The Kinkajou Project:  
Product Design of a Low Cost Microfilm Projector

by

Stacy L. Figueredo

Submitted to the Department of Mechanical Engineering  
on May 9, 2003 in Partial Fulfillment of the  
Requirements for the Degree of Bachelor of Science in  
Mechanical Engineering

Abstract

The design of a new product requires careful consideration of its form. This paper follows basic product design processes to develop a new housing and user interface for a low cost microfilm projector, called a Kinkajou. Through an assessment of user needs, a sketch of product form, a rendering of materials, a sketch model assembly, and a CAD representation of its design, a form was developed that fulfills the needs of the user. The product was designed to be robust, inexpensive, lightweight, compact, easy to operate, and simple to understand. The solution to the design was a Kydex plastic housing with a film advancing dial, a power switch and power junction, a focusing ring and a microfilm access panel. The housing design allows an auxiliary power source to power the device, allows the user to easily change microfilm spools, and protects internal components from dust and moisture.

Thesis Supervisor: David R. Wallace  
Title: Esther and Harold E. Edgerton Associate Professor of Mechanical Engineering
# Table of Contents

Abstract .............................................................................................................................. 2  
List of Figures ..................................................................................................................... 5  
1 Introduction ...................................................................................................................... 6  
2 Background ....................................................................................................................... 7  
   2.1 History of the Kinkajou Project .................................................................................... 7  
   2.2 User Needs for the Product ....................................................................................... 8  
3 Theory ............................................................................................................................... 8  
   3.1 Human Factors Design ............................................................................................... 8  
      3.1.1 Understanding the User ...................................................................................... 9  
      3.1.2 Ergonomics and Product Use ............................................................................ 10  
      3.1.3 Aesthetics as a Method of Interaction ................................................................ 10  
   3.2 Understanding the Product ....................................................................................... 11  
   3.3 The Product Design Process .................................................................................... 11  
      3.3.1 Establish a Need for a Product .......................................................................... 11  
      3.3.2 Determine User Needs ....................................................................................... 12  
      3.3.4 Investigate Organization of Internal Components ............................................ 12  
      3.3.8 Determine Most Effective Form ......................................................................... 14  
4 Design Procedure .......................................................................................................... 15  
   4.1 Evaluate User Needs .................................................................................................... 15  
   4.2 Determine Form Specifications for New Design ........................................................ 16  
   4.3 Investigate Organization of Internal Components .................................................... 17  
      4.3.1 Materials and Apparatus for Internal Components ........................................... 17  
      4.3.2 Internal Components Modeling Procedure ....................................................... 19  
   4.4 Idea Sketches ............................................................................................................. 22  
      4.4.1 Sketching Apparatus ......................................................................................... 22  
      4.4.2 Idea Sketching Procedure ............................................................................... 23  
   4.5 Two Dimensional Rendering of the Kinkajou ............................................................ 25  
      4.5.1 Rendering Materials and Apparatus .................................................................. 25  
      4.5.2 Procedure for Creating a Rendered Kinkajou Image ....................................... 25  
   4.6 Creating the Kinkajou Sketch Model ....................................................................... 27  
      4.6.1 Materials and Apparatus for Creating the Kinkajou Sketch Model ................. 27  
      4.6.2 Sketch Model Procedure ............................................................................... 28  
   4.7 Deciding the Final Kinkajou Form .......................................................................... 30  
   4.8 Solid Model of Kinkajou Form ............................................................................... 31  
      4.8.1 Solid Modeling Apparatus .............................................................................. 31  
      4.8.2 Dimensioning the Kinkajou Form ..................................................................... 31  
      4.8.3 Creating the Kinkajou Mold ............................................................................. 31  
      4.8.4 Modeling Machine Details of The Form ........................................................... 32  
      4.8.5 Creating Additional Components of the Form ............................................... 32  
      4.8.6 Finishing Touches ............................................................................................ 34  
5 Results ............................................................................................................................ 35  
6 Discussion ....................................................................................................................... 37  
7 Conclusion ....................................................................................................................... 39  
8 Acknowledgements ......................................................................................................... 40
List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>SolidWorks 2000 and Kinkajou model.</td>
<td>18</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Volume model materials.</td>
<td>18</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Views of Internal Model.</td>
<td>19</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Volume Templates.</td>
<td>20</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Template Applied to Pink Foam.</td>
<td>20</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Wire Foam-Cutter.</td>
<td>21</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Final Foam Pieces.</td>
<td>21</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Volume Model of Internal Components.</td>
<td>21</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Sketch Tools.</td>
<td>22</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Beginning Sketches.</td>
<td>23</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Loose Sketches.</td>
<td>23</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Loose Sketches Develop.</td>
<td>24</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Sketch Process Drawings.</td>
<td>24</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Final Kinkajou Sketch.</td>
<td>25</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Initial Rendering Steps.</td>
<td>26</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Development of Renderings.</td>
<td>26</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Completed Rendering.</td>
<td>27</td>
</tr>
<tr>
<td>Figure 18</td>
<td>Additional Sketch Model Materials.</td>
<td>28</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Sketch Model Templates.</td>
<td>28</td>
</tr>
<tr>
<td>Figure 20</td>
<td>Foam Preparation.</td>
<td>28</td>
</tr>
<tr>
<td>Figure 21</td>
<td>Edge Detailing.</td>
<td>29</td>
</tr>
<tr>
<td>Figure 22</td>
<td>Assembled Form.</td>
<td>29</td>
</tr>
<tr>
<td>Figure 23</td>
<td>Finished Sketch Model.</td>
<td>30</td>
</tr>
<tr>
<td>Figure 24</td>
<td>Modeling the Housing.</td>
<td>31</td>
</tr>
<tr>
<td>Figure 25</td>
<td>Kinkajou Mold.</td>
<td>32</td>
</tr>
<tr>
<td>Figure 26</td>
<td>Kinkajou Housing.</td>
<td>32</td>
</tr>
<tr>
<td>Figure 27</td>
<td>Focusing Ring.</td>
<td>33</td>
</tr>
<tr>
<td>Figure 28</td>
<td>Power Switch.</td>
<td>33</td>
</tr>
<tr>
<td>Figure 29</td>
<td>Film Advancement Dial.</td>
<td>33</td>
</tr>
<tr>
<td>Figure 30</td>
<td>Spool Cover.</td>
<td>34</td>
</tr>
<tr>
<td>Figure 31</td>
<td>Kinkajou Assembly.</td>
<td>34</td>
</tr>
<tr>
<td>Figure 32</td>
<td>Available Color Palette.</td>
<td>35</td>
</tr>
<tr>
<td>Figure 33</td>
<td>Isometric View of Final Kinkajou Design.</td>
<td>36</td>
</tr>
<tr>
<td>Figure 34</td>
<td>Back Isometric View of Final Kinkajou Design.</td>
<td>36</td>
</tr>
<tr>
<td>Figure 35</td>
<td>Back View of Kinkajou Design.</td>
<td>37</td>
</tr>
</tbody>
</table>
1 Introduction

Mechanical design defines the components of a product that will perform a desired function when inputs are provided. While the mechanical design process establishes a solution for a device, it does not wholly determine the success of a product. Theoretically, one would think that the device that performs a task the fastest or the most accurately would be the most desirable product. However, a design may function as specified mechanically and still be considered a “poor” product.

This may lead a mechanical designer to wonder if there are other requirements of a product besides those of a purely mechanical or operational nature. If a machine works, why would an individual not want to use it, or why would they prefer another device? After some thought, this question may be answered quite simply- a product allows for human use where a device may not. For a device to be successful as a product, it must allow for human interaction and human preferences in addition to performing a function.

The complex nature of human interaction with mechanical devices is the heart of product design. Rather than determine the requirements of a device from all the possible technologies that can perform a function, the product design process investigates the technology and form that best fits a set of user-defined criteria. For example, a mechanical engineer could probably design a device that turns on a light using a complex arrangement strings. However, because a person would not want the frustration of installing and repairing strings, such a contraption would not be considered a good design. There may many ways to solve a problem, but the best solution for a product considers human needs as the determining factor for success.

The challenge of product design arises in how to merge the needs of a user with the requirements of the working device. This design must consider issues such as how to protect working components from the wear of human interaction as well as how to shield the user from personal injury. The product must inform users about the function of the product, reveal how to interact with the product, and encourage such interaction. A designer must incorporate needs from cost to portability to durability all while allowing the components to operate freely.

The process of designing a product is both interesting and challenging to a mechanical engineer, as it demands more of a device than numerical limits. This document presents the process for determining the design for a mechanical device and developing its presence as a product. The existing technology is a low-cost microfilm projector, named Kinkajou, which is to be used as a teaching aid in third world countries. While a design for the mechanical operation of the device has been established, engineers working on the project desired a specific design for the external housing and controls of the projector. The design was to
include specifications for form and materials, taking into account details such as organization, color, and symbol usage. These user considerations would ensure that the product engineers were introducing to a community would be eagerly used and quickly assimilated.

2 Background

To understand the status of the Kinkajou before the product design was considered specifically, this section details the history of the Kinkajou Project and the needs of the user that were established previously.

2.1 History of the Kinkajou Project

The Kinkajou Project is a mechanical design that attempts to solve the need for educational reading materials in third world countries. The project began as a 2.009 design project (web.mit.edu/2.009/www) for a group of students in the mechanical engineering department at MIT. The group of sixteen students designed a microfilm projector that would provide one year worth of reading materials for classrooms in third world countries at a cost of less than fifty dollars. The projector, named Kinkajou because the bright light it displays resembles the shining eyes of the South American mammal, was developed through contact with nonprofit groups including World Education and by researching classroom conditions in locations such as Mali.

Following a semester of class work on the project, several students decided that the project should continue forward in order to make the Kinkajou available to an actual community. The Project Manager Kateri Garcia met with the designers of the first prototype and found that several major changes had to happen in the mechanical design and product design in order for the projector to succeed as a product. A fellow student Martin Tolliver committed himself to the redesign of the internal components, in order to create a more robust design. Although not an original member of the Kinkajou design team, I was asked to contribute to the product design and outer housing of the Kinkajou after taking a product design course under professor David Wallace. With the help of this small team and the suggestions of original members, the Kinkajou project evolved over the course of the spring semester of 2003 to create a working prototype of the new projector.

It is the hope of the creators of this product that the Kinkajou projector will contribute to the education of people in communities where conventional teaching tools are inaccessible, overpriced, or otherwise inadequate.
2.2 User Needs for the Product

The user needs of the original Kinkajou were established based on interviews with members of the World Education organization and research into the economic, cultural, and academic characteristics of third world countries. Specific research was conducted regarding small communities in Mali, where Barb Garner, a member of World Education, provided first hand information about the user. Based on information obtained from the above research, the group determined that the user would need a product that: was readable from two feet away, used a readily available power source, lasted the entire academic career of a student, and could be used for various curriculum. The first Kinkajou research team also determined that the product needed to be inexpensive enough that one could be provided to a class of 10-20 students by a non-profit organization. The product also had to be easy to set up, safe to use, portable, and able to withstand both normal wear and an accidental fall. Finally, the product needed to withstand environmental factors such as humidity, dust, and high temperatures. A chart of these user needs and product specifications was constructed by the original research team and is included in Appendix A.

After creating a prototype of their original design, the Kinkajou group determined that some of the user needs were not fully met by their design. The product was not robust enough to withstand environmental stresses, such as rain or dust. It was also not as compact and light as desired to ensure portability. Finally, the design was not understandable from a user standpoint, as to how the product operates. These findings are the basis of the redesign of the Kinkajou projector.

3 Theory

Once the Kinkajou Team decided that their previous design was inadequate in terms of a human interaction and a product design standpoint, it was necessary to look at some of the ways in which a new design could be established that would fulfill the same needs of the customer, but with a more direct product design approach. Because the design of a product involves thinking about its physical properties in several ways simultaneously, it is important to look at the many considerations that affect a product’s creation. To understand the methodology that is applied when designing for human use, this section explains some of the basic concepts that are involved in product design including human factors design, understanding the product and the product design process.

3.1 Human Factors Design

In order to create a product that is useful to the community, it is crucial to understand how users will interact with that product. While the mechanical
design of a device is important to its operation, ensuring that a product is usable from a human perspective is the focus of product design.

3.1.1 Understanding the User

In order to create an object that is both useful and useable, it is important to understand who will interact with the product and to what extent they will understand the device they are using.

While a device may have the same basic purpose, different users may require a completely different product form. One example of such a product is writing utensils for different age groups. The differences in dexterity of a child and an adult determine the form of the utensil, even though both are used to write. Because children typically do not have as much dexterity, they require bigger utensils with more grip, as is often seen in products such as large crayons and oversized chalk. Adults, who have greater dexterity can be limited in speed and accuracy of their stroke by a large writing utensil, and may prefer a thin and precise pen. Thus, the form of a product is highly dependent on the user, even when the function of the product is the same.

One important fact to know about the user is the level of understanding they may have of the device they are using. If a user is not aware of the hazards of electrocution from a live wire, it may be necessary to insert a warning or to symbolize danger, via color or symbol, to ensure the device does not harm them. If the user does not fully understand the inner workings of the product, the maintenance cycle of a device may need to be much longer than for an expert of that product. An example of this can be seen in the design of home computers versus performance computers. The imac cannot be serviced by a user because it is designed for a user that does not know about the inner workings of a computer. On the other end of this spectrum would be a power mac, which is designed to be easily customizable by an experienced user. In either case, the product is more useful when the user is considered in the design.

Another fact that must be considered is the level of interaction that is to be expected from the user. If a product is made to be operated continuously, such as a machine tool in an assembly line, it may want to visually stand out from its environment or signal the user so that the product continuously has the attention of the user. If a product is meant to be non-obtrusive, it may need to have a use cycle that is partly automated and its form should not be visually distracting. Its colors may be subdued and its may require the device to be low-noise.

Finally, the amount of attention the user will give to the product care is also important to the design of a product. Because the form of the product protects the internal component from the impact, temperature, dirt, and other external factors, its form should consider the level of wear and the amount of maintenance that is expected. A vehicle that is expected to last ten years will
need to be designed with yearly maintenance in mind. A product that is meant to be portable may require a lightweight material that can withstand being dropped. A child’s toy may have to operate when used regularly and never cleaned. These demands are based on the expected care the product will receive and can greatly influence the form of a product.

3.1.2 Ergonomics and Product Use

Ergonomics is another factor that can increase the usability of a product in all stages of use. Ergonomics, which is a method of designing form based on the anatomical dimensions and physical capabilities of humans, allows people to interact with products in a manner that is intuitive as well as productive. During the actual use of the product, ergonomic design can signal where a product should be touched as well the order in which operations should occur. For example, a handle area on a product can easily be identified as a handle because it may have proportions that are easily held in ones hand or indentations that suggest the form of human fingers. The placement of buttons on such a handle would suggest that once a person holds onto the device, the pressing of a button causes the tool to function. An easily visible display can also inform the user of product functions. Ergonomics can increase the productivity and safety of a product by eliminating improper use of a device, such as holding a device at in a way that is strenuous on the body or touching a dangerous moving part, simply by suggesting proper use through the product form.

Transport and setup of a product can also be improved upon by designing a product ergonomically. When a designer specifies an area where a product is held, they eliminate damage by users who may pull on or lift by fragile parts of a product. During setup of a product, ergonomics can eliminate the need for instructions or diagrams by making the process more intuitive via product form. Appropriate dimensions and weight of a product can also ensure that a user can set up and transport a product without bodily injury or damage to the product. For instance, a portable product should be light enough for a person to carry without strain as well as balanced so that the product does not tip when moved. Finally, the size of the product can also ease the transport by ensuring that product dimensions relate to the width of a hand that is holding it or an arms length of a person carrying the product. When the ergonomics of a product is considered in all phases of use, the design enables users to interact with a product in an intuitive, safe, and efficient manner.

3.1.3 Aesthetics as a Method of Interaction

While aesthetics are to some extent socially and culturally based, the character of a product, at least in the sense of artistic styling, can be expressed through rules for color, form, and materials. Even though there are many theories as to why humans respond to colors in a specific way, it is safe to say that there are general trends in human behavior to color that a designer may use when
determining the palette for a product. For example, grouping colors by temperature, where cool colors like blue are considered to be calming and warm, colors such as red are thought to be stimulating, is often one way to design a product palette. Pairing colors based on their relative position on a color-wheel, is often applied to create effects of contrast or coherence. Similar theories of contrast apply to materials and form, where materials of similar luminosity or texture, or forms of a similar curve shaping, will appear to blend. Differences in form and materials can create a sense of motion or separation. In reality, aesthetics is a complex notion that is deeply rooted in personal preference. Although following generalizations of aesthetic principles provides some guidance, a successful designer may take these rules as mere suggestions and should be confident that their design decisions are a risk worth taking.

3.2 Understanding the Product

As much as a designer must be aware of the user, he/she must also understand the product that they are designing. A designer should be aware of the value of the product, the safety hazards of a device, as well as the delicacy of its components. A product’s value will often inform the designer as to the materials and form of a product. An expensive device should look expensive, both to emphasize the quality of the product as well as to ensure that the best material is protecting precious components. Detailing for expense often ensures that a product is treated respectfully and remains in demand. A designer must also consider the safety of a product so that the form can properly shield a user from dangers such as radiation or electrocution. A poorly designed product could result in injuries that cost a company their credibility as well as their earnings. Finally, a designer must consider wear on a product over its life. For example, a child’s toy may require soft edges and impact resistant materials so that it can sustain the abuses such as being left in the rain or dropped from a shelf. In effect, the nature of a product can provide useful information for a product design.

3.3 The Product Design Process

While some would regard product design as subjective or “an inexact science,” product design, like all other forms of design, involves a specific process with explicit rules that determine the form of a product. This section explains some of the key steps in designing form and determining organization of a product. This process is derived from Ulrich and Eppinger Product Design and Development.

3.3.1 Establish a Need for a Product

As is often the case in mechanical design, the origination of a product stems from the needs of a user. Typically, a designer or company will think of a problem area where customers may desire a new or improved product. They may look at
market research that suggests what consumers are purchasing and may speculate an area that is likely to be desirable to customers.

3.3.2 Determine User Needs

After establishing a potential need for a product, a company may research market trends in the product, interview potential customers about the attributes of the product, and establish focus groups to distill the requirements for a new product into user needs. Users needs are typically not specific to the form of the product per se, but rather suggest ways in which the product should operate. For example, a user need for a bicycle lock may be that it is compatible with most bicycle frames. This need would then lead the designer to make the form of the product, in this case a bike lock, such that it fulfills the specified need.

3.3.3 Specify User Needs in Terms Product Attributes

Once a design team has established a list of user needs for a product, these needs are quantified into physical constraints that define the form and function of the product. An abstract user need, such as that a product must be easy to use, is translated into a product attribute, like an automatic shut-off timer. A user need for portability may be specified in terms of product attributes, such as a weight of less than 6 ounces or a maximum volume of 200 cm$^3$. Product attributes are usually measurable in some way, or in the case of aesthetics, based on experimental data that suggests they fulfill the user need.

3.3.4 Investigate Organization of Internal Components

While product attributes establish some limits for the designer in terms of form, the organization of internal components often sets the basis for the major structure of a product. In other words, while the product attributes may tell the designer what a product should include, the internal workings of a product specify what the product must include for it to function. Luckily for the designer, the internal organization if product components often suggest a program for the product form. That is, the rule of organization of the components and the way that they operate can be abstracted into rules for determining form. This is comparable to the famous notion of “form follows function” proposed by the architect Louis Sullivan.

For a designer, this step in the design process simply requires that the internal components and basic function of a product be considered at some level. This may mean investigating the motion of dynamic components or determining the organization of working materials and volumes. In any case, scrutinizing the necessary components of a product will make the designer more aware of what they are creating, and will usually result in a more appropriate and thoughtful product form.
3.3.5 Create Idea Sketches of Basic Form

Once the necessary attributes of a product and the organization of its components are established, the designer may begin working on a product concept in sketch form. Because drawings are generally less expensive and less time consuming than other media, a designer may feel free to work with many possible product forms in a loose and uninhibited manner. Often the beginning sketches for a product may be abstractions of forms that express the character of the product rather than the actual form. This could be anything from lines that suggest motion to shapes that convey stability. This “brainstorming” stage, as it is often called, allows a designer to work out basic concepts of a product without focusing on creating something that is of a presentable nature.

After working with creative doodlings, a designer may begin to create concrete sketches that convey the form of the product as it may appear. These sketches often suggest approximate scale and organization of the product as well as ways in which the user may interact with the finished item. A series of concept sketches may be presented to a design team that selects the most favorable ideas to be further developed.

3.3.6 Render Idea Sketches into Realistic Forms

Although concept sketches show some form and features of a product, a more informative drawing of a design is a rendering. A rendering often shows the materials, texture, color, and forms of a product with realistic detail. A designer may generate a rendering of an idea to present to a client that suggests the form of the product. This drawing is more time consuming than previous sketches, but useful in the development of sketch models and other three-dimensional representations of a product design.

3.3.7 Create Sketch Models of Possible Forms

When a designer has chosen one or more concepts that may develop into a finished product, he/she often creates three-dimensional sketch models of the product form. A sketch model is a rough three-dimensional form that represents the form, size, and organization of a product. It generally does not suggest specific materials or surface characteristics, but may distinguish between separate areas of a product. In fact, it is often useful for a sketch model to be created in a monochromatic fashion so that the form of the item may be carefully studied without the distraction of color. Details such as the placement of buttons and display screens are usually shown, but it is not always necessary to have them precisely detailed. Sketch models are meant to be relatively quick, although the exact time required depends greatly on the size and complexity of the product. Overall, the main goal of the sketch model is to see how well
rendered forms appear in three-dimensions, as a nice design on paper may not translate well into reality.

3.3.8 Determine Most Effective Form

After quite a commitment into several product designs, it is necessary for a designer or design team to choose a product form that best fulfills the user needs of the product. As further steps in the design process require additional time, money, and materials, one product form is usually chosen as early as possible. It is often helpful to choose a final design based on customer feedback, where drawings and models are presented to individuals who may purchase or use the product. Since manufacturing costs are a significant portion of a company’s investment, cost of production should also be considered in the final design. Once the overall design is chosen, finishing touches may be added to buttons and parting lines may be decided in two or three-dimensional sketches.

3.3.9 Create Solid Model of Product

One tool that has revolutionized the speed of product development is the CAD model. A CAD model, also called a solid model, is a computer-generated model that uses mathematical representations of surfaces to create three-dimensional shapes. Since solid models are inexpensive in terms of materials and can be changed multiple times at a rate faster than traditional hand modeling, many designers now use solid modeling as their main design tool. Current technology in three-dimensional printers allows actual models to be created from their computer representations. A designer can also directly translate their solid model into part drawings and machine tooling paths so that exact replicas of the design are easily manufactured.

3.3.10 Create Looks-Like Model of Product

With a solid model of a product design created, a designer may construct a “looks-like” model for a final presentation of their design. A looks-like model of a product is a representation of a product with all the outer detailing that a user would expect to see when looking at the product on a store shelf. It is realistic in every way except that it may not contain the actual hardware or electronics that make the device operate. This model is extremely time-consuming compared to other design steps because great care is taken in the form as well as the surface treatments of the model. In fact, a looks-like model is often used in advertising when the actual product has not yet been manufactured.

3.3.11 Apply Design to Product Prototype

After the design of the product form and materials selection is complete, the designer produces and actual physical form that is applied to the product prototype. This prototype may undergo testing and evaluation by experts and
consumers to ensure that the product is safe and effective in all aspects of the
design. The prototype is usually produced with the same methods as mass scale
production but with smaller machinery and in lesser quantities. Successful
completion of the product prototype ends the design process up until the
manufacturing stage of product development.

4 Design Procedure

In order to create a successful form for the Kinkajou, the subsequent design
procedure was followed. Materials and apparatus are listed along with each
section because different tools are necessary for individual steps.

4.1 Evaluate User Needs

Because the initial Kinkajou form did not fit the user needs as specifically as the
group would have liked, the user needs were looked at in terms of how they
could apply to the product design. Below are the user needs for the improved
design and their relationship to the form and materials of the housing.

Inexpensive- Materials for the Kinkajou form should be inexpensive to purchase
and relatively cheap to manufacture into the desired form.

Robust- Form should be able to withstand some impact and material wear, such
as scratches and being dirty, while protecting the optics components from
damage.

Compact- The form should be relatively small and simple so that is easily
portable and less likely to be damaged during setup and transport.

Light- Materials for the Kinkajou form should be lightweight so that they are
portable and less expensive to ship.

Sealed from dust- The form of the Kinkajou should be tightly sealed to avoid
damage from elements while allowing convection to cool heat sink.

Simple to understand- The human interface for the Kinkajou should be
composed of a minimal number of controls with an easy to comprehend
sequence of events and method of interaction.

Easy to use- Kinkajou should be easy to setup, transfer, and operate.
4.2 Determine Form Specifications for New Design

Based on the evaluation of the user needs for the Kinkajou and what they mean in terms of the product housing form and materials, the specifications for the Kinkajou can be defined as specific attributes for the design.

Inexpensive-
• The form of the Kinkajou should be made of a cheap material such as plastic.
• The housing should be possible to thermoform, since it is a relatively inexpensive manufacturing method.
• The mold for the kinkajou should be easy to manufacture from traditional mold materials such as wax impregnated urethane foam.
• Kinkajou controls should be pre-manufactured or easily injection molded.

Robust-
• The Kinkajou form should avoid sharp edges that are prone to stress cracking.
• Materials should be able to withstand moisture, heat, dirt, and being dropped without failure.
• Form should be able to be assembled and removed for maintenance at least 50 times without wearing.
• The power supply connection should be able to be removed at least 1000 times without damage from bending, breaking, or separation.

Compact-
• The volume of the product should contain all components of the projector other than the power source.
• The projector should fit on traditional desktop that is used in third world classrooms.
• The projector should be able to be held by one person and moved from a stored location to a usable position.
• The projector should be small enough to be placed in a carrying case.
• Approximate dimensions of the Kinkajou should be 5 inches high by 10 inches deep by 12 inches wide.

Lightweight-
• The housing should be made of a lightweight plastic such as Kydex.
• A minimal number of fasteners should attach housing to internal base.
• The housing should be the minimum thickness to maintain robustness requirements.
• As few controls as possible should be added to the form.

Sealed from dust-
• The opening for optics unit to protrude should be tightly fit to less than a 1mm gap.
• Slots for air convection to the heat sink should be as small as possible and isolated from other components.
• The method for changing microfilm should be tightly sealed when the projector is in use.
• The power source connection should puncture the form but have gap of less than 1mm on all sides.
• Rubber gaskets or seals should be inserted into all possible leak points that can be dressed.

Simple to understand-
• All directions on the housing should use symbols instead of words.
• Controls should be differentiated from housing by color, form, and/or texture.
• The location of controls should suggest their purpose.
• Warnings should be located near dangerous areas, such as heat sink and power inlet.

Easy to use-
• The Kinkajou form should allow for height adjustments.
• The form should allow film to be changed with one tool at most.
• The same tool should be used to remove the form as required to maintain components.
• One control to turn power on/off, and one control included for fast/precise indexing should be used.
• A dial for the optics unit should be accessible on the front of the lens.
• The controls should not interfere with viewing of images, except for the dial on the optics that would be adjusted before use.
• The connection to the power supply is easy to use and does not interfere with leveling of product.

4.3 Investigate Organization of Internal Components

Once the attributes of the Kinkajou were defined in terms of product specifications, the organization of the internal components was considered. This investigation involved looking at the newest solid model of the Kinkajou and then creating a block model of the major volumes internal to the projector system.

4.3.1 Materials and Apparatus for Internal Components

In order to look at a model of the Kinkajou components that were to be included in the new design, SolidWorks 2000, a PC running the Windows operating system, and the model for the new design, were necessary. This software is shown in Figure 1 with the Kinkajou model displayed. To make the volume model, a ruler, pencil, Exacto knife, cardboard sheets, double sided tape, pink insulation foam, and a wire foam-cutter were used. Other materials such as a triangle and a utility knife may also be useful and are shown in Figure 2.
Figure 1: SolidWorks 2000 and Kinkajou model. The SolidWorks CAD package displays a model of the internal components of the Kinkajou.

Figure 2: Volume model materials. The images above show tools used for creating the volume model including a cutting tool, safety gear, and pink foam.
4.3.2 Internal Components Modeling Procedure

To look at the model of the internal components, SolidWorks 2000 was installed on a Windows operating system computer and the files of the new kinkajou design, which were created by Martin Tolliver, were opened. These files were rotated to look at the basic components of the system and their relative locations as seen in Figure 3.

The main components included an optics unit, heat sink, two microfilm spools, two main base plates, and a rod for indexing the microfilm. The optics unit had to be positioned in between the microfilm spools so that the film would pass in between the LED and the lens. The optics unit had to be directly in front of the heat sink so that the LED would be properly cooled. The base plates had to be parallel to one another so that gears could sit below the microfilm spools. Finally, the rod for turning the microfilm had to be behind the unit so that the user was not interfering with the image when using the device, and so that the belt connecting the gears to the rod had enough friction to drive the system without slipping.

Figure 3: Views of Internal Model. This image shows side, front, and top views of the Kinkajou internal components.
After determining the organization of the components, dimensions of the optics unit and heat sink, microfilm spools, and base plates were taken from the SolidWorks model. These measurements were used to create cardboard templates of the components as displayed in Figure 4. The templates were then cut out with an Exacto knife and attached to a piece of pink insulating foam (Figure 5).

To cut out the form of the components from the foam, two identical templates were stuck to the foam so that they were parallel to one another and the block of foam was placed into the hot wire cutter (Figure 6). The hot wire cutter was set to a temperature that was hot enough to cut through the foam without burning the template. The wire was then run along the edges of the template.

Once a template was cut from the foam, templates for the other views of the piece were attached to the foam and cut out with wire. With all views for a component cut, the templates and extra foam were removed to reveal the volume of the component as represented in Figure 7. This process was repeated for each part to complete the volume model of Kinkajou’s component architecture. The result is shown in Figure 8.
Figure 6: Wire Foam-Cutter. The apparatus above is used to cut pink foam using a hot wire.

Figure 7: Final Foam Pieces. Once a foam piece is cut it is easy to see how the form relates to the template for each of the components.

Figure 8: Volume Model of Internal Components. After cutting the individual components, the volume model for Kinkajou is complete.
4.4 Idea Sketches

The volume model of the Kinkajou (Figure 8) provides a useful three-dimensional aid to visualize the product form. Using this foam model as a tool, rough sketches of the product form were created.

4.4.1 Sketching Apparatus

In order to create idea sketches, a variety of media can be used. Because the first step in the procedure is mainly a brainstorming exercise, trace paper and china markers were used for their loose feeling and low cost. Any paper, markers, paints, or other media that is readily available could also be used. The volume model of the internal components was also on hand to determine proportions and layout.

To create a more defined sketch, a drafting table with a parallel rule bar (Mayline) was used (Figure 9). Other tools included a ruler, triangle, and erasing shield. Materials such as trace paper, drafting tape, a lead holder with pencil leads, an eraser, a black fineliner marker, and a black artists marker were also used.
4.4.2 Idea Sketching Procedure

To render an image that was useful to determining a form, a printout of the plan and elevation of the internal components was sketched onto a sheet of trace paper. The elevation and sectional views were broken down into basic rectangular sections according to various concepts, including regions of motion and regions of human interaction. These areas were overlaid with many colors to generate abstract notions of the product in terms of a mixture of colors, as seen in Figure 10.

![Figure 10: Beginning Sketches. This first sketch was colored to represent different areas of use and action.](image)

After loose sketches of regions of the product were produced, groups of possible plans and elevations of the Kinkajou were created with china markers. These sketches take into account the product attributes that were specified earlier to determine the product form (Figure 11). These sketches also capture the feel that the Kinkajou form will most likely take on. Colors of the sketches were used to suggest different areas of the product, such as buttons, but do not necessarily represent the color scheme of the product (Figure 12).

![Figure 11: Loose Sketches. First pass sketch of possible product form.](image)
Figure 12: Loose Sketches Develop. Several loose sketches from top, front, and side show development of form.

With the rough sketches of multiple views of the Kinkajou drawn, a two-point perspective sketch of the product form was created. To do so, a horizon line and two vanishing points on that line were used to create the perspective. Vertical lines remained perpendicular to the horizon line. Lines for the basic rectangular volumes were lightly drawn with pencil, and curved sections of the form were drawn by creating tangent arcs (Figure 13). Final lines of the form were darkened with a black fine-liner pen and the pencil lines were erased. To make the sketch stand out from the paper, the outer lines of the sketch were thickened with a black marker (Figure 14). If desired, the sketch could be transferred onto a higher quality paper such as vellum for presentation purposes.

Figure 13: Sketch Process Drawings. Sketch drawings of product volume and rounded form for the Kinkajou.
4.5 Two Dimensional Rendering of the Kinkajou

Once the basic form of the Kinkajou was sketched, it was necessary to render the form so that the nature of the materials and textures could be more easily understood. This section details the materials and procedure applied to create the rendering.

4.5.1 Rendering Materials and Apparatus

Rendering a sketch requires the same materials as the initial sketch as well as a few other supplies. The first is marker paper, which holds ink without drying out the markers or smudging. A series of markers including cool grey tones, black, and limited colors were also utilized. Details on the sketch were completed with colored pencils, and an opaque-white pen. The rendering was completed with the drafting table and drafting apparatus as mentioned in the previous sketching section.

4.5.2 Procedure for Creating a Rendered Kinkajou Image

To begin the rendering, the initial sketch of the Kinkajou was lightly traced onto marker paper with a pencil. Using a 30% warm grey marker, the top and sides of the form were colored with an even wash. The features that were of different material than the general form were then washed with a 10% cool grey to distinguish their material. The form was colored a second time with 30% warm grey and 10% cool grey, this time with an emphasis on the curved nature of the form (Figure 15).
Details on the rendering, such as white reflections on the clear acrylic portion of the form and glass lens, were added using an opaque white pen (Figure 16). The center portion of the form that connects the clear sections was lightly colored to distinguish it as a separate element of the form. Finally, the outer edges of the rendering were thickened with black marker to neaten the drawing.

The final rendering of the Kinkajou is shown in Figure 17 with the outer edges completely outlined.
The rendering is finished by outlining the form with black to make the image stand out.

4.6 Creating the Kinkajou Sketch Model

With a concept rendering created, a three-dimensional model of the Kinkajou form was created to look at how scale and usability could be refined. The procedure for creating a foam sketch model is similar to the volume model, but includes more detail and additional steps.

4.6.1 Materials and Apparatus for Creating the Kinkajou Sketch Model

Since the sketch model for the Kinkajou was made using pink foam, it required the same materials as listed in section 4.3.1, as well as rubber cement, spray adhesive, fine grit sandpaper, a small file, acrylic paint, and a foam brush. In addition to the materials listed above, a drill press with a 2" diameter router bit, and stationary belt sander were used. Figure 18 shows some of the additional materials for the sketch model.
4.6.2 Sketch Model Procedure

To begin the sketch model, cardboard templates of the rendered form were created for the overall form as well as the on/off switch, film advance knob, and focusing ring (Figure 19). A section of pink foam was stacked and bonded with spray adhesive, as shown in Figure 20.

The resulting foam block was then cut with a hot wire cutter along the templates to create the basic Kinkajou form. The edges of the form were filleted with sandpaper and a hole for the focusing ring was drilled using a drill press. Ribbed edges were added to the film-advancing dial with a small file (Figure 21).
Figure 21: Edge Detailing. The rough form was sanded and filed to create details on the edges and components were detailed with a file.

The foam components were assembled and joined with rubber cement (Figure 22). After further sanding the form, the model was painted a monochromatic off-white to unify the form (Figure 23).

Figure 22: Assembled Form. The foam components were assembled into a final form.
With the sketch model completed, the form could be presented to other members of the design team.

4.7 Deciding the Final Kinkajou Form

After meeting with the project manager Kateri Garcia and the chief engineer Martin Tolliver, the specifics of the product were further developed. After looking at the final internal model of the new design it was found that the form would have to include a front lens adjustment ring because of a lack of finger space on the lens housing. Considerations for the material were decided on ABS plastic or Kydex with an approximate thickness of 0.125” after samples from companies were researched.

Methods for producing the controls in the rendering were adjusted to allow for integration of existing controls or for injection molding of the main button. It was also noted that a draft angle would have to be added to the final form so that the housing could be separated from the thermoform mold. The scale of the Kinkajou was limited by the decision to use 12” x 12” sheets for the base plates. This was a challenge because the measurement from the outer edge of one spool to another was 10.7”, leaving the remaining portion for a draft angle and for finger clearance between the spools and the housing.

The power source was finalized by the chief mechanical engineer, and the power junction for the Kinkajou was designed to allow a simple connection to a lead-acid battery or adapter cable that could connect to a more conventional power grid.
4.8 Solid Model of Kinkajou Form

Once the overall form of the Kinkajou design was completed, a CAD model of the form was created to determine exact dimensions and to generate a thermoform mold. This sections presents the solid modeling process of the Kinkajou product design.

4.8.1 Solid Modeling Apparatus

The apparatus required to create a CAD model of the Kinkajou included SolidWorks 2000 and a PC running Windows. The sketch model was used as a reference for approximating the dimensions of the forms in addition to a solid model of the internal components.

4.8.2 Dimensioning the Kinkajou Form

Once the sketch model was constructed, a CAD model was derived from its form. First, the internal components were dimensioned in SolidWorks. The maximum and minimum dimensions of the baseplate and the optics unit were noted and a sketch of the bottom of the Kinkajou was created from their measurements.

This sketch was extruded with a 5° draft angle to ensure that it could be removed from a thermoform mold. This volume was then lowered in the back to allow for the film advancement dial and power switch. The form was then filleted on the top corners to create a softer look to the Kinkajou.

![Figure 24: Modeling the Housing](image)  The housing is constructed from a sketch that is extruded to create a volume.

4.8.3 Creating the Kinkajou Mold

After the basic form of the Kinkajou was produced, a mold was created by offsetting the edges of the form by the thickness of the thermoform material. The mold was then marked with indentations to indicate where the thermoform part would be machined. Finally, the amount of material that would be needed was calculated by measuring the surface area of the form.
4.8.4 Modeling Machine Details of The Form

Although the mold was the main component that manufacturers would use during the thermoforming process, the details of Kinkajou form were detailed to show how the thermoform part would be machined. A hole for the optics unit and focusing ring was cut into the front of the form so that the parts could be inserted properly. Openings for the adjustment dial rod, power switch, and power connection were also created. The top of the Kinkajou was also machined to allow the spools to be removed when necessary. Finally, ventilation slots were added to the unit below where the heat sink is situated. These slots are isolated from the spools and optics units so that any moisture or dust will only contact the heat sink.

4.8.5 Creating Additional Components of the Form

Several of the components for the Kinkajou would need to be separately manufactured using machine tools and injection molding. These components were modeled in separate part files so that their forms could be considered in the design.
The focusing ring was created so that the front face tapered in towards the lens, which avoids cut-off of the image. The side of the ring was then ribbed to provide a textured grip surface for the user. The ring protrudes above the housing so that the dial can be accessed during a presentation without obstructing the image.

The film adjustment dial was created in a cylindrical shape that could be injection molded out of plastic. An inverted dome was placed on the top surface of the dial to allow the user to scroll quickly with one finger. The sides of the dial were then ribbed to allow for precise advancement.

A power switch for the Kinkajou was created to indicate when the power was on using a very small colored circle in the center of the switch. When the unit was powered, the switch would appear white in the center. If the unit was turned off, the center would appear black. This change in the color of the switch would indicate the operational state of the Kinkajou.

The spool cover was created so that it could be manufactured with a waterjet machine or using traditional machining methods. Its flat face was cut to closely fit the thermoform part, to avoid dust from entering the unit. A channel was cut into the bottom of the cover so that a rubber gasket could seal the edges of the cover. Holes for screw attachments were also drilled into the cover so that it could be removed to access the microfilm spools.
Feet for adjusting the height of the Kinkajou were placed on the front corners of the baseplate to allow an angle of approximately 10° from the surface to the image source. The rubber feet with threaded attachments allow the base to rise by 1.25”. This provides some variation in the height that a user may require for different classroom designs.

4.8.6 Finishing Touches

After all components were modeled, they were assembled in SolidWorks to represent how they would interact as a whole. This was done by creating mates between parts that defined how each component was oriented in relation to the others.

The assembly was then used to represent the rendered surfaces of the Kinkajou. To do so, the material properties of the components were modified to reflect the quality of its surface.
Once the surface properties were modeled, the color of the Kinkajou was changed to suggest the properties of the plastic and metal parts. Because it is least expensive to use the basic colors of Kydex, the product palette was limited to the 34 choices provided by the manufacturer. With the colors chosen, the form of the Kinkajou design was complete.

Figure 32: Available Color Palette. The color scheme of the Kinkajou was limited to the standard 34 colors of Kydex.

5 Results

After following the steps of the design process, the images below represent the form of the Kinkajou that will be used for the beta prototype. The Kinkajou microfilm projector incorporates a user interface that is easy to operate by limiting the controls to an on/off switch, a focusing ring, and a film-advancing dial. The housing is made of 0.125" thick Kydex, which can be thermoformed in one pull. Machining of the housing is limited to five major cuts including the optics opening, the spool access compartment, the power supply connector, power switch, and the rod for the advancing dial. Other components of the housing such as the power switch, advancing dial, and power connector can be injection molded with a very small mold. The spool access plate can be machined out of Lexan and edged with aluminum.
Figure 33: Isometric View of Final Kinkajou Design. The final Kinkajou form with front portion shown.

Figure 34: Back Isometric View of Final Kinkajou Design. The final Kinkajou design from a back corner standpoint.
The volume of the Kinkajou is approximately $200 \text{ in}^3$ and with dimensions of $12'' \times 9'' \times 3''$. The materials for the housing weigh approximately 1lb and are able to withstand forces of $15 \text{ ft}^*\text{lb/in} [795\text{J/m}]$. The housing can also withstand moisture, dust, and heat exposure by being designed with tight tolerances and rubber gaskets.

6 Discussion

The Kinkajou design, as presented in the results above, fulfills the design criteria that were specified by the user. The Kinkajou design is inexpensive compared to similar products because the housing is made in one thermoformed piece. The additional components for the user interface are simple forms that can easily be manufactured or found pre-made. Raw materials for the entire form, including components, cost approximately $15$ dollars for the prototype. This cost could be reduced by approximately $20\%$ with larger production volumes.

Robustness of the product is addressed in the design by creating a simple, compact form. The shape of the Kinkajous has no sharp edges that would break when handled, and its rounded corners prevent wear along the edges of the product. The Kydex sheet that is used for the housing has an impact strength of $15 \text{ ft}^*\text{lb/in} [795\text{J/m}]$ and a Rockwell Hardness of 94, as listed by the manufacturer.
Kleerdex Company (www.kydex.com). The power supply connection is press fit into the housing, so that it may withstand daily removal. The simple housing access to the microfilm spools ensures that internal components are not damaged.

The Kinkajou design is compact, as desired by the user. The volume of the Kinkajou is 200 in$^3$, which is 30% of the original design and less than 10% of a standard microfilm projector that one would find in a public library. The front to back dimension of the form is less than 12”, so that it may be placed on a small desk or table. This size is easily manageable by a small user, such as a young student who may operate the projector.

In addition to its size, the Kinkajou form is lightweight. The materials for the housing and components weigh approximately 1lb, which is approximately 10% of the target weight of 10lbs. This is accomplished by using a lightweight plastic that has a high strength for a given thickness. This allows the manufacturer to use less material and still produce a durable product.

The product design of the Kinkajou microfilm projector protects internal components from the elements by using a plastic with a water-absorption of 0.07% over 24 hrs (ASTM D-570) as specified by Kleerdex Company. The interface between the housing and controls is protected through tight tolerances and rubber gaskets. The design of the housing is made to isolate the heat sink ventilation system from the electronic and mechanical components as well as the microfilm spools. Because of this, dust and moisture are unable to enter the housing where sensitive parts are located.

The Kinkajou form is simple to understand because it is designed to require no words to describe the operation of the controls. The on/off switch suggests the state of the light in the projector, and the turning of the advancing dial suggests the ability to move from on slide to the next and back. The dial proportions of the advancing dial, power switch and focusing ring are all based on the size of the human hand and fingers, so that the textured areas of the controls are understood to be touched. The power connector junction is designed to not be touched because it is recessed. A finger or pencil cannot be inserted in a way that would injure the user.

Ease of use is also incorporated into the design of the Kinkajou. To operate the system, the user plugs in the unit, and presses the power switch. They may move to a section of teaching material with the advancing dial, adjust the image using the focusing ring, and they are ready to learn. When a class is finished, the teacher may turn off the power switch, unplug the Kinkajou, and store it in its case.

In the design of the Kinkajou that was stated above, several assumptions were made. It was assumed that an external power supply would be provided as an
accessory, or an external generator could be attached to the power junction. It was also supposed that the dimensions of the internal components in the solid model of the Kinkajou were exact. These design constraints may affect the overall size of the projector and the shape of the power junction.

7 Conclusion

After completing the design process for the Kinkajou, the results are sufficient to present to the entire design team to begin actual production of the beta prototype. The material specifications and exact dimensions provide the level of detail necessary to be manufactured by a machine shop or within the MIT Pappalardo Laboratory. The user needs have been investigated in depth, and the proposed solution presents one way of meeting the user needs.

In order to truly verify the success of the Kinkajou design, it will be necessary to present the prototype to users in third world classrooms. This is the task of the Kinkajou design team in the future. In the next two months, a prototype will be built and sent to a classroom in Mali. Members of the team will accompany the project supervisor in evaluating the performance of the product. This feedback may demand additional changes be made to the form. In any case, this investigation sheds light on the design process and provides a unique look at a mechanical engineering challenge.
8 Acknowledgements

There is nothing more significant to my experience at MIT than the mentoring that I have received along the way. For his constant support and enthusiasm, I would like to thank my mechanical engineering thesis advisor Professor David Wallace. Since my first UROP as a freshman in his lab, Professor Wallace has encouraged my interests in design. His advice in my coursework as well as personal interests in mechanical design and architecture has allowed me experience the richness of mechanical design at MIT. His lectures are priceless to a young engineer and his passion for design is inspiring. For his guidance, I am sincerely thankful.

My experience at MIT has been enriched by the counseling of my advisors Professor David Parks and Professor Les Norford. They have been supportive through my successes as well as my difficulties. Their advice has helped me through the challenges of a double major and they have always pointed me in the right direction when I was unsure of my decisions. I would like to thank them for their welcoming and sincere correspondence.

When details of a project needed to be worked out, the Mechanical Engineering Department has been supportive in every aspect of my education. The MIT Pappalardo Laboratory staff is undoubtedly dedicated to the curiosity of students and I have the utmost respect for their expertise. Their suggestions and one-on-one design assistance is invaluable to me as a mechanical engineering student. The friendly reminders, understanding, and support of Peggy Garlick in the M.E. Undergraduate office are sincerely appreciated.

I would like to thank my peers in the mechanical engineering department for their partnership in many engineering challenges. It has been an honor to work with students that are so excited about learning. Specifically, I would like to thank Martin Tolliver and Kateri Garcia for asking me to work on the Kinkajou Project. It has been a great project to develop and I am happy to have investigated it as a thesis project. Weeks of two-hour naps and coffee breaks were survivable with their support.

Finally, I would like to thank my family and friends. Thank you for the checking in on me to make sure I have eaten. Thank you for cheering me on when I was excited about a project, and for cheering me up when I thought I couldn’t last another sleepless day. I will return all your phone calls when I finish writing this.
# Appendix A: Kinkajou User Needs

This appendix presents the user needs that were established by the 2.009 team that first developed the Kinkajou microfilm projector.

<table>
<thead>
<tr>
<th>Customer Needs</th>
<th>Design Attributes</th>
<th>Engineering Specs</th>
<th>Risks</th>
<th>Countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can read/copy images from a distance of 2 feet</td>
<td>x x x x x Clear Image</td>
<td>Ability to focus image by adjusting the distance of lens from light source / screen</td>
<td>Must hold screen 0.5 inches away from the lens to project 8.5x11&quot;</td>
<td>Attach screen to projector, or make it a backlit projector</td>
</tr>
<tr>
<td>Should work with easily available batteries</td>
<td>x x x x x Bright and Even Image</td>
<td>a) 1 W green LED bulb</td>
<td>Light is too big to fit the microfilm image</td>
<td>Put light underneath film and direct it through a mirrored column which reflects off a 45degree mirror that projects the microfilm (see diagram)</td>
</tr>
<tr>
<td>Should last the student his/her entire academic career</td>
<td>x x x x x Plastic Casing</td>
<td>Injection Molded ABS plastic</td>
<td>Plastic Lens 8mm focal length CCD lens assembly</td>
<td></td>
</tr>
<tr>
<td>Should withstand high temp, humidity and dust levels</td>
<td>x x x x x Plastic Lens</td>
<td>8mm focal length CCD lens assembly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Could be used for various curriculum at home or in school</td>
<td>x x x x x Rechargeable Batteries</td>
<td>x x x x x Micro Film</td>
<td>Each image on microfilm is 4mm X 5.75mm and 100-1000 images (pages) per cassette</td>
<td>Cassette minimizes, but does not fully eliminate, risk of contamination</td>
</tr>
<tr>
<td>Could be used for various curriculum at home or in school</td>
<td>x x x x x Non-toxic Materials</td>
<td>ABS plastic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimal handling</td>
<td>x x x x x Ease of locating information</td>
<td>To advance film, coarse (10 pages/turn) and fine (1 page/turn) dials using gears</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Attributes</td>
<td>Engineering Specs</td>
<td>Risks</td>
<td>Countermeasures</td>
<td></td>
</tr>
<tr>
<td>Clear Image</td>
<td>Ability to focus image by adjusting the distance of lens from light source / screen</td>
<td>Must hold screen 0.5 inches away from the lens to project 8.5x11&quot;</td>
<td>Attach screen to projector, or make it a backlit projector</td>
<td></td>
</tr>
<tr>
<td>Bright and Even Image</td>
<td>a) 1 W green LED bulb</td>
<td>Light is too big to fit the microfilm image</td>
<td>Put light underneath film and direct it through a mirrored column which reflects off a 45degree mirror that projects the microfilm (see diagram)</td>
<td></td>
</tr>
<tr>
<td>Plastic Casing</td>
<td>Injection Molded ABS plastic</td>
<td>Plastic Lens 8mm focal length CCD lens assembly</td>
<td>Plastic Lens 8mm focal length CCD lens assembly</td>
<td></td>
</tr>
<tr>
<td>Rechargeable Batteries</td>
<td>x x x x x Micro Film</td>
<td>Each image on microfilm is 4mm X 5.75mm and 100-1000 images (pages) per cassette</td>
<td>Cassette minimizes, but does not fully eliminate, risk of contamination</td>
<td>Instruct user to rewind tape each time after use so that only the &quot;dummy tape&quot; is exposed</td>
</tr>
<tr>
<td>Non-toxic Materials</td>
<td>ABS plastic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of locating information</td>
<td>To advance film, coarse (10 pages/turn) and fine (1 page/turn) dials using gears</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compact</td>
<td>Folding mechanism to make it easy to store</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light weight</td>
<td>Under 1.5lbs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Cost</td>
<td>Cost to manufacture unit below $20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Bibliography


[www.kydex.com](http://www.kydex.com) (product specification sheets for and color availability.)