Toolmark manual

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Date: June 22, 2022

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Introduction

This manual serves as a guide and description of the forensics tool mark experiment housed at the University of Pennsylvania and led by Professor Maria Cuellar (contact: mcuellar@sas.upenn.edu). The funding for this project has been provided by the National

Institute on Standards and Technology (NIST), directly to Iowa State University and as a subcontract to UPenn.

Materials

Screwdriver description

The screwdrivers used in this experiment were generously gifted to us by Klein Tools.[1] Klein Tools was founded in 1857 years ago by a German immigrant, Mathias Klein. His descendants, now into the sixth generation, lead the company. They sell tools to a variety of suppliers, including Home Depot, where the screwdrivers can be purchased for amounts between $10 and $15. These low prices make the tools available to the general public, and thus make it interesting for us to study them in a forensics project.

We selected three sizes of flat-head screwdrivers.

- Small: 1/4-Inch Keystone Tip, Cushion-Grip Screwdriver # 600-4
- Medium: 5/16-Inch Keystone Tip Screwdriver, Cushion-Grip, 6-Inch # 602-6
- Large: 3/8-Inch Keystone Tip Screwdriver Square # 600-8

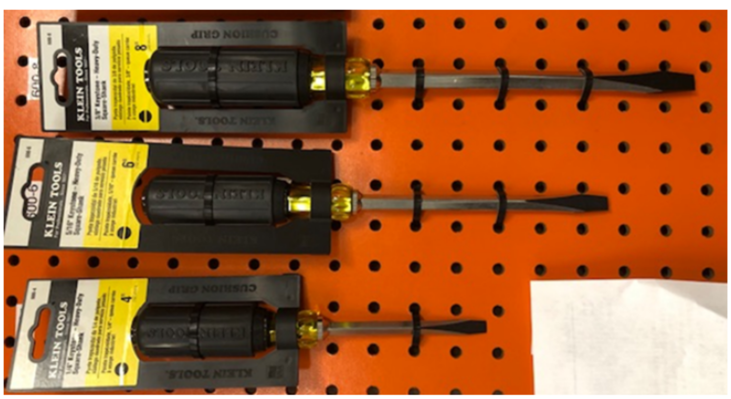

Figure. Samples of screwdrivers that we obtained from Klein Tools.

We have 20 screwdrivers of each size, for a total of 60 screwdrivers. Each set of 20 screwdrivers was consecutively manufactured. (But the three sets were manufactured separately, and in fact on different days because the factory only manufactures some sizes some days.) The Klein Tools team sent us a video of them manufacturing the small screwdrivers, showing how they were taken out of the machine together. We do not know the order in which the screwdrivers were produced within each set.

[1] Contact at Klein Tools:
- Thomas R. Klein: Chairman Corporate Administration
- John Hankus: Manufacturing process
- Sunil Malhotra: Executive Vice President, Operations

Figure. Klein Tools design for the screwdriver tip.

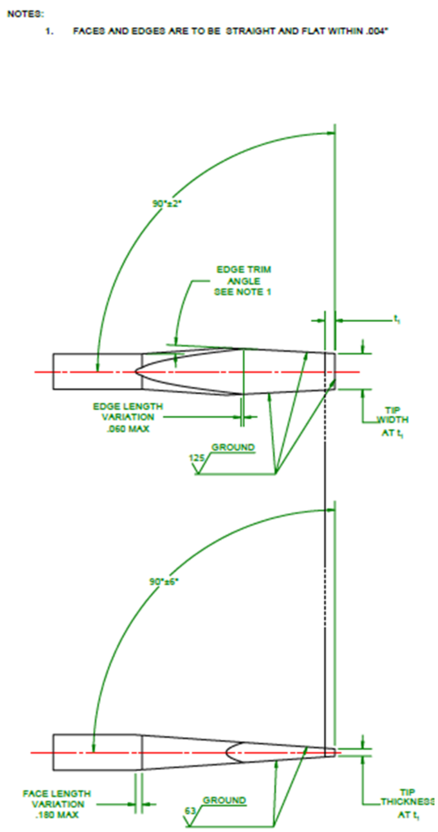

Figure 1 shows the design of the flat-head screwdrivers at Klein Tools. Their design aims to have straight and flat edges within 0.004”. The technical notes from Klein tools are as follows: For the 600-4, the square shank is .250”. The tip width at the t1 of the keystone is .274” +/- .007”. The thickness is .040” +/- .004”. t1 (Dimension where measurements are taken) is .024”. For the 602-6, the round shank is .304”. The tip width at t1 of the keystone is .336” +/- .007”. The thickness is .046” +/- .004”. t1 (Dimension where measurements are taken) is .028”. For the 600-8, the square shank is .375”. The tip width at t1 of the keystone is .396” +/- .010”. The thickness is .055” +/- .004”. t1 (Dimension where measurements are taken) is .034”.

Klein Tools did not share details about their entire manufacturing process with us because of proprietary information. However, they did share with us the information about the last few steps of the process that determine the final shape of the screwdriver tip. After the screwdriver is stamped to the right shape, it is heat treated to harden and temper it (1400 to 1600 degrees Fahrenheit). Then it is plated, the tip is ground (see more on this below), and then black oxide is applied. 6150 steel was used for the slotted screwdrivers, because it is fantastic for a low bending moment. It is "cold formed" into that shape and processed down to a 30 micro inch finish.

They use a CNC grinding machine that forms the final tip geometry using grinding wheels and a water based coolant. While it is grinding with the grinding wheel, it is rinsed with a rust-preventative, cooling liquid. This liquid is then filtered to remove metal shavings, and it is recirculated. The grinding wheel can move up and down in the z direction, and a fixture controls the x, y movements. The Siepmann grinding wheel has a donut shape.

The final step is to treat the screwdriver tip with black oxide, where they send the blades with the ground surface exposed to be blackened in a hot dip black oxide tank at an outside vendor. This is added as a rust preventative measure and improves cosmetics. This is a surface coating only and is essentially just staining the part black and add a layer of rust prevention.The tip gets heated up (to about 120 degrees Fahrenheit) and then dunked in the black oxide, which will only sticks to a raw metal surface (not the chrome plating). Black Oxide, sometimes called blackening, is the act of converting the top layer of a ferrous material with a chemical treatment. Treating fasteners with a black oxide coating not only adds a nice clean black look but can also add a mild layer of corrosion and abrasion resistance. Everything afterwards is assembling the handle and packaging.

Klein Tools uses ASTM standards, and they perform ASME testing. To verify, 6, 8, 12 in from tip, must meet a minimum bend moment, and they use a 2-300 footpalm range.

Screwdriver organization

1. The screwdrivers are stored in the global industries case with the black handle.

Metal plates description

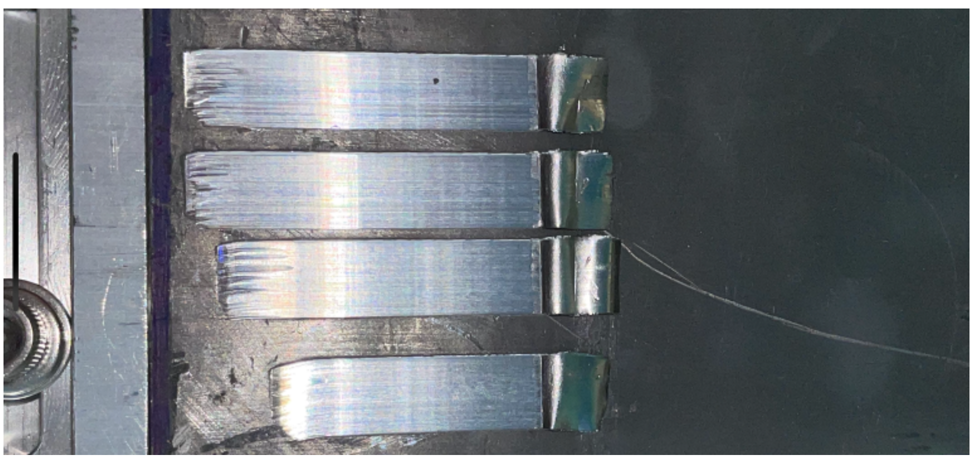

Figure. Lead plate used to make screwdriver striation marks.

We tested a variety of materials to see which plates would be best suited to capture the screwdriver tip striation marks. We tested blue machinable wax from Freeman Supply, copper, aluminum, and lead. The size of the plates is exactly 3.46 x 1.97 in. Lead was clearly the best material to capture the striation marks. It did not leave a "jitter" (i.e., lines perpendicular to the striation marks), it provided a smooth mark without having to use high force (this can sometimes make the motor stop), and it seemed to capture the marks well. Robert Thompson (NIST) also recommended using lead. Anecdotally, the marks seem to persist well over time, although they do rust. We have compared 3D scans of marks that were freshly made versus marks that were made three months earlier, and the signatures are indistinguishable - although we have not tested this statistically.

Machinable wax | Copper | Aluminum | Lead (3D scan)

Figure. Material tests for making screwdriver striation marks on plates. The lead plates were superior according to our qualitative analysis.

Metal plates organization

2. The lead plates are stored in the “Toolmarks Case 1” and “Toolmarks Case 2” global industries cases with the red handle.
3. Toolmark case 1 contains plates 1 through 39 and test plates 1-4
4. Toolmark case 2 contains plates 40 and over
5. The plates can be found by referencing the lid.
    a. The plates start closest to the handle (1) and end towards the back of the case (14). Row 2 (middle) starts with plate 15. The row on the right has additional test plates (starts with Test plate 1).

Toolmark rig

Figure: Toolmark rig.

Description

The rig was originally produced by NIST for a study about chisels.[2] We hired Peter Szczesniak, the Manager of the Manufacturing and Fabrication Services at the Mechanical Engineering and Applied Mechanics Department at Penn, to modify the rig so it could generate marks on screwdrivers (not just chisels) of varying sizes and do so at varying angles.

The rig has a motor (Velmex VXM-1 with a PK296 motor and a UniSlide) that controls the direction and speed of the plate.

Motor commands on COSMOS and Python

1. If you are not using the provided tablet, download IDLE for Python from the internet. Then download Anaconda navigator. Open Jupyter notebook.
2. In the GitHub toolmark repository, there is a file “Commands for motor in Python (Jupyter notebook)”. Copy this into Jupyter notebook.
    a. There is also a file called “additional code and troubleshooting for VXM motor in Python”. This contains a package you may have to reinstall if there are updates and a section of code to identify the name of the VXM motor port (in case it is no longer COM3).
3. Once the Velmex motor USB is plugged into the computer/tablet and turned on, you should be able to hit “Run” and the motor will follow the command loop which is not commented out. The loop explanation is written out in the comments of the Python code.
4. If the motor does not run in Jupyter notebook, go to Velmex.com -> products -> Controls/Motors -> controllers -> scroll down and click downloads -> Software, diagnostics, Patches -> download COSMOS
5. You can take the same Python code (looks like F,C,S1M4100, I1M36000, P350, S1M2000, I1M10000, P200, S1M4200, I1M-46000, P150,LA4,R) and run it in COSMOS. In COSMOS, do not include VXM.Command, quotation marks, or .encode()
6. If you have any issues with the motor, code, or connectivity between the motor and the tablet, email Cliff at cliff@velmex.com. He is familiar with the project, but will need a refresher.

[2] See Zheng, A. X., Soons, J., Thompson, R., Villanova, J., & Kakal, T. (2014). 2D and 3D topography comparisons of toolmarks produced from consecutively manufactured chisels and punches. *AFTE Journal*, *46*(2), 143-147.

Making the Tool Marks with the Rig

1. All of the “steps” in the Python code above are correct if you start the plate at the blue tape. If you choose to move the starting position/tape, you will need to adjust the steps in the code.
2. The screws on the back of the machine should be 5 holes down from the top for an angle of 80 degrees for the small screwdrivers.
3. The screws should be 4 holes down for making marks with the large screwdriver at 70 and 80 degrees. We have found that 7 holes down works for large screwdrivers at 60 degrees.
4. For the large screwdrivers, there is a bolt which we have turned upside down at the bottom of the machine. This holds up the screwdriver holder piece. If the bolt is turned so that the holder is held up approximately 2.5 mm, then you don’t have to manually hold up the holder piece with your hand when tightening the screwdriver into place. You should be able to allow the screwdriver tip to rest on the lead plate and tighten it into position. Secure the 2.5 mm gap by tightening the washer. The spacing of this gap will have to change for different angles of attack.
5. Using the smallest allen wrench, loosen the 4 screws at the four corners of the plate holder. Take off the top of the plate holder and set the lead plate inside. Put the top of the plate holder back on and tighten the 4 screws.
6. Using the next largest allen wrench, loosen the 2 screws at the top and bottom of the plate holder (this only has to be one turn). This allows the plate holder to slide left and right so that you can fit 4 small toolmarks side-by-side. Align the middle of the top screw with the line drawn (sometimes it is better to align the screw so that the line is a little to the right of the center). Tighten the screws again. Start with the line on the left as you are standing in front of the machine.
7. During the first pause of the code, place the screwdriver upright in the holder. If you want to make a mark with side A, make sure the side A label is facing out toward you. If you are making a mark with side B, the side B label should be facing away from you. The screwdriver tip should be touching the lead plate.
    a. If the screwdriver is on the “ledge” of the plate holder, then the plate holder should move forward more.
8. With one hand, lift up the square piece that holds the screwdriver and with the other hand tighten the two screws on the front. At this stage, you only need to tighten the screws enough so that the square piece stays lifted. This should reduce the area between the handle of the screwdriver and the curved holder. Using the 4th largest allen wrench tighten the 2 front screws as tight as possible.
9. Tighten the large screw at the top of the rig. This controls how much force is present or how deep the screwdriver makes the mark in the lead. Turn the large screw until you feel the first instance of resistance, then go a half turn more.
    a. If you turn more than a half turn, the force will be too much and the motor will not be able to move the plate holder. You will hear a very loud noise and the screwdriver tip will not move.

b. If you forget to turn the force screw or don't turn it enough, the screwdriver tip will only slide across the surface. While you will still have a toolmark, there won't be any edges. The edges/hills are used as the starting points for the signature extraction, so you will need to redo the mark again with more force.
c. It is ok to redo a mark over a shallow existing mark as long as the screwdriver tip is aligned with the edges of the first mark. Do not redo the mark if the first was a deep mark because you will go all the way through the plate.

10. Once the mark is made, loosen all the screws in the reverse order that you tightened them so:
    a. Loosen the top force screw
    b. Loosen the two screws holding the screwdriver and remove the screwdriver
11. Once the plate has returned to the starting position, loosen the two screws on the plate holder and shift the plate one mark to the right.
12. Repeat this process for 4 toolmarks.
13. When you remove the plate after the first 4 marks are made, use the metal etching pen to label the marks just below where the toolmark stopped. Label the edge of the plate with the screwdriver number, plate number, screwdriver side, angle, and material
    a. For example: Sc##.Pl###.S.A/B.An##.Pb
14. Put the plate back in so that 4 more marks can be made on the same side across from the marks you just made. Keep in mind that the next 4 marks you make are still **side A.**
15. Once you have made 8 marks on the plate, use the scissors to cut off the excess lead that is sticking up.
    a. Make sure the scissors stay parallel to the plate so that you don't scratch the mark with the point of the scissors.
16. Use the bottom of the giant allen wrench to flatten the excess lead that is left behind after using the scissors. You want to push the lead backwards away from the mark and more towards the number. Make sure there aren't any sharp edges so that you do not rip/puncture the gel of the GelSight when you go to scan the marks.
17. Vacuum up the lead pieces that you cut off with the scissors.

GelSight 3D microscope

Description

The GelSight[3] 1.0X instrument is a 3D microscope that does not use the usual confocal microscopy to scan 3D objects. Instead, it uses a breakthrough elastomeric tactile sensor (proprietary) technology that involves pressing a gel disc onto a hard surface, and taking multiple pictures of the protrusion on the gel. It was originally developed for aerospace engineering, for scanning very small marks found on the surface of rockets or aircraft, which might be invisible to the naked eye but could lead to problems.

[3] https://gelsight.com/

This GelSight scanning technique is suitable for metals in a way that light microscopes are not because using a light scanner can be difficult with shiny objects. The instrument is hand-held, which makes it easy to use at crime scenes. It cannot be used to scan certain types of marks, such as very deep marks or sometimes right or more acute angles because the gel must conform to the shape that is being scanned. It is very well-suited for scanning striation marks like the ones in this experiment.

For this experiment, we are using the 1.0X instrument. We tested the 5.0X instrument, and did not find that it had sufficiently high resolution to observe the relevant marks on screwdriver striation marks. We are using the silicone gels, which are stiffer than the others available, and produce higher resolution images.

The GelSight instrument produces 3D images of the scans in STL format. We then save these as x3p files and process them in the R software.

Calibrating the GelSight instrument

1. Note: Each gel lasts for about 400-450 scans. The red surface starts becoming “see-through” and you can sort of see holes in it. While the gels technically do not have a limit on the maximum number of scans, we have noticed that around 450 scans is when the gel appears to have rips/tears in the red portion that are transparent/white. Do not get rid of the old gels. Instead, put them back in the GelSight case and label the clear holders with the number of scans.
2. For each new gel, you must calibrate it. This can be done under Configuration on the GelSight Mobile software.
3. The gel number (on the clear part around the red gel) must be added to the current gel under “device”
4. Under calibration targets:
    a. BGA Target should be kept at Name: BGA D05 S10, Diameter: 0.5 mm, and Spacing: 1.0 mm. This information can be found on the BGA dot plate in the small black box in the GelSight case.
    b. Groove target should be kept at Type: GelSight CAL-G500 Serial Number: A214. This information can be found on the groove calibration plate in the small black box in the GelSight case.
5. Under calibration policy:
    a. The Max deviation we have been using is 2.00 microns +/- 1.0 % groove depth (GelSight uses 2.0% error for their paper studies).
        i. It should be noted that the error is not a direct correlation. For example, 1.7% error doesn’t mean the data is off 1% from data with a 0.7% error
    b. The spatial complexity should be 2 because that is the most accurate.
6. When you hit calibrate under Calibration. You will need to capture scans of three different surfaces: flat, BGA dots, and groove.

    a. When you go to calibrate, the GelSight will automatically pick a shutter speed which is usually between 1.00 and 1.303 ms.
    b. The flat surface is the glass circle encased in bubble wrap. This is located in the small black box inside the GelSight case. Center the gel on the glass, press down and scan.
    c. You must take 4 scans on the BGA dot plate. It doesn't matter which side starts facing up, but you have to rotate the BGA dots 90 degrees so that each side faces up at some point. Keep track of which side you start on. The dots should be highlighted in yellow after each scan.
    d. We recommend putting the groove plate in the cap of the GelSight so that it is centered. Press down firmly to capture the groove. There should be a yellow line in the groove if the scan was successful.
7. When you hit calibrate, the measured depth will either be above or below the 1.0% error.
    a. If it is less than 1.0%, you can accept the calibration and be done here. We usually aim for 0.5% error or less.
    b. If it is above the 1.0% error, but no more than about 9.0% error, increase the angular bias under the parameters and recalibrate.
        i. Angular bias modifies the nominal section of reference of the calibrated balls of the BGA used in the computation of the calibrated model. It is used to mainly stretch or compress the measurement in the vertical direction.
        ii. Do not change the field of view or complexity. These parameters are optimized by the GelSight software.
    c. If the calibration is still over 1.0% or the percent error is over 10%, you must change the shutter speed.
        i. We have been using a shutter speed of 1.303 ms. Decrease the shutter speed if the scans are too bright and increase if the scans are too dark. Areas of extreme light and dark are missing data.
8. Other calibration errors:
    a. If the center dots of the BGA scan are not highlighted, the shutter speed is most likely too high
    b. If the BGA dots are all highlighted but an error message shows up that the dots aren't detected
        i. most likely that the dots weren't rotated 90 degrees (there's a duplicate)
    c. If the groove isn't highlighted, it's because there isn't enough contrast (shutter speed is either too high or too low)
    d. If you still cannot calibrate the GelSight after attempting the above modifications email Abby Lindberg at abby@gelsight.com. The next person to contact if she is unavailable or you both cannot resolve the issue is Thierry Mantel at thierry@gelsight.com.

Scanning the marks with the GelSight 1.0X

1. Currently we are using GelSight Mobile 2.2 which can be found on the tablet desktop (the software may need to be updated).
2. Plug in the GelSight scanner USB into the tablet and you should see an option to capture on the homescreen in GelSight Mobile
3. After clicking on capture, you may just see a black square. This is because the GelSight scanner has to warm up to 35 degrees Celsius before you can start capturing images.
4. Wearing your gloves, place the plate on a piece of paper on your desk. Make sure that the “live” option is checked in the capture window.
5. On the right side there is a box next to the white cross which tells you what folder your scans will go into. If you click the cross, you can label the folder. Label the folders with the info on the plate.
    a. For example: Sc##.Pl###.whole (note that the “whole” may change if scanning medium or large toolmarks which will not fit in one scan)
6. Use the blue masking tape to remove any fibers, lead particles, etc from the gel tip. Use another piece of tape to remove any fibers, lead particles, etc from the toolmarks on the plate.
    a. You will know there are fibers or other materials on the gel or mark because, in the live view, the mark will look bumpy and/or have squiggles.
7. Scan the toolmark with the GelSight scanner button facing **away** from you. Scan the mark so that the flattened lead piece (where the mark ends) is closest to you and the start of the mark (the edge of the plate) is further away from you. The orientation of both the mark and the GelSight is important for the signal extraction later.
8. Press down relatively hard when scanning. I usually lower the table and make the mark while standing so that I can press my body weight down onto the GelSight.
    a. You will know you aren’t pressing down hard enough if toward the edges of the mark there is an area of lighter gray with no striations. This indicates there is an air bubble and the gel isn’t getting all the way into the corner.
    b. Try to remove as much of the air as possible, but know that there will always be at least a small line of light gray (sometimes due to too much light or shadow as well)
9. Press the button to take the image when you can see the width of the entire mark on the live view.
    a. If you can only see one edge, make sure you pick up the GelSight to move it left or right. Do **not** drag the gel tip over the toolmark to reposition as you will tear the gel.
10. When you take the scan, you should see the scan on the right side with a blue loading circle. You can take scans of the next toolmark while this is still loading.
11. Take the scans of marks 1-4 and then flip the plate 90 degrees so that 5-8 are oriented the correct direction (excess lead/stopping point closest to you).
12. After taking the scans of marks 1-8 of one of the sides. Click explore on the left, the folder you just created, and click on the first scan with two fingers. You should get a drop down with three options: rename, delete, and show in explorer. Rename the scan with

the screwdriver number, plate number, mark number, side, angle, material, and whole (or left/right for larger marks). Do this for all the scans in the folder and then go back to capture to scan the 8 marks on the opposite side.

Code and software

Exporting toolmark STL files and uploading to the box

1. While in the Explore page on GelSight Mobile, single click one of the toolmark scans, then click PDF. A report should be generated with all of the GelSight information and a 3D image.
2. On the right side of the screen, scroll all the way to the bottom and click export STL. When it is ready, a new file explorer window will appear.
3. With the current software, the STL files are a rainbow colored water drop icon.
4. Using split screen, drag and drop the STL into the corresponding screwdriver folder in the Box. The Box will show that it is uploading and during that time, you can exit and export the next STL.
5. If you need to find the STL files on the tablet:
    a. right click any of the toolmark scans in explore and click show in explorer.
    b. The long way is File explorer -> local disk -> Users -> Public -> Public Documents -> GelSight -> Scans

Adding Metadata/Excel Toolmark Inventory

1. The metadata instructions are for Mac/Macbook. The code is currently not letting us write to x3p on windows. It can read x3p's and write csv's, but when we use "write_x3p" no file is produced
2. Metadata:
    a. In the toolmark repository there is a folder (code) with a R script (adding_metadata)
    b. Once you have run all the packages, you can add metadata to the x3p files. This is important to keep track of the calibration dates of different marks and to include comments about marks which are unusual, found in a different location, or need special instructions.
    c. Follow the comments in the code for specific instructions on adding metadata to groups of toolmarks or individual toolmarks.
3. Google Sheets:
    a. Dr. Cuellar will invite you to the toolmark inventory spreadsheet in Google Sheets
    b. There is a master sheet to keep track of all the marks made by each size toolmark set. There is also a metadata sheet which contains additional information such as: the date the mark was scanned, the calibration date of the gel, the gel number, and any comments.

c. Variables that do not change (or don't change very often) are on the left
d. Keep these sheets updated so that anyone knows where you are in the process.
e. The comments on both sheets should be cross listed with the comments in the metadata of the x3p files.

GitHub Desktop

1. If you have a Mac/Macbook, you will need to download the toolmark GitHub repository.
    a. First download GitHub for desktop.
    b. Make sure the R and RStudio applications are fully updated on your device.
    c. You must receive an invitation from Dr. Cuellar and then you can join the toolmark repository (https://github.com/mariacuellar/toolmarks). Under the green code dropdown, you can open with GitHub desktop
2. In the GitHub desktop, you will need to Pull all of the information that myself and Dr. Cuellar uploaded. The first time you do this will take a long time because there are many files.
3. Once the pull is done, you can view the files of your repository in the finder. All of the toolmark code, x3p and STL files should now be on your device.
4. Open the the repository in the external editor (RStudio)
5. In RStudio, under files, open toolmarks.Rproj
6. You will need to download all the packages (like tidyverse, x3ptools, bulletetxtrctr, etc) to run the R scripts under the code folder.
7. To run some packages, you will also need to download Xcode and XQuartz from the app store (note that Xcode is a very large app and will require hours to download)