Tactile illustrations are a highly beneficial form of communication for members within and without the visually impaired community, providing a useful conceptualization of the material. Often, unfortunately, they fail to achieve their goal by being expensive, requiring specialized equipment to create, and having a convoluted printing process. Prior work has barely scratched the surface of the potential of a laser cutter to create tactile images, and so we aim to break new ground and open up avenues of expansion.

Our research thus far has yielded interesting results. First, we tested capsule paper, made up of paper layers with small capsules between them, which expand when exposed to heat such as that of a laser. A Universal Laser Systems model PLS6.75 CO2 laser cutter with a wattage between 75-80 W was tested, but the wattage was too high to achieve sufficient results with any power or speed levels. The maximum exposure the capsules could receive before the laser burned a hole through the paper was too low for ideal tactiles. Using a model Duo 3 Razor CO2 laser cutter at 30-35 W produced much more prominent results under differing powers and speeds, although this required lasering the back of the paper to produce results on the front, leaving behind a transparent film on the back. Using a 5W blue diode laser also produced good results. Using this cutter, lasering from the front at maximum power rather than the back produced highly prominent tactiles. Testing revealed lasering from the back worked on lower speeds, but generally the front seemed better for the blue diode laser. It’s difficult to say whether this is specifically due to the power level or the type of laser, and more testing is definitely needed in this area. We hypothesize that lasering from the back is mostly effective on the upper end of acceptable laser powers, allowing the capsules to swell without being incinerated. Additionally, specifically for the creation of braille dots, the technique of lasering each dot individually was found to be more effective than strafing across each row of pixels with the laser.

We also did brief testing with a 1064 nm 50W fiber laser. This did not produce particularly well tactile bumps, but was notable anyways: this laser could create a wide range of unique tactile surfaces, but seemed to be too focused to produce the large bumps that are effective for braille. Additionally, it proved capable of creating multiple colors on the page, allowing for a wider range of potential visual and tactile hybrid uses. This type of laser would likely be helpful for supplementary effects, or assorted tactile graphics aside from braille. Having tested lasers at a varied range, it seems that a low-intermediate wattage level is most effective, and further testing within that range could prove beneficial. In addition, testing with more varied types of laser cutters would be valuable, as we only had easy access to CO2 and blue diode lasers.

We also found a unique effect in laser produced tactile graphics. We first noticed this effect in a sample that lasered the outline of Texas, wherein the more complex parts of the border seemed to be better developed than the straightaways. Upon further testing, we discovered that laser cutters seem to convey noticeably more heat to areas where maneuvers are performed. In a significant test, we showed that at a very specific speed the 5W blue diode laser would only blacken the lines leading up to a right angle corner, but poke out pinpoint holes on the corners. This does make sense; absolute perfect heat distribution doesn't matter much when engraving wood or cutting steel, but differences become notable when we put an incredibly sensitive heat detector like capsule paper in the machine. This is part of what made strafing across each row of pixels with the laser less suitable, as the edge dots received more heat output, and it adds another layer of complexity to producing consistent quality tactile graphics, which already is quite difficult.

On that topic, one major thing we realized during this process is that capsule paper is extremely sensitive, especially at the high powers we're working with. We have had cases where we attempted to replicate the exact same graphics with the exact same settings on the exact same laser, but the product differed significantly. Sometimes this had a clear cause, such as the case of the laser lingering during complex maneuvers, and sometimes we couldn't figure out quite why it was happening. One other reason we found, completely by accident, is that capsule paper can expire. One test page was left out in the sun, causing one side to become bleached while the other remained yellow. When lasering onto this page, bumps developed much more easily and were larger on the still yellow side of the page, as opposed to the bleached side which developed lower quality bumps. Moreover, capsule paper is not uniform and one new, untouched sheet can be different from another. This also makes it difficult to distinguish between the front and the back of multiple sheets, which is a potential cause of some previously mentioned issues with identical circumstances producing differing results.

All of our testing so far was done on capsule paper. Ideally, other types of paper could produce good tactiles as well. For example, using lasers to indent classic wood-based paper would be far cheaper if an effective process was found. Tractor feed paper could be even better, as it could potentially be used in future processes to automate the lasering of multiple pages. Braille paper itself could also potentially be used for its thickness and integrated compatibility with tactiles. Additionally, lasering inverted images on non-capsule paper could have effective results. Capsule paper has proven to be effective at making tactile graphics and text, so doing the same on other paper is a possible next step. Above all, our goal after testing is to find ways to automate the process as much as possible, allowing lay users to easily and quickly obtain tactile graphics they need with as little oversight and specialized knowledge of the systems as possible.

Another aspect of our research was developing a tool to replace our capstone project, "The Embrailler". The project originally was meant to be a tool that allowed the easy conversion of braille materials into a vector format for use in a laser cutter. However, the original suffered from many issues, such as an unreliable backend, reliance on a paid API, and formatting as a website without any reliable hosting. In order to address these issues, we created a project called BrailleVector, which can be found hosted on GitHub at https://github.com/WilliamTichenor/BrailleVector and should be bundled with this document, as well. BrailleVector is a pure python program, which despite having several python package dependencies, works fully locally, offline, and has a far simpler installation and setup process. We also made the decision to switch to using SVG files as opposed to DWG files, which are clunky, and difficult to work with on account of being proprietary. Our experience creating braille materials over the past year gave us far more insight than we had upon starting The Embrailler, and this reflects positively in the features and workflow of using the new program. The application is still in a beta state and will be worked on after the conclusion of this research credit, but for now is fully functional.

Notably, our work is designed to be a stepping stone to further research. We seek above all for people to pick up where we left off and create a better world for the visually impaired. There are myriad ways our work can be expanded upon, some of which have already been mentioned. As stated, we have scarcely scratched the surface of the potential of laser cutters to create tactile images, from braille to maps to pictures, and more types of laser cutters could be attempted along with other settings, other types of paper, and any other criteria. Predominantly, we want the process to be as automated as possible with as little manual user input as possible, so it is simple, accessible, and fast. One possible way to accomplish this would be feeding a roll of capsule paper through a plotter printer, which, after optionally printing ink on the page, moves it over to a laser cutter that can develop the paper and even cut it free from the roll. We were unable to source a plotter for this during the semester, sadly. Additional braille customization options would be a valuable asset to the system as well, providing users with more options for font size and formatting. As the system gains commercial use, the implementation of languages beyond English will become increasingly important. In regards to the visible dots burned into the back of the paper in some use cases, a phone app could be developed and used to make the tactile graphic accessible to visual and non visual users, and enhance the quality of interactions between tactile graphics users and their teachers and peers. Similarly, assuming the system is eventually able to encompass both braille and other tactile graphics, pages could be created with QR codes alongside the braille, providing textual translations and other information. It is important to note that these are ideas and are not absolute, and since this is such a novel area of research, it would benefit greatly from any and all new thoughts others could bring and new tests others can conduct. This is work that can change people's lives, and there is always room to improve it.