes
7	5	7	Neutral
8	5	8	Neutral
9	4	9	Yes

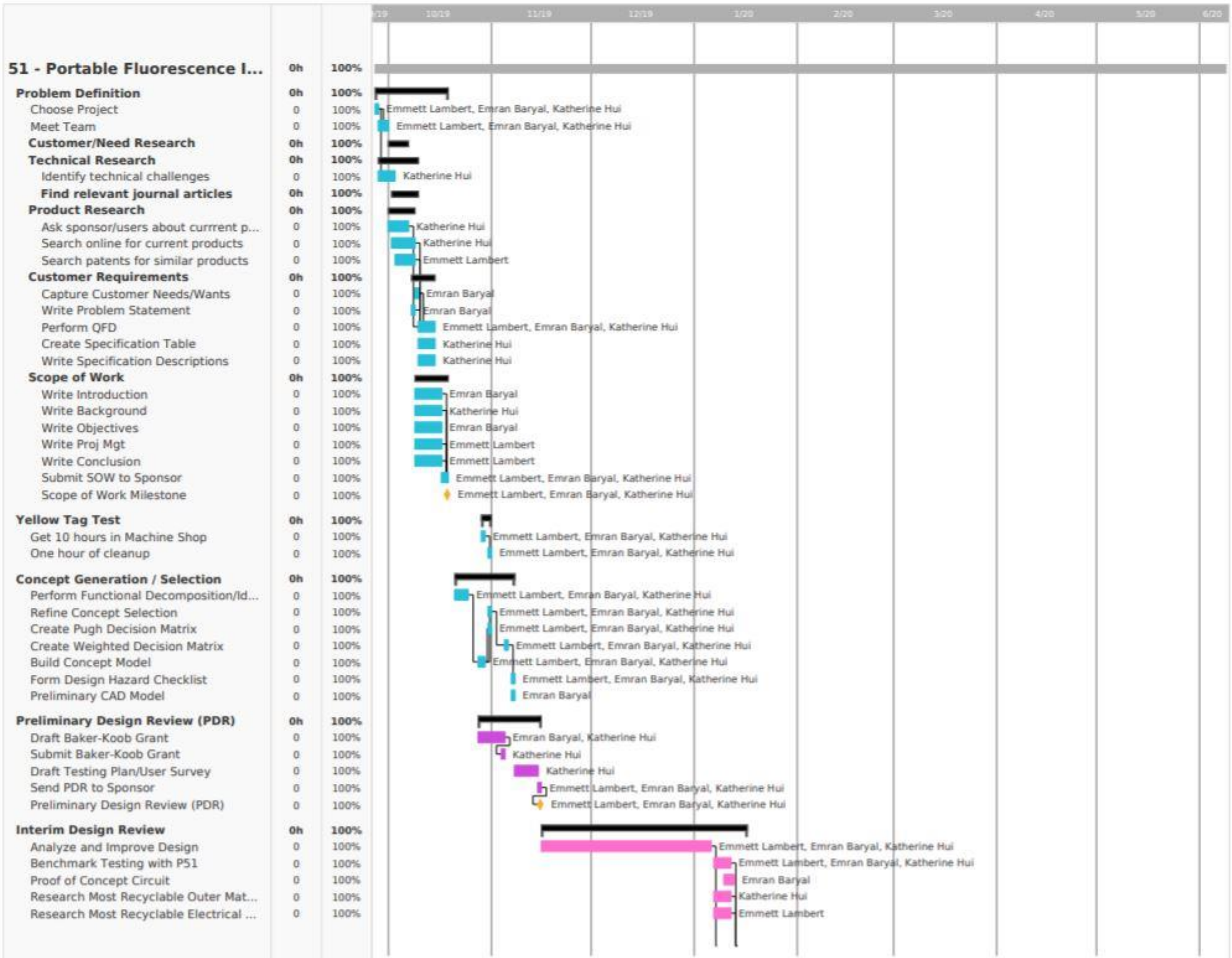
Question	
What improvements to the instructions do you think could be made? Were there any areas where you became confused?	
Subject	**Response**
1	More consistent images. More visual instructions (annotated images) would be better than having to read steps. Less text, more use of bolding/italics to identify important instructions. Video will help a lot!
2	Just make sure that it is clear to put the UV strip on top of the gold pins and make sure all of the pictures are in the correct orientation! also notate the illuminator logo position on the picture itself to help show orientation. Make it clear on which parts the folding orientation matters and where it doesn't matter. (now that Im looking at the instructions again for step onion the box folding, should the logo be up or down? it seems like with it up and folding the pieces towards you, you then have to fold them the other way in step 2?)
3	Just make sure the orientation of the folding instructions matches what the user would be seeing. Maybe say that you have to snap in the battery. If possible, maybe use a clearer picture of the connector so we can see which side is which/the gold prongs.
4	It might be helpful to add letters or numbers to indicate the directionality of the folding - ie fold A to B and C to D or something of that nature, sort of like ikea furniture. Step 5 on page 10 had the picture incorrect which caused me to have to redo a step.
5	The images seemed a little dark and it was not as easy as possible to understand the "fold towards you" instructions. I think that the blue lines on the image with blue lines was incorrectly drawn. The images could have been improved by having a lighter background.
6	The directions on the set up of the filter component could have been more clear.
7	The images should be consistent and reflect what the words of the instructions say.
8	I think maybe breaking up some of the instructions could make them easier to follow. Like on step 1 of the sheath instructions, it was clear, but because we were folding both up and down in the same step I think it could be easy to mix up. Splitting that into a "fold all these lines up" then a "fold all these lines down" step could make it easier to follow.
9	There were some issues with the orientation of pictures and it would be helpful if key points were bolder.

Question		Question		Question	
How satisfied are you with the final, assembled design of the illuminator? *(1 – Not satisfied at all, everything needs to be redone; 10 – Very satisfied, it's amazing!)*		How confident are you that the design will be able to perform the functions of the illuminator? *(1 – Not confident at all; 5 – Very confident)*		How portable is the illuminator? *(1 – Very difficult to carry and bulky; 5 – Very easy to carry)*	
Subject	Response	Subject	Subject	Subject	Response
1	10	1	1	1	5
2	9	2	2	2	5
3	9	3	3	3	5
4	9	4	4	4	3
5	9	5	5	5	4
6	8	6	6	6	5
7	9	7	7	7	5
8	10	8	8	8	5
9	7	9	9	9	5

Question	
What improvements could be made to the illuminator device's design? Is there any design features you would like to see in the device that are not currently available?	
Subject	Response
1	Notches in the small tube holder didn't stay in place, can these be improved?
2	Include a tool or recommend household ones that help open the electronics connector and insert the battery. One possibility could be for the sheath to have a piece that covers one of the openings so that the box only slides in on one side and also can only fall out of one side. Also would it be feasible to also put the illuminator logo under the viewing window, or to put is there rather than on the back of the sheath so that use can still use it as a directionality marker but it is more front and center on the product?
3	I like it, I noticed a big difference between observing the tube without the illuminator versus with. The heating element would be cool to see as well!
4	Once the device is fully put together, it seems sturdy and functional for its intended purpose. In terms of the incubation function, I'm curious if it will be able to retain heat
5	I do not have any suggestions for the design. I think that it functions well.
6	I think adjusting the design of the filter, maybe a slot that the filter could go into, then strapped in place. This would be in contrast to how if the filter were now have to be switched, the component holding the filter would have to be unfolded and refolded. Additionally, maybe a slot in the top of the illuminator that would allow the slows for tubes of GFP or other proteins be easily accessible to pull in and out.
7	The electronics part will most likely be a huge barrier for students to assemble. I recommend that this part is streamlined so that assembly is not halted by this. Also, the part that holds the acrylic is not too stable. Maybe adding a Velcro there, just one Velcro for the battery?
8	No, I think you guys did a great job of fulfilling the necessary functions
9	The technology was very difficult to put together which was ultimately very frustrating. Preassembling some of the tech would be very helpful. I also found that the wires did not stay in the case and would easily come out, i'm not sure if this was just something I did wrong. I also found that the tube racks did not stay together very well and would come unfolded when I tried to close the box, blocking the window.

Question	
Any additional comments?	
Subject	Response
1	Overall - great job!! Bugs are minor and fixable.
2	I think the yellow acrylic was even better than orange and I was so impressed at how sturdy the folds were! A video to watch during assembly would be even better than just written instructions, and filming a timelapse of GFP expression in the illuminator would be so cool!
4	Put the clasp on the led strip before giving to students
8	As you guys saw, the electronics were definitely frustrating. I think attaching the wire connector to the strip would be worth the extra labor. Or including an additional connector

APPENDIX Q: GANTT CHARTS



Research Low-Power Heating Elemen...	0	100%
Develop New CAD/BOM	0	100%
Interim Design Review	0	100%
Critical Design Review (CDR)	**0h**	**100%**
Design Optimization	**0h**	**100%**
Order illuminator lights & electrical c...	0	100%
Produce User Survey for Assembly T...	0	100%
Finalize Box Design	0	100%
Manufacture 2-3 Working Prototypes	0	100%
Manufacturing & Test Review	**0h**	**100%**
Risk Assessment	0	100%
Safety Review	0	100%
Order Filter, Paperboard, Wire Conne...	0	100%
Manufacturing & Test Review	0	100%
Testing	**0h**	**100%**
VP Build Day	0	100%
VP Sign Off	0	100%
Perform Drop Test	0	100%
Perform Assembly Tests with Prototy...	0	100%
Perform Deformation Test	0	100%
DVPR Sign-Off	0	100%
Materials Purchasing/Illuminator A...	**0h**	**100%**
Organize Baker-Koob Budget	0	100%
Purchase Materials for 80 Illuminators	0	100%
Assemble 5-6 Final Prototypes	0	100%
Create Final Cricut Design File	0	100%
Senior Project Expo	**0h**	**100%**
Expo Website	0	100%
Project Expo	0	100%
Final Design Review (FDR)	**0h**	**100%**
Finish FDR Report	0	100%
Peer Review for FDR	0	100%
Submit FDR	0	100%
Baker-Koob Final Report	0	100%
House Keeping	**0h**	**100%**
Assemble Kits for Dr. Oza	0	100%
Send Out Kits and Cricut Machine	0	100%