Design and Fabrication of Injection-Molded and 3D-Printed Battery Clips for "Chibitronics" Circuit Sticker Workbook

By

Paelle M. Powell

SUBMITTED TO THE
DEPARTMENT OF MECHANICAL ENGINEERING
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2015

Signature of Author: Signature redacted
Department of Mechanical Engineering
May 8, 2015

Certified by: Signature redacted
Joseph Paradiso
Director, MIT Media Lab Responsive Environments Group
Thesis Supervisor

Accepted by: Signature redacted
Anette Hosoi
Professor of Mechanical Engineering
Undergraduate Officer

Design and Fabrication of Injection-Molded and 3D-Printed Battery Clips for "Chibitronics" Circuit Sticker Workbook

by
Paelle M. Powell

Submitted to the Department of Mechanical Engineering
on May 8, 2015 in Partial Fulfillment of the Requirements for the Degree of
Bachelor of Science in Mechanical Engineering

ABSTRACT

In order to create an injection-molded battery clip for the Chibitronics Circuit Sticker kit, both manufacturing and product design principles were considered to inform product feel and form as well as ensure manufacturability in future iterations of the clip. Prototypes were initially designed using modeling clay. These prototypes were then developed in Solidworks and printed on a MakerBot 3D printer. Three iterations of prototypes were tested and design decisions were made based on user need and aesthetic appeal of the battery clips. These prototypes were used to determine a final design decisions and the creation of a mold that will be used in future manufacturing of these battery clips.

Thesis Supervisor: Joseph Paradiso
Title: Director, MIT Media Lab Responsive Environments Group

Acknowledgements

The author would like to thank Jie Qi, PhD Candidate in the MIT Media Lab Responsive Environments Group for her mentoring through both the Fall and Spring semesters. The author would also like to thank Tom Lutz for helping with 3D print runs on a regular basis. Finally the author would like to thank Dave Dow, lab instructor for 2.008 Manufacturing and Design II for teaching all of the necessary skills for the author to be successful in designing injection-molded parts.

Biographical Note

Paelle Powell, Mechanical Engineering '15, has always been both an artist and an engineer. Her time at MIT has been dedicated to learning everything possible about manufacturing products and mechanical design. She has been very fortunate to have opportunities at MIT to lead her peers through the design process from brainstorming to manufacturing, and also has done many projects on her own to improve her hands-on technical skills, such as building robots. Paelle strives to implement simplicity and beauty into her mechanical work and has thoroughly enjoyed doing so first as an Undergraduate Researcher and then as a Senior working on her thesis in the MIT Media Lab.

Table of Contents

Abstract	3
Acknowledgements	4
Biographical Note	4
Table of Contents	5
List of Figures	6
List of Tables	6
1. Introduction	8
1.1 Chibitronics Background and Project Overview	8
1.2 Product Design and Development	9
1.2.1 Product Design Considerations	10
1.2.2 The 10-Step Design Process	10
1.3 Design for Manufacturing and Assembly	11
1.4 Injection Molding Background	12
2. Chibitronics Battery Clip Design Considerations	13
2.1 Identification of User Need	13
2.2 Materials	13
2.3 Specifications	15
2.4 Mechanical Considerations	16
2.4.1 Battery Contact	16
2.4.2 Wear of Thermoplastics	17
3. Process	17
3.1 Sketches and Initial Prototypes	17
3.2 Solidworks Models and 3D Print Runs	20
3.2.1 Iteration 1	21
3.2.2 Iteration 2	22
4. Injection Molding the Clip	24
4.1 The Mold	24
4.2 Statistical Process Control	26
5. Further Work and Manufacturing Recommendations	27

5.1 Injection Mold Production Run 27

5.2 Considering the Costs of High Volume Manufacturing 27

6. Concluding Statements

7. Appendix 28

7.1 Iteration 1 CAD Models 28

7.2 Iteration 2 CAD Models 32

8. Bibliography 35

List of Figures

Figure 1:	Current Chibitronics Kit	8
Figure 2:	Circuit with Battery Placement	8
Figure 3:	Circuit with Binder Clip	9
Figure 4:	Sewable Battery Clip	11
Figure 5:	Injection Molding Schematic	12
Figure 6:	Non-optimal Wiring Configuration	16
Figure 7:	Diagram of Maximum Stress Concentration	17
Figure 8:	Initial Clip Sketches	18
Figure 9:	Inner Bump Sketch	18
Figure 10:	Snap-closed Clip Design	19
Figure 11:	Polymer Clay Prototypes	19
Figure 12:	Force Distribution Sketch	20
Figure 13:	Iteration 1 3D Printed Models	21
Figure 14:	Car Clip	21
Figure 15:	Successful Integration of Car Clip	22
Figure 16:	Iteration 2 3D Printed Models	23
Figure 17:	Dinosaur Clip	23
Figure 18:	Cavity Mold in MasterCAM	25
Figure 19:	Core Mold in MasterCAM	25
Figure 20:	Frequency Distribution	26

List of Tables

Table 1:	Material Properties of Polymers	15

1. Introduction

1.1 Chibitronics Background and Project Overview

Chibitronics Circuit Stickers are a set of electronics stickers developed for the purpose of doing both educational and artistic projects.

Figure 1. Current Chibitronics kit, and conductive thread used in sewing projects.

The current Chibitronics kit that is being sold at Makershed.com includes a workbook that teaches basic electronics concepts, LED circuit stickers and a variety of sensor stickers. The projects are powered using a 3-Volt Lithium coin-cell battery and wired together using copper tape. The method for attaching the battery into the current circuit is to use a black binder clip.

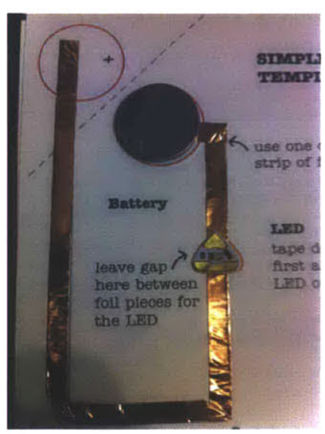


Figure 2. Circuit with battery placement.

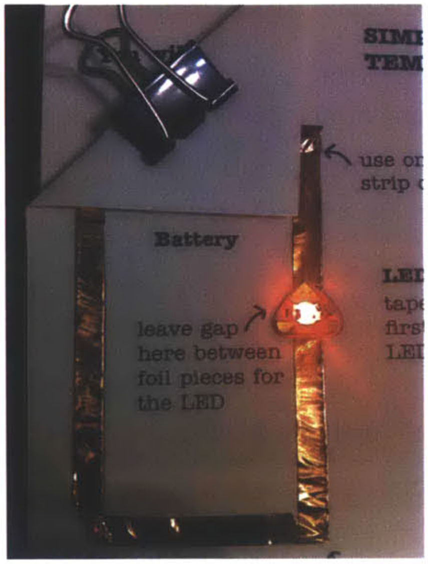


Figure 3. Circuit with binder clip.

During Fall 2014, projects were created using fabric and conductive thread in order to explore the possibilities regarding the use of Chibitronics Circuit Stickers in fabric and wearables. In order to attach the coin cell battery into these fabric projects, it was necessary to order a specific coin cell battery holder that is rectangular and bulky.

Both options for inserting batteries into the circuits were large and could not be easily visually integrated into projects.

The purpose of this project has been to design and prototype a variety of possibilities for a new injection-molded battery clip that is simple to use and integrates both mechanically and visually with the current workbook. The intention has also been to develop a clip that blends in or complements art projects created using the Chibitronics Circuit Stickers.

1.2 Product Design and Development

During the course of this project, the outline of the product development process from MIT's 2.009 – Product Engineering Processes was used in conceptualizing and implementing the design for the Chibitronics battery clip. This outline begins with a product in the brainstorming phase. It leads from the identification of customer need and definition of specifications, through concept generation, selection and testing. Once a design has been chosen, it is optimized for the environment and for manufacturing. Over the course of this entire process, prototypes are to be built and tested to confirm hypotheses regarding appropriate design parameters [1].

1.2.1 Product Design Considerations

In order to succeed in an increasingly competitive global marketplace, it is imperative that product designers consider questions that will ensure the product is high quality, using the best materials and processes for the particular product at the same time as minimizing cost. Some of the questions that designers must check and verify and that were addressed during the design of the Chibitronics Battery Clip include the following:

- Have all alternative designs been investigated?
- Can the design be simplified or the number of components minimized without affecting its function and performance?
- Can the design be made smaller or lighter?
- Are there unnecessary features in the product; can they be eliminated or combined with other features?
- Can specified dimensional tolerances be relaxed without adverse effects?

These questions aided in the simplification and appropriateness of the design of the clip for its specific application.

1.2.2 The 10-Step Design Process

Throughout this project, the 10-Step Design Process was followed. This process was outlined and taught in an MIT class, ESD.051 Engineering Innovation and Design:

1. Identify a Need
2. Gather Information
3. Identify the Stakeholders
4. Planning and Operational Research
5. Hazard Analysis
6. Specifications
7. Creative Design
8. Conceptual Design
9. Prototype

10. Verification

Upon identifying the need for a new style of battery clip in the Chibitronics Circuit Sticker workbook, information was gathered regarding the kinds of battery clips that currently exist, identifying the number of components and overall look of these clips. In particular, the clip that exists on Adafruit.com for integration of the coin-cell battery into sewing projects was examined.

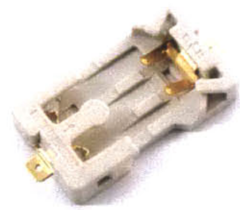


Figure 4. Sewable coin-cell battery holder from www.adafruit.com.

The timeline for the project was planned out over the course of the semester and stakeholders were identified to be customers buying the Chibitronics kits, as well as those who had developed and were currently working on the kit. Hazard analysis included the consideration of timeline uncertainties regarding tasks that had to be done by other people, such as assistance with use of the MakerBot 3D printer for doing prototype runs as well as ability to use the 2.008 Manufacturing machine shop for mold creation and final production runs.

Once the first five steps of the 10-Step Design Process were completed, specifications were determined and the physical design process could begin.

1.3 Design for Manufacturing and Assembly

In order to ensure that the Chibitronics Battery Clip could be manufactured at high volume, Design for Manufacturing (DFM) principles were incorporated into the design and considered when evaluating each iteration of clip prototypes.

DFM integrates the design process with the production methods involved. There are four main categories of consideration in DFM: cost, rate, quality and flexibility. Depending on the part or product, few or all of these categories may inform the design and tooling choices based on variability in machine performance, dimensional accuracy and desired surface finish of the part. Analysis and optimization of the design leads to ease of manufacturing and reduction of product cost [2].

Also considered in the design of the Chibitronics Battery Clip were the concepts of Design for Assembly and Disassembly (DFA and DFD). While the clips themselves were envisioned to be a single component, it was important to keep in mind that the battery and circuits were to be inserted into the clip and then removed many times. DFA and DFD ensure that the part will retain its integrity during the process of being assembled and disassembled, which is the normal use for which the battery clip is intended.

Assembly as a phase of manufacturing requires ease, speed and cost of putting together individual components. Since the assembly of the circuit is left to the user, ease and speed of the assembly of the battery and clip are an important consideration in user experience.

1.4 Injection Molding Background

Injection molding is a process in which pellets or granules are fed into a heated cylinder and the melt is forced into a mold by a hydraulic plunger or rotating screw system. The barrel is heated externally to promote the melting of the polymer, and a great portion of the heat transferred to the polymer also comes from frictional heating. After sufficient cooling, the mold is opened and ejector pins are used to remove the part from the mold. This process can be repeated automatically [2].

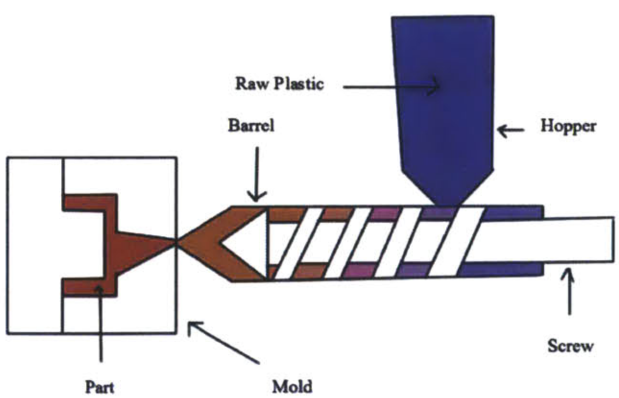


Figure 5. Injection molding machine schematic.

Since the intended method of manufacturing for the Chibitronics Battery clip is injection molding, specific design criteria related to the injection molding process had to be adhered to during the design and prototyping phases.

Injection molding is one of many forming processes, a general term which also includes processes such as metal casting and sheet metal forming. Forming processes are used to create parts in high quantity and variety. Injection molding, in particular, is often chosen for manufacturing due to its high rate and quality. While the upfront cost in creating the mold is high, the individual part cost is very low; therefore, for high quantities of parts, the overall cost of injection molding is considered to be moderate to low.

In contrast to general machining, where a set of cutting tools can be used to create a wide variety of finished parts, injection molding relies on one mold to create the geometry of the finished part [3]. This means that the injection molding process (and forming processes in general) are not as flexible when it come to design changes as a machining process would be. The benefit of forming processes is the fact that it produces "near net shape" parts: the parts are almost exactly the same once they have been produced. In Section 4.2, Statistical Process Control, a discussion follows regarding how to determine the number of parts that will fall within an acceptable tolerance range based on trials run during a set number of injection molding processes.

Since the battery clip will be injection-molded, simplicity was a very important consideration in the design. Surfaces needed to be design with either flat or simple curved edges to ensure that the parts could be ejected from the mold.

Choosing a design with near-uniform thicknesses and reducing the thickness of parts would also ensure that the clips did not warp upon cooling. Designing with these parameters in mind also reduces cycle time and cost of mass-production of parts like this.

Finally, part numbers also needed to be minimized and surfaces needed to be simple enough for machining into two-part core and cavity molds. Ideally the clips were to be only one piece. The maximum number of pieces would be two.

2. Chibitronics Battery Clip Design Considerations

2.1 Identification of User Need

The first step in the Product Development Process is to identify Customer Needs [1]. In order to identify those needs, it is necessary to consider whether a certain need or desire may not be currently fulfilled by existing products, or whether a current product in an existing market could better or more completely fill the needs of the users. In the ideation phase of the Chibitronics battery clip, it was determined that while the current use of a black binder clip as the battery clip did fill the physical need, the clip could be made better with regards to size, aesthetic and form.

The two user bases considered in integrating the battery clip into the Chibitronics Circuit Sticker book were people who are new to creating circuits and young students. The needs of these customers encouraged consideration of both the fun aspect of the clip as well as how to make its form factor easy to handle. For users who intend to use the Chibitronics Circuit Stickers without the workbook and integrate them into paper and fabric projects, it was important to consider how the clips would either inform or be incorporated into a wide variety of projects.

2.2 Materials

Polymers were an ideal choice in the design and manufacturing of the Chibitronics Battery Clip due to their manufacturing advantages, including low cost, good performance and ease of manufacturing [2]. Polymers also have low electrical and thermal conductivity. All of the polymers used in development of the battery clip were thermoplastics. When the temperature of a thermoplastic is raised above its glass transition temperature, T_G, the thermoplastic becomes easy to form. This raised temperature weakens secondary bonds in the chained molecules, and adjacent chains then move easily with respect to each other as they are subjected to external forces [4]. When a thermoplastic cools, it returns to its original hardness and strength.

The thermoplastics used in the design process of the Chibitronics Battery Clip are listed in the following table, along with relevant material properties:

Material	Young's Modulus (GPa)	Ultimate Tensile Strength (MPa)
Polymer Clay	0.014 to 4	7-55
ABS	1.4-2.8	28-55
Polypropylene	0.7-1.2	20-35

Table 1. Material properties of polymers used in battery clip prototyping and design.

Polymer clay and ABS plastic were used for prototyping and polypropylene pellets were the intended injection molding material. The early use of polymer clay was successful for visualization of integration with the battery, but fatigued after only a few assembly/disassembly tests. This particular polymer clay was inexpensive and likely on the low-end of the scale for Ultimate Tensile Strength.

ABS plastic proved to be good for visualizing final designs but less helpful in testing due to its rigidity. Parts that were dimensioned to fit the battery and printed in ABS plastic were especially difficult to slip on and off of the battery due to tight tolerances as well as tolerance limitations of the MakerBot 3D printer. The relatively high Young's Modulus of ABS causes it to resist elastic deformation, giving it little ability to bend unless the part thickness is minimal.

It was determined that the polypropylene plastic used in injection molding would be an ideal material for the final clip manufacturing due to its low Young's Modulus and reasonable Ultimate Tensile Strength, properties which ensure good performance in snap-fit applications.

2.3 Specifications

The critical dimension of the Chibitronics battery clip was the inside width between the faces that mated with the battery surfaces. For early prototypes, this dimension was defined to be that of the battery thickness and the tolerance of the calipers used to measure the battery: 0.123" +/-0.001."

More specific tolerances were added in later prototypes. For those later prototypes, two thicknesses of the paper that would be inserted between the battery and the clip was included as part of a positive tolerance on the inside width: 0.123" +0.018/-

0.000." This paper thickness was measured to be 0.009" from the Chibitronics Circuit Sticker Workbook.

In the final mold design, negative tolerances were specified in order to ensure snap-fits based on recommendations from the MIT 2.008 Yoyo project handouts. The inside dimension and tolerance of the final mold design were 0.123" +0.005/-0.000."

The surface area on the inside of the clip also had to be large enough to ensure contact between leads made of copper tape. Ideally if the conductive copper tape was placed all the way near the left edge of the battery on one side, and near the right edge of the battery on the other side, contact would still be made upon insertion into the clip. The material thickness also had to be great enough to ensure a sturdy connection between the battery and the copper tape leads. The specific numerical values stated for these parameters were found during the prototyping process.

2.4 Mechanical Considerations

2.4.1 Battery Contact

The two conductive materials used with the current Chibitronics Circuit Stickers in order to wire together the stickers are copper tape and conductive thread. Both of these materials have small leads. In order to ensure that the battery contacts the leads, pressure must be exerted over the majority of the surface area on both the top and bottom of the battery.

Clip designs that did not cover a majority of this surface area were discarded due to the difficulty of lining up leads properly to be sandwiched between the clip and the battery.

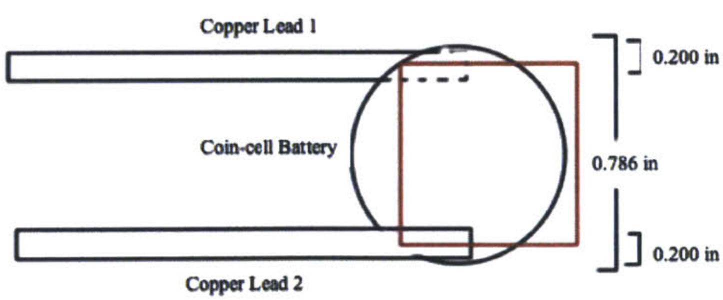


Figure 6. The above schematic shows a non-optimal wiring setup of which the Battery clip should still be able to maintain contact between leads and battery.

2.4.2 Wear of Thermoplastics

Thermoplastic wear is similar to that of metals. The abrasive-wear behavior depends on the ability of the part to deform and then recover elastically. Polypropylene is one of the polymers that has particularly good wear resistance [2].This means that stresses introduced in the material will not cause the part to break, even when the stress is cycled many times.

3. Process

3.1 Sketches and Initial Prototypes

After creating initial sketches, prototypes were made out of polymer clay. Once the clay was baked, it became a rigid piece with minimal strength and elasticity. This method of rapid prototyping was used for its speed and simplicity in the early stages of design, mainly for visualization purposes – the material properties were not appropriate for further testing, as the polymer clay clips broke very easily under minimal stress.

This breakage did help to inform future designs as well. Since the breakage occurred in similar places in a few of the polymer clay clips, a brief analysis could be done to confirm the point of maximum internal stress concentration in the clip.

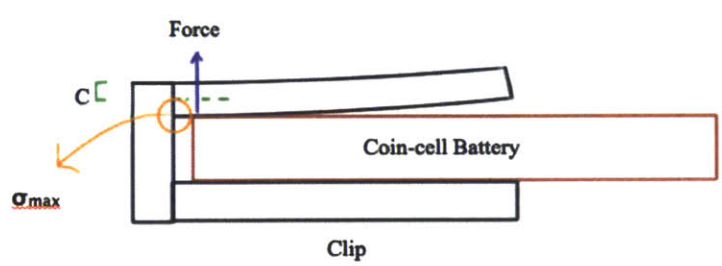


Figure 7. The green dashed line in the clip denotes the neutral axis. The maximum stress occurs a distance C from the neutral axis along the face experiencing the maximum bending moment. In this case that face is the one that mates with the battery.

$$\sigma_{max} = \frac{M * C}{I}$$

σ_{max} – maximum normal stress in the member occurring at the point on the cross-sectional area farthest from the neutral axis

M – resultant inertial moment

C – perpendicular distance from the neutral axis to the point where sigma max acts

I – moment of inertia of the cross-sectional area about the neutral axis [5].

In order to get a general sense of the form and feel of different sizes of battery clips, six different shapes and thicknesses were created. Then each initial design was clipped onto the battery and evaluated based on whether the clip was easy to put onto the battery and then remove, based on its visual appeal, and based on whether the mating surface between the clip and the battery had enough surface area to ensure contact between the leads of the circuit and the face of the battery.

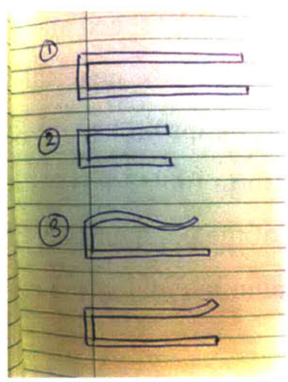


Figure 8. Initial clip sketches.
The design was intended to be very simple and a press fit around the battery.

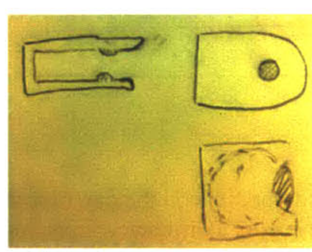


Figure 9. Sketch of the design with inner bump. Instead of helping to maintain contact with battery, the bump reduced the contact area and was less effective.

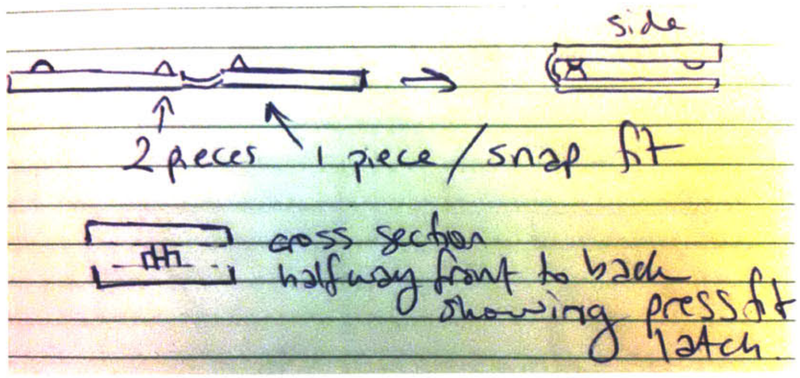


Figure 10. This snap-closed clip design was very complicated. It was decided that a simpler design was desirable for manufacturability.

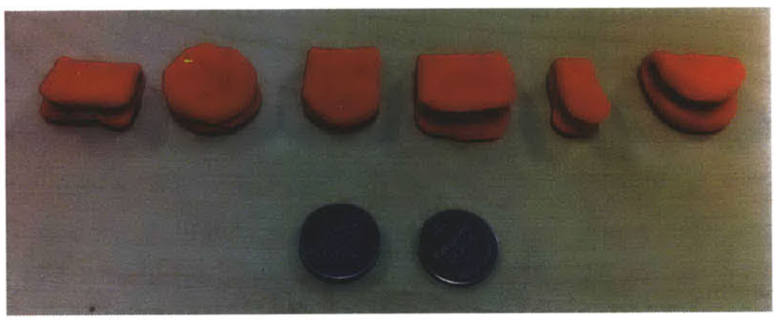


Figure 11. Clay prototypes helped to physically test contact area of each clip design on the battery as well as form factor when handling the clip.

Upon testing the intial prototypes, it was found that clips with top view area greater than that of the battery were very difficult to remove from the battery once put together. Clips with top-view surface area smaller than the clip were much easier to manipulate once the battery was inserted. Adding a bump on the inside of the clip reduced the contact area between the clip and the battery to a single point, which was especially ineffective for ensuring contact between the leads of the circuit and the battery.

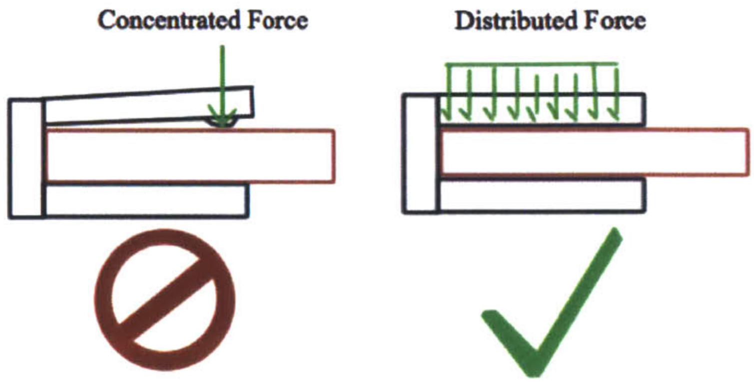


Figure 12. Designing the clip to ensure an overall pressure distribution was much more effective than the early designs that incorporated a bump and caused a concentrated force to be imparted upon a single point on the battery.

After creating and testing these initial prototypes, it was decided that further clip iterations should maximize contact area with the battery without encapsulating the battery, in order to ensure physical contact between leads when the battery was clipped into a circuit and to ensure that the battery could be easily removed from the clip by hand.

3.2 Solidworks Models and 3D Print Runs

Solidworks was used in the next prototyping phase of the Chibitronics Battery Clip for its ability to 3D model not only the desired parts, but also to help visualize the final battery assembly before parts were 3D printed. Files can be exported as .stl to the MakerBot 3D printer and printed in ABS plastic.

Upon choosing the final clip design, Solidworks also provides the capability to create and export injection mold drawings that include shrinkage allowances and relief angles as specified. These drawings can be opened in MasterCAM, modified to include proper machining parameters for both the Lathe and Mill as necessary, and exported as a tool path in G-Code that is then used as numerical control on either the Lathe and Mill. These tool paths can be optimized to reduce the cycle time for machining of the mold, thereby reducing the overall production cost of an injection molded part.

3.2.1 Iteration 1

The initial 3D print clip designs were chosen to test form and size. A Thin clip was printed as a proof-of-concept, while the Plus and Minus clips were printed in two different sizes in order to explore whether the size affected the part rigidity and integrity. The Car clip was designed in order to explore the tactile experience of a curved clip surface as well as whether increased part thickness increased or decreased clip function. Dimensioned Solidworks models and the Car clip/battery assembly for iteration 1 can be found in Section 6.1, Iteration 1 CAD Models.

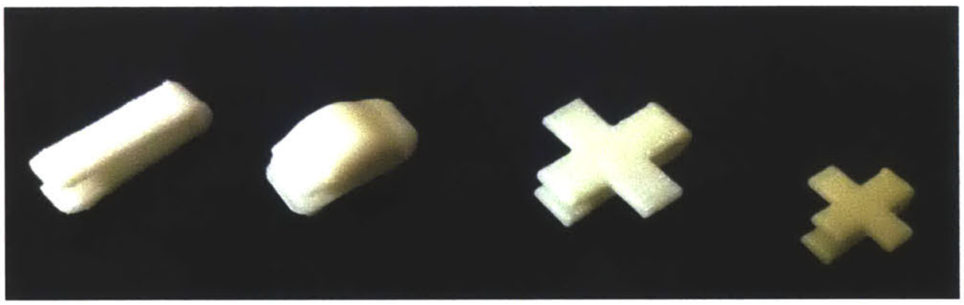


Figure 13. The initial 3D print run had four designs. These designs were chosen for their variety in terms of simplicity, novelty and size comparison.

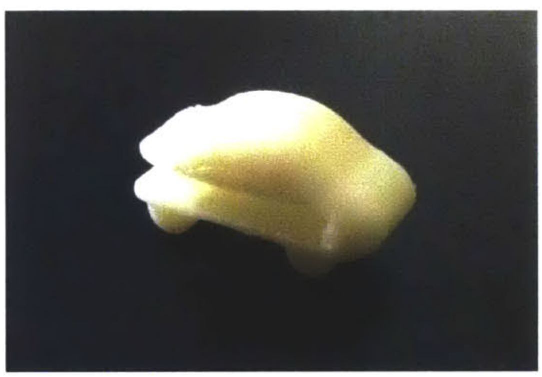


Figure 14. This car design showed that thickness of material did help to ensure contact between the mating surfaces of the battery. While it was fun to integrate into circuit designs, it was decided that its form could influence circuit design choices too much.

Upon testing of each of the four clips from iteration 1, it was found that the Plus and Minus clips (3D-printed thickness: 0.053") and the Thin clip (3D-printed thickness: 0.057") did not keep proper contact over the surface area of the battery. Each of these clips was bending upwards in a similar was to the polymer clay from the initial prototyping method. Although these clips were not breaking, the force that the battery was imparting at the back wall of the clip was causing the material to bend outwards in a similar fashion to that which was discussed in Section 3.1 regarding the point of maximum stress concentration on the clip.

The Car clip was the most successful clip in the first iteration. The extra material gave the clip added strength which resisted the outward forces exerted by the battery when it was inserted into the clip. Contact was maintained between the battery and the circuit leads when the car clip was added to the circuit. The smallest thickness on the Car clip after it was 3D-printed was 0.051" and the largest thickness was 0.158."

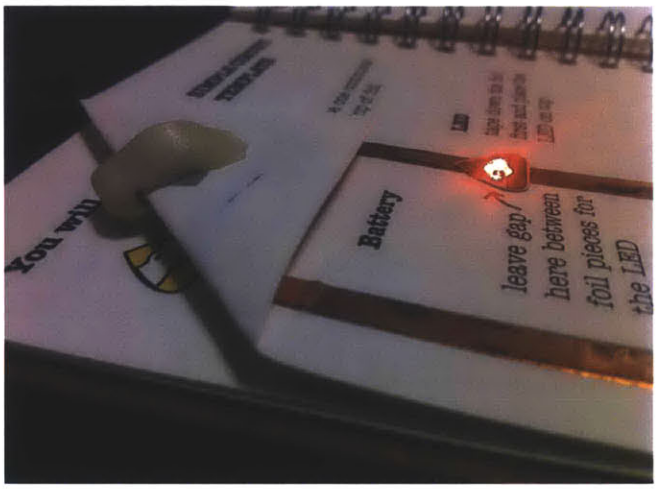


Figure 15. Successful integration of Car clip into Chibitronics Workbook.

3.2.2 Iteration 2

For the second iteration of 3D printing, clips were designed with tactile appeal and structural integrity in mind. In order to continue to include the tactile appeal that the Car clip from the previous iteration had, curved surfaces were created using splines in Solidworks and used in the design of each new clip. Designs were much thicker than in the previous 3D-print iteration. The inside dimensional tolerance was modified slightly to -0.000/+0.018" to account for the inclusion of paper around the battery.

The Dinosaur clip was created in order to test the feasibility of holding the battery in two different configurations: horizontal and vertical. Dimensioned Solidworks models and the Dinosaur/battery assembly can be found in Section 6.2, Iteration 2 CAD Models.

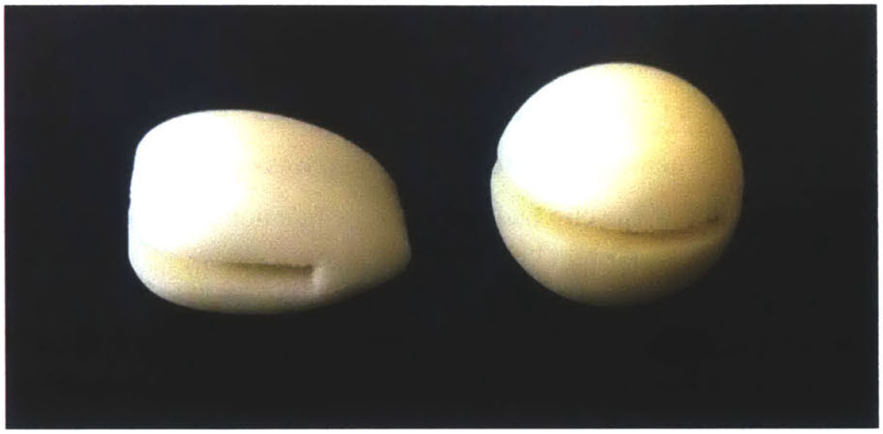


Figure 16. Clips with more rigidity were better able to hold onto the battery. Also, a simplistic design allowed for artistic interpretation when integrated into the circuits.

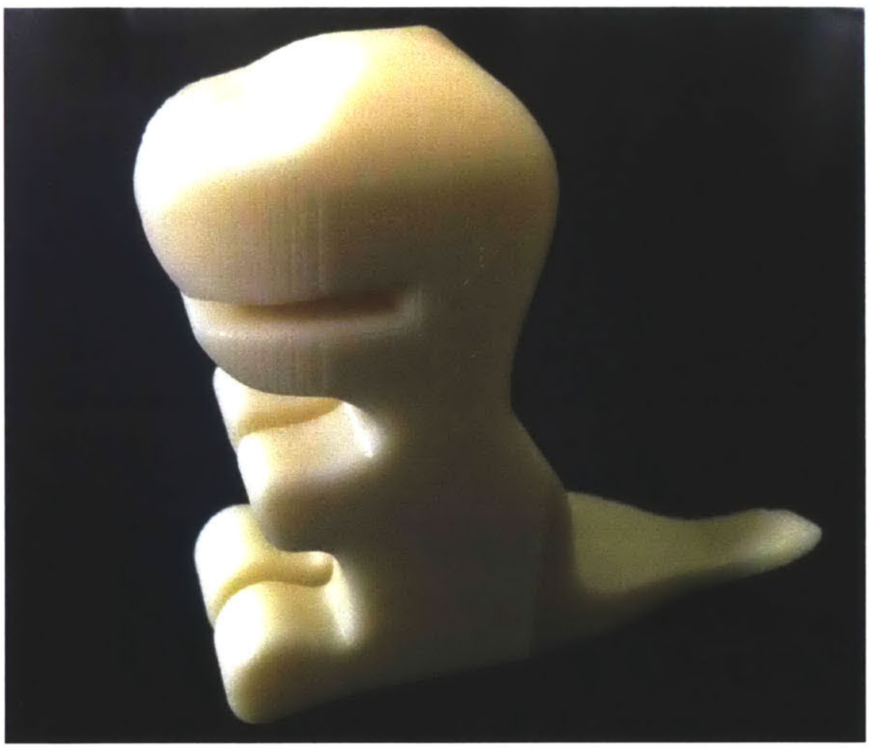


Figure 17. This dinosaur clip could hold the battery in two configurations.

After testing the Sphere, Clamshell and Dinosaur clips, it was determined that the Clamshell clip was ideal for its thickness and form. The Sphere clip was too bulky to place into the circuit, even with its flat bottom, and while the dinosaur allowed for interesting vertical circuit configurations, it was much too large and complicated to be considered for a final design.

The surfaces of the Clamshell clip that mated with the battery were large enough to ensure connection between copper leads, but the clip was not too wide so as to trap the battery inside of it. Although the clip had proven to be functional, to guarantee ease of removal of the battery from the clip, the final Clamshell design for injection molding would be further reduced in width.

4. Injection Molding the Clip

4.1 The Mold

After the final Chibitronics Battery Clip design was chosen, the injection mold was created in SolidWorks.

A 5% relief angle is included on the outside face in order to allow the clip to be pushed out of the mold once it had cooled. Relief angles were not included on the inside dimensions that mate with the battery and ensure the snap-fit. Ejector pins will be placed along the back of the cavity mold to assist in releasing the part from the mold.

Shrinkage is also a concern when creating injection molded parts. In order to determine expected part shrinkage, dimensions of injection molded parts that had been created during past semesters in the MIT 2.008 machine shop were measured and compared to molds that had been saved and stored. The approximate shrinkage of each measured part was 2.5%. In order to allow for this shrinkage, using the mold that has been designed with proper relief angles in Solidworks, the part drawing within the mold will be scaled up by 2.5% in MasterCAM.

In order to ensure a snap-fit between the battery and the clip, the inside dimensions should have a 0.010" interference with the surface of the battery. The tolerance of the inside dimension is the critical dimension and should be +0.005/-0.000" to ensure interference. All outside dimensions should be allowed a tolerance of +/-0.005" since outside dimensions are not required to snap-fit with any other parts. These tolerance dimensions are informed by recommendations in the MIT 2.008 Discrete Parts Manufacturing lab handouts.

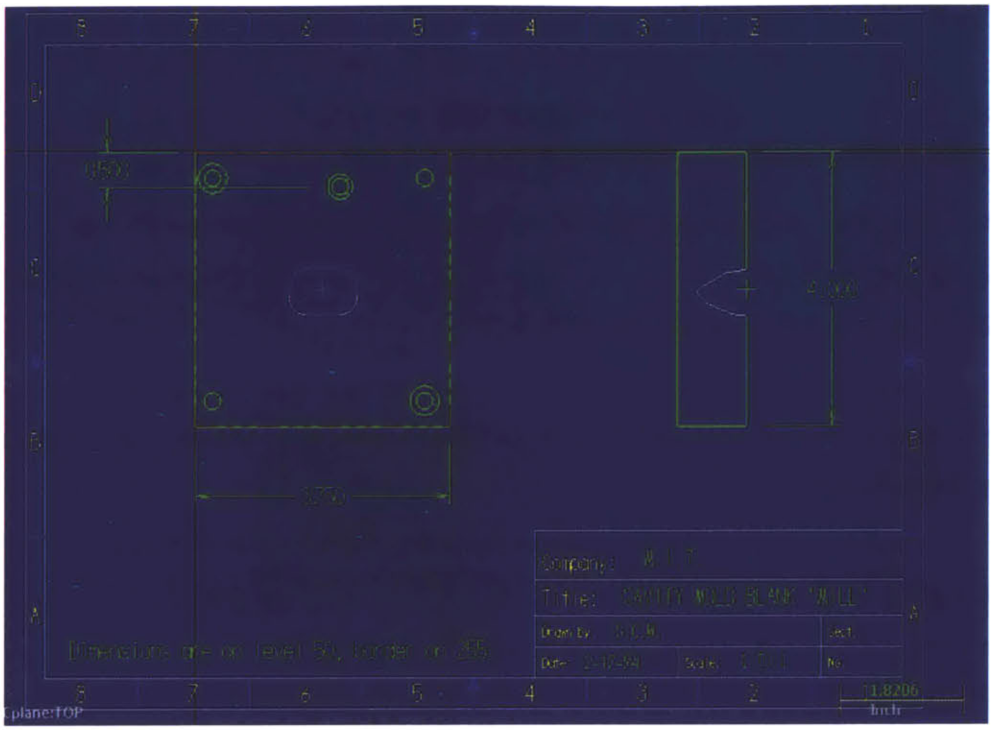


Figure 18. The Cavity Mold in MasterCAM.

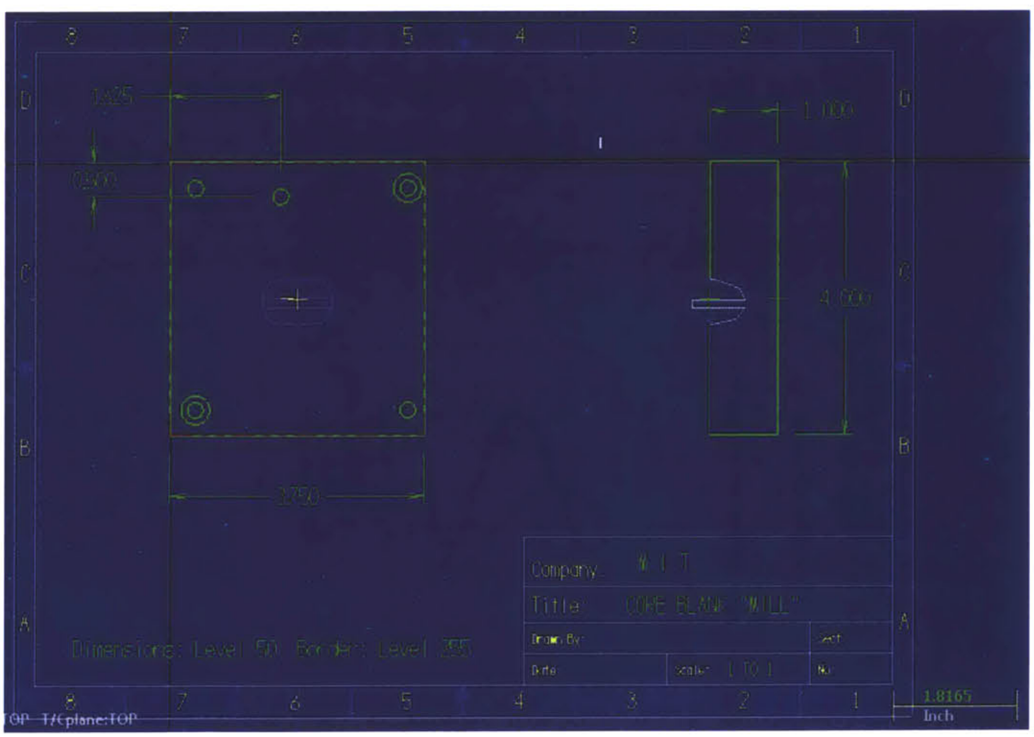


Figure 19. The Core Mold in MasterCAM.

4.2 Statistical Process Control

During the injection molding process, certain variables are commonly observed. Part dimensions and characteristics vary over time due to mold wear; machinery performs differently based upon its quality, age and condition (old machines may chatter and vibrate and do not maintain tolerances as well as new machines); environmental conditions such as temperature and humidity affect performance of machines; and other variables may affect the production run as well.

By inspecting the parts produced, or by inspecting a subset of the parts produced, it can be determined whether tolerances and surface finishes fall within a specified range of acceptable values.

Since data from manufacturing processes often fit normal distribution curves, by measuring the mean and standard deviation of a chosen set of parameters, it is possible to determine the number of defective parts that can be expected in any given production run. This information can help to determine whether tolerances should be changed or whether a different machine should be used in final production [6].

After doing the production run of the Chibitronics battery clip, measurements will be taken of each cooled part in order to plot the frequency distribution of distances between the part surfaces that mate with the battery in order to determine the percentage of parts that will properly mate. Ideally, the measurements will fall entirely between the specified Upper Standard Limit and Lower Standard Limit, therefore the frequency distribution will look something like the one below:

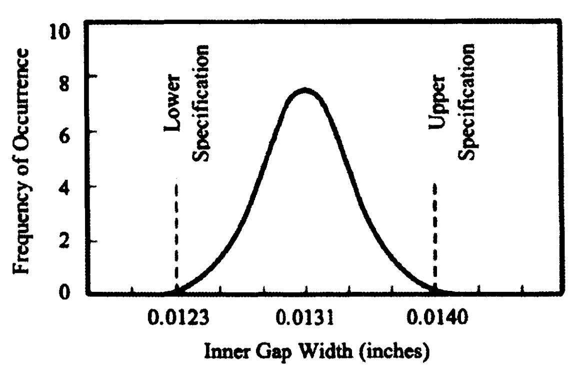


Figure 20. Expected frequency distribution during production run.

5. Future Work and Manufacturing Recommendations

5.1 Injection Mold Production Run

Following this project, the molds from Section 4.1 will be machined in the 2.008 machine shop and the injection-molding machine will be used to do both a test run and a production run of the final battery clips. For the test run, 10 parts will be injection molded, and their dimensions will be measured using calipers after they have fully cooled. If any changes need to be made to the mold to ensure quality in the production run, the molds will be remachined at that time.

In order to better understand the manufacturing process, a frequency chart will be created for the inside dimension of the clip based on a 100-part run. Data gathered from this production run will be used to determine whether tolerances of the mold should be changed again during high-volume production in order to reduce the number of clips that fall outside of specification.

5.2 Considering the Costs of High Volume Manufacturing

It is recommended that, in order to make a decision about whether to use injection molding for high volume manufacturing of the Chibitronics Battery Clip, manufacturing costs and cost reduction methods should be evaluated.

Materials, tooling and production quantity will all affect the total cost of the clip itself. Fixed, capital and labor costs will depend upon the company chosen for manufacturing. Since polypropylene is a cheap material, the material per part cost of the battery clip will be minimal. Production quantity will further reduce this cost, as the initial purchase of a greater amount of material will reduce the per-unit-volume cost of that material [2].

The main concern in injection molded part cost is the tooling cost of the mold. For the purposes of this project, a mold will be created that interfaces with the injection molding machine in the MIT 2.008 Design and Manufacturing machine shop. For higher volume manufacturing, the mold would likely have to be re-tooled by the company doing the production in order to ensure that the mold interfaces properly with their machines.

Since the expected life of the mold is high, the tooling cost of the mold is likely a justifiable expense if it is decided that high production quantity is desired for the Chibitronics Battery Clip.

6. Concluding Statements

In the design of the Chibitronics Battery Clip, form and function were kept in mind as well alongside DFM requirements for injection molding in high quantities. In order to ensure quality and usability, interactions with the users were considered. The overall shape of the battery clip was developed based on how the clip would be inserted into the Chibitronics workbook.

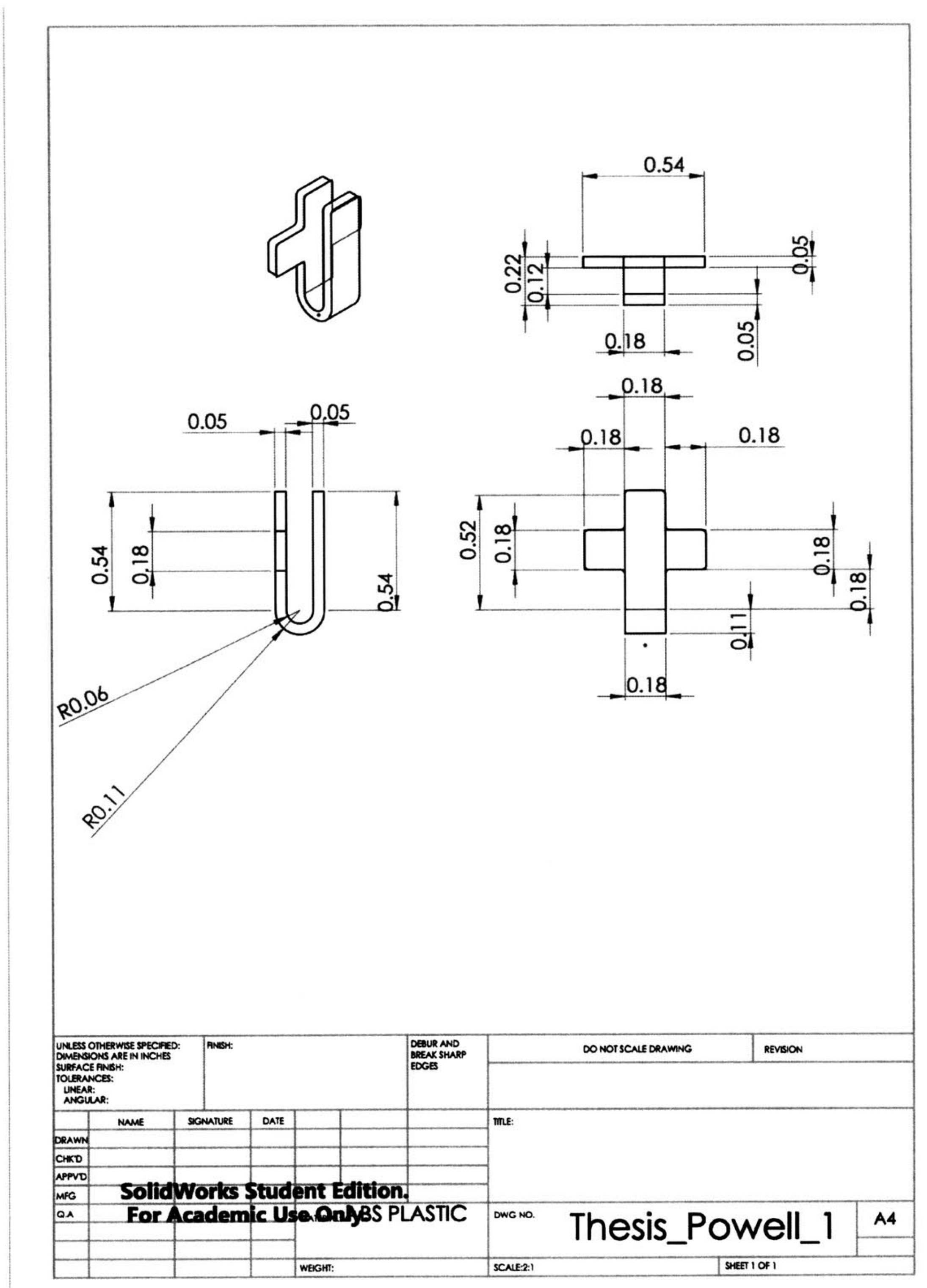
Design for Assembly was also a big consideration in the development of the battery clips because the clips would have to be inserted and taken out of the circuit sticker workbook easily. This insertion and removal was intended to happen many times over the lifetime of the battery clip, so the thickness of the clip was increased in order to reduce the impact of concentrated stresses in the clip.

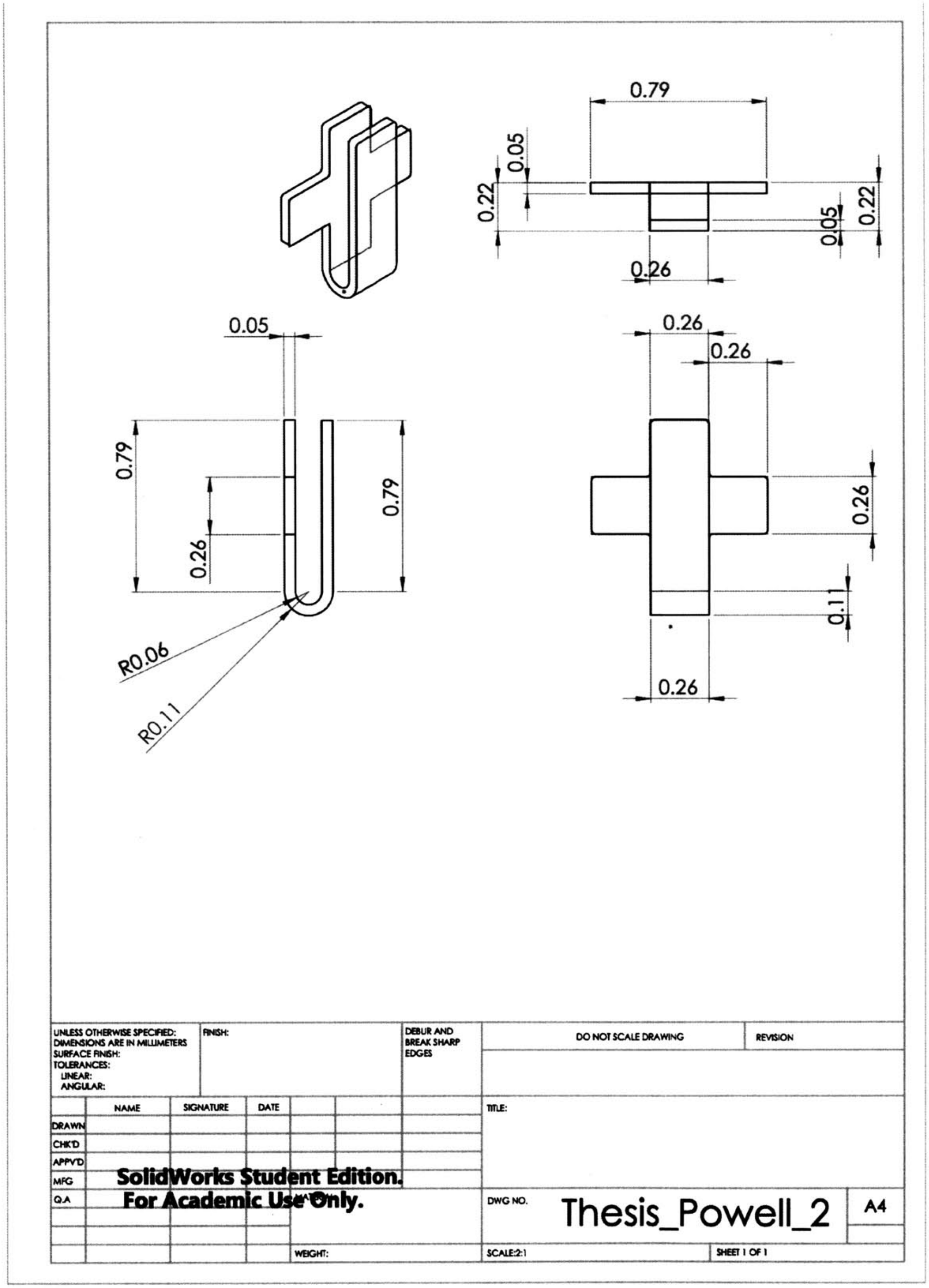
Finally, in designing the mold for the chosen clip design, DFM for injection molding parameters were included in the mold, such as draft angles and shrinkage allowance.

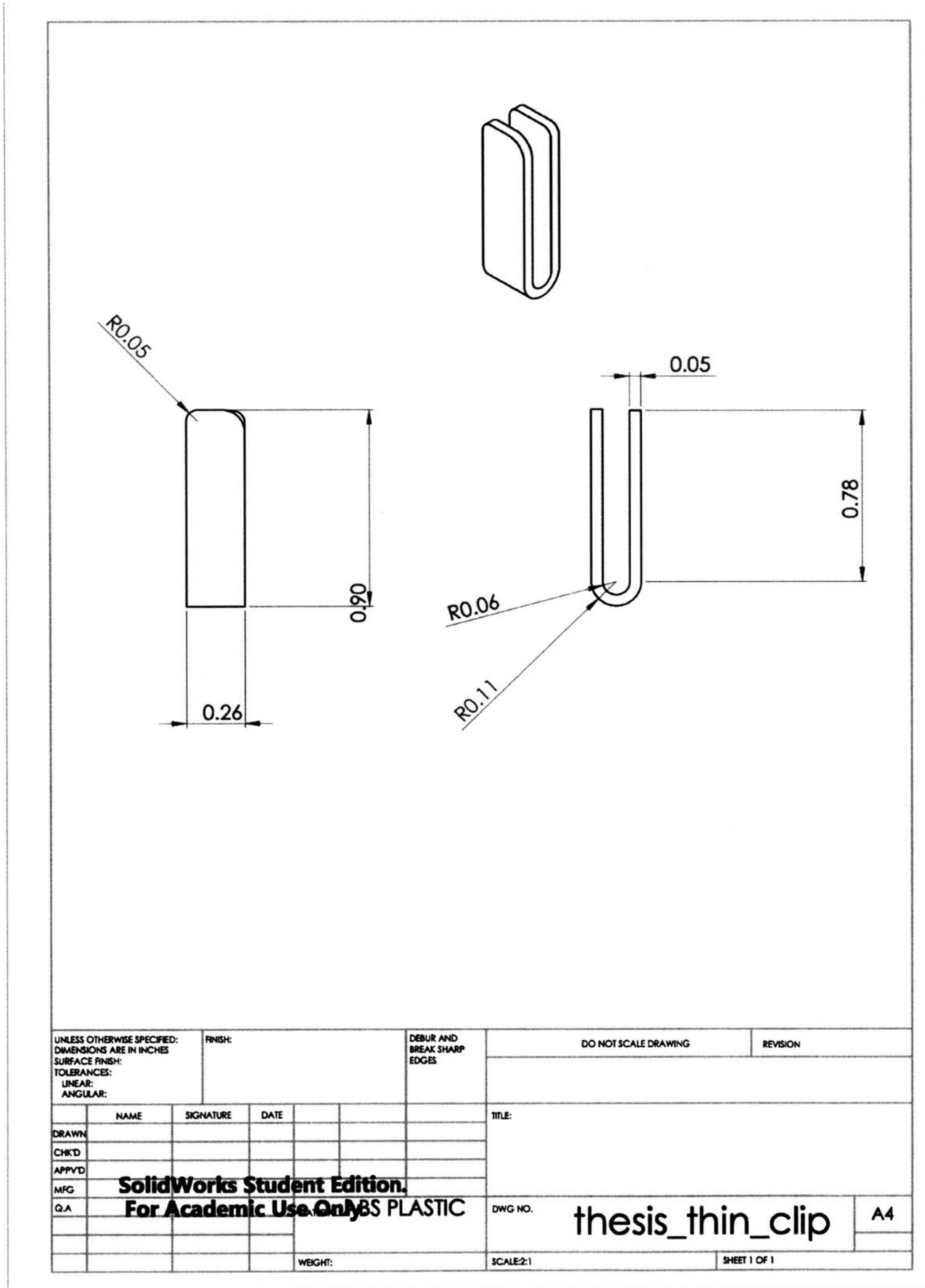
This process has led the Chibitronics Battery Clip up to the manufacturing testing stage, in preparation for high-volume manufacturing to be carried out if desired.

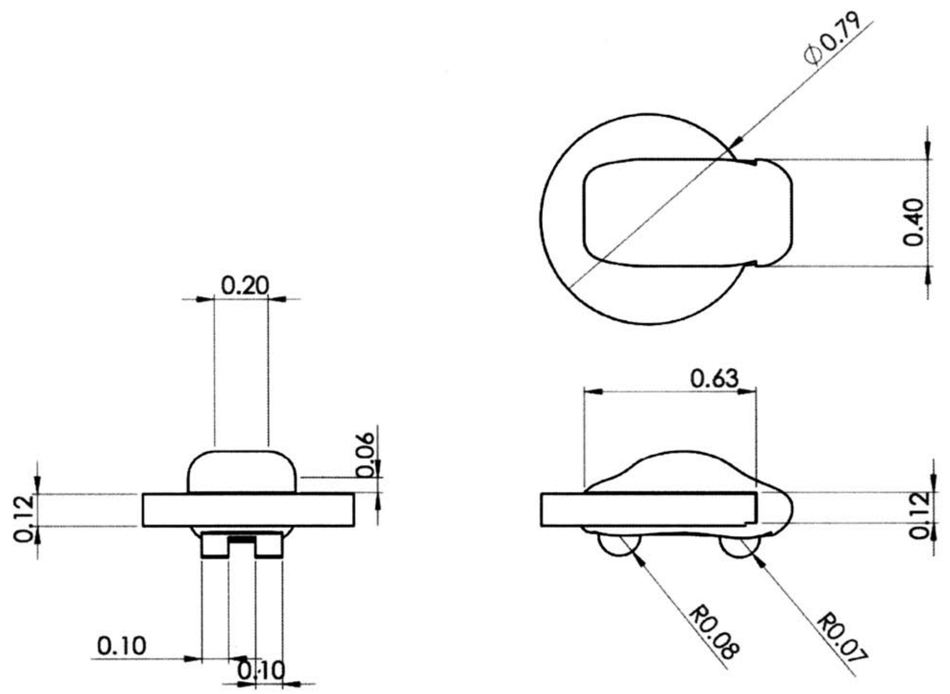
7. Appendix – Solidworks Dimensioned Drawings

7.1 Iteration 1 CAD Models




0.79
0.05
0.22
0.22
0.05
0.26
0.05
0.26
0.26
0.79
0.79
0.26
0.26
0.11
R0.06
R0.11
0.26
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
SolidWorks Student Edition.
For Academic Use Only.
DWG NO.
Thesis_Powell_2
A4
WEIGHT:
SCALE:2:1
SHEET 1 OF 1


R0.05
0.05
0.78
0.90
R0.06
R0.11
0.26
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
SolidWorks Student Edition.
For Academic Use Only.
ABS PLASTIC
DWG NO.
thesis_thin_clip
A4
WEIGHT:
SCALE:2:1
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
INSIDE: +0.009"
OUTSIDE: +/-0.005"

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL: ABS PLASTIC

DWG NO. thesis_car_assembly

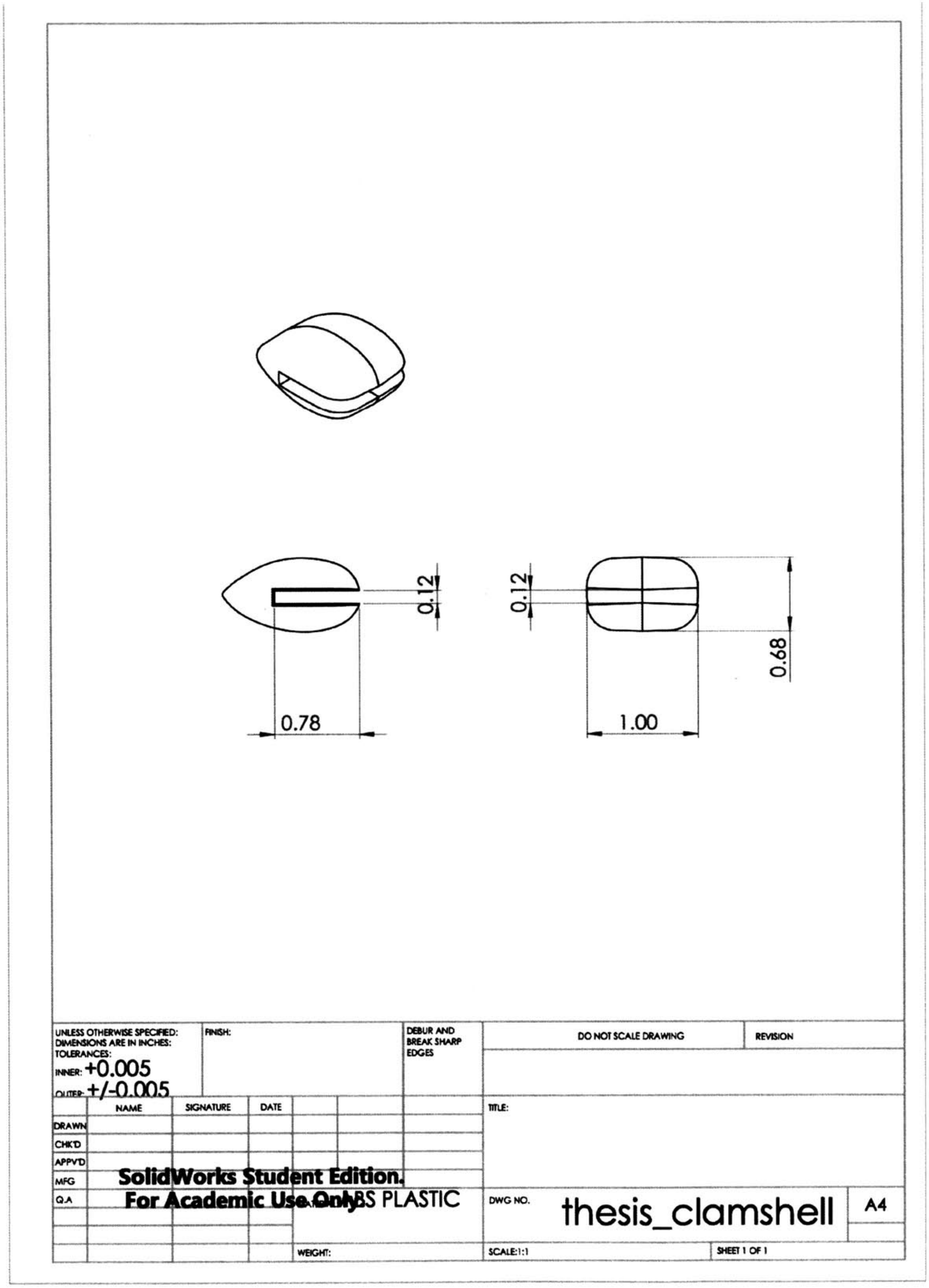
A4

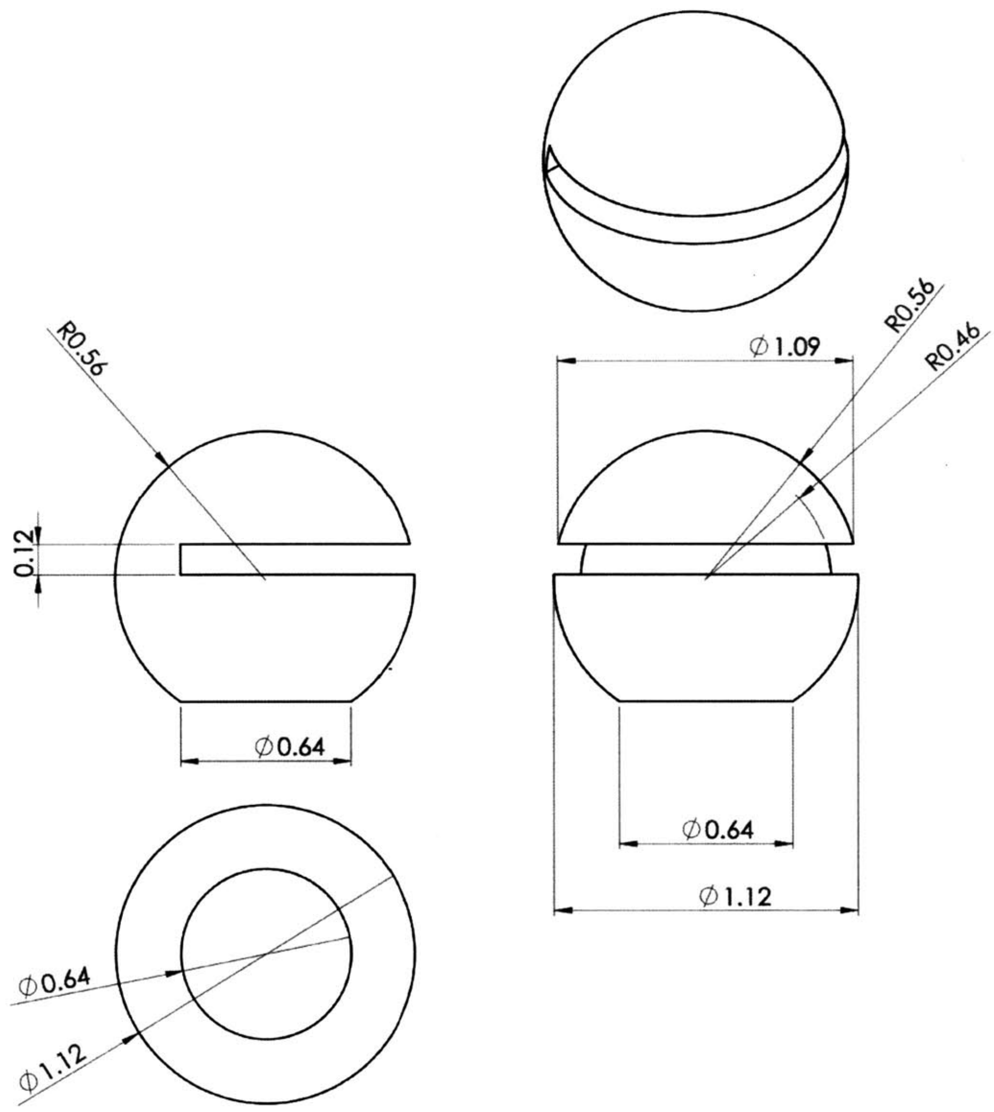
WEIGHT:

SCALE:2:1

SHEET 1 OF 1

7.2 Iteration 2 CAD Models





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
INSIDE: +0.009"
OUTSIDE: +/-0.005"

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

SolidWorks Student Edition.
For Academic Use Only

ABS PLASTIC

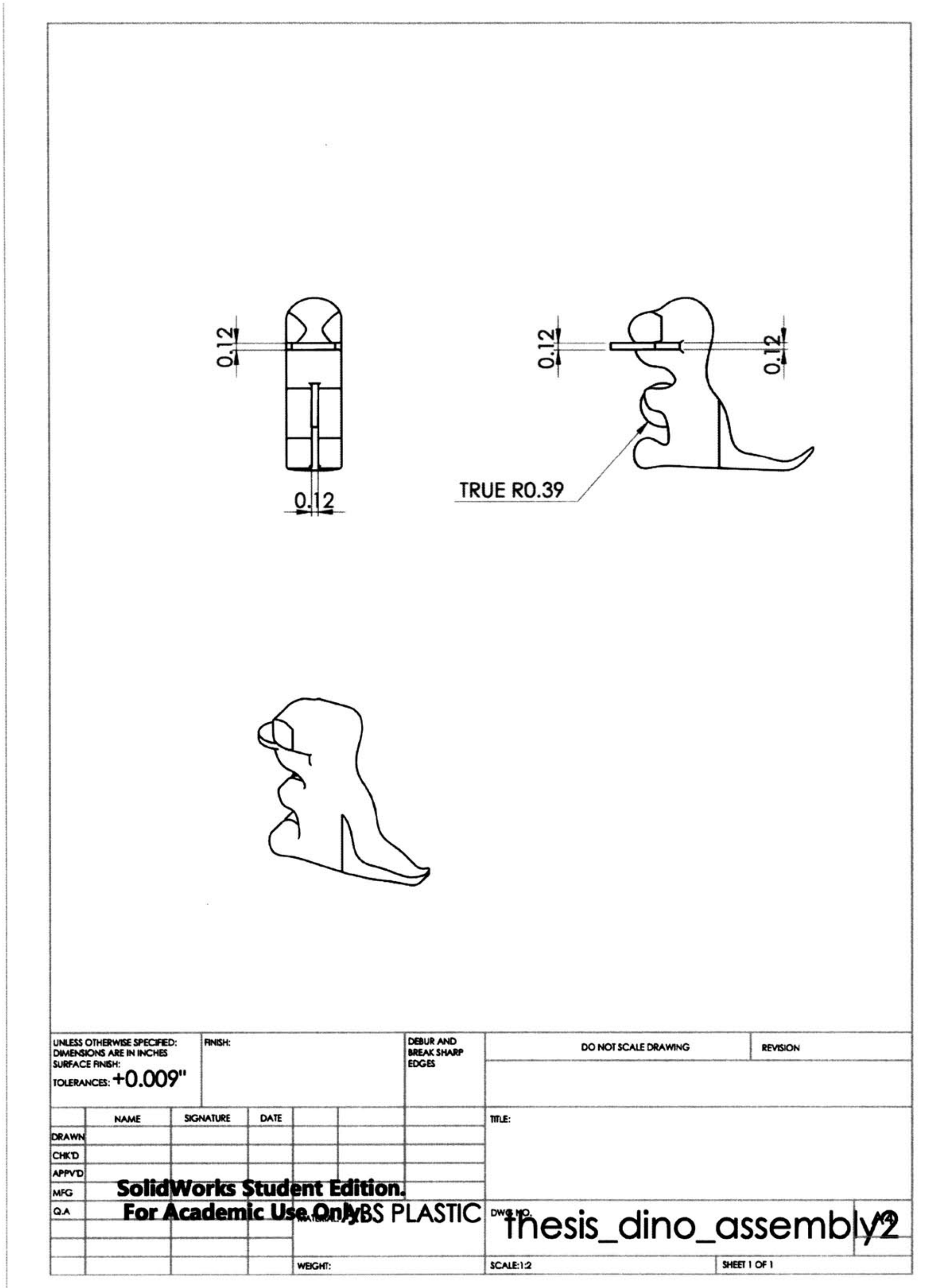
DWG NO. thesis_sphere

A4

WEIGHT:

SCALE:2:1

SHEET 1 OF 1


0.12
0.12
0.12
0.12
TRUE R0.39
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES: +0.009"
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
SolidWorks Student Edition.
For Academic Use Only
MATERIAL: ABS PLASTIC
DWG NO.
thesis_dino_assembly2
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1

8. Bibliography

[1] Ulrich, K. T., and Eppinger, S. D., 2008, *Product Design and Development,* 5th Edition, MacGraw Hill, Marlborough, Massachusetts.

[2] Kalpakjian, S., and Schmid, S. R., 2009, *Manufacturing Engineering and Technology,* 6th Edition, Prentice Hall, New York.

[3] Dow, D., *2.008 Design and Manufacturing II, The Discrete Parts Manufacturing Labs,* Unpublished, Massachusetts Institute of Technology, Cambridge, Massachusetts.

[4] Anand, L., 2011, *Introduction to the Mechanical Behavior of Materials: Lecture Notes,* Unpublished, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

[5] Hibbeler, R. C., 2011, *Mechanics of Materials,* 8th Edition, Prentice Hall, New York.

[6] Hardt, D., 2014, *Manufacturing Processes and Process Control,* pp. 1-6, Laboratory for Manufacturing and Productivity, Massachusetts Institute of Technology, Cambridge, Massachusetts.

[7] Piotti, S., and Mennegazzo, R., 2014, *Wa: The Essence of Japanese Design*, Phaidon Press, London.