# Creating DNA from Scratch for DNA-Based Data Storage


Team 12

Client: Iowa State University

Advisor: Meng Lu

Connor Larson: Software Engineering → GUI Design

Nathan Armstrong: Electrical Engineering → LCD/LED Hardware Development

Lucas Heimer: Electrical Engineering, Minor in Biomedical Engineering → Flow Cell and Controller Design

Kyle Riggs: Software Engineering → GUI Design

Brandon Stark: Electrical Engineering → LCD/LED Hardware Development

Team Email: sddec22.12@gmail.com

https://sddec22-12.sd.ece.iastate.edu/



Revised: 4/24/2022 - Version 3

# Executive Summary

## Development Standards & Practices Used:

- Coding syntax for C#
- Hardware development
- 3D modeling software
- Circuit element testing (power)

## Engineering Standards Applied:

- IEEE 802.11 - Wireless Networking “WiFi”
- IEEE 260.1 - Standard Letter Symbols for Units of Measurement
- IEEE 830 - Software Requirements Specifications
- IEEE 1588 - Precision Time Protocol
- IEEE 802.6 - Standards for information exchange between systems
- IEEE 1074 - Software Development Life Cycle
- IEEE 1471 - Software Architecture / System Architecture

## Summary of Requirements:

- Create an affordable system for synthesizing DNA
- Design a user friendly interface to control the DNA microarray size
- Use UV light to denature DNA and serve as catalyst for nucleotide to nucleotide bonding
- Use LCD screen to selectively control the location of UV light exposure on the microarray
- Design a microfluidic system to flow the nucleotides through the system periodically
- Accurately encode digital information into the DNA strand

## Applicable Courses from Iowa State University Curriculum:

- E E 201: Electric Circuits
- E E 230: Electronic Circuits and Systems
- ARTIS 308: Computer Modeling, Rendering and Virtual Photography
- E E/BME 341: BioMEMS and Nanotechnology
- BIO 212: Principles of Biology II
- CPRE 281: Digital Logic
- Com S 227: Object-Oriented Programming
- Com S 228: Introduction to Data Structures
- SE 319: Introduction to Design Structure

## New Skills/Knowledge acquired that was not taught in courses:

- Understanding of how an LCD screen works
- New software used (Fluigent's OxyGEN software)
- Understanding of the current DNA synthesis technologies
- Components and design of microfluidic systems

# Table of Contents

## List of Figures



## List of Tables



## Definitions

DNA synthesis: process of bonding individual nucleotides to create a desired DNA sequence

Flow cell: device used to serve as active region for bonding or chemical reactions in microfluidics

Microfluidics: system designed to flow small volumes of fluid through a given space

UI: User interface

LCD: Liquid Crystal Display

WPF: Is the project type we used for the UI

# 1 Team

## 1.1 Team Members

Connor Larson, Kyle Riggs, Brandon Stark, Lucas Heimer, & Nathan Armstrong

## 1.2 Required Skill Sets for Your Project

The required skills for this project include: coding, DNA sequencing, and hardware testing. We are required to program our own UI so we are able to precisely synthesize DNA autonomously. We also needed to gain a background knowledge of biology to aid in understanding the required components for synthesizing DNA with the provided technology. Finally, we are required to apply a variety of practices in hardware testing so we are able to verify the sufficient amount of UV exposure is resulting in the expected bonding of nucleotides.

## 1.3 Skill Sets covered by the Team

- Knowledge of coding: Connor Larson & Kyle Riggs
- DNA sequencing and biology principles: Kyle Riggs & Lucas Heimer
- Hardware development and testing: Brandon Stark, Nathan Armstrong, & Lucas Heimer

## 1.4 Project Management Style Adopted by the team

Each member is assigned to a sub-team working on a specific component of the project. Week by week we are assigned a set of goals to accomplish. These goals are determined at the end of every meeting we have with our advisor, Professor Meng Lu. Project resources and progress are shared via slack and google drive.

## 1.5 Initial Project Management Roles

- Connor Larson keeps track of the team organization as well as supporting the firmware side of the project.
- Kyle Riggs leads the GUI development for sending and receiving user input as well as client interaction for software issues.
- Brandon Stark leads client interaction in regards to the electrical engineering aspect of the project.
- Lucas Heimer leads the component design of the electrical engineering part of the project and works closely with the microfluidic system and 3D printer components

- Nathan Armstrong is focused on the testing aspect of the project and develops unit tests to verify our progress as we go.

# 2 Introduction

## 2.1 Problem Statement

To successfully perform DNA synthesis with the use of components from a Photon Mono 3D printer that will satisfy a new medium of digital storage to keep up with increasing demand at an affordable price.

## 2.2 Requirements & Constraints

***Requirements:***

- Use a Photon Mono 3D Printer's LCD screen to selectively control UV light exposure
- User interface to control the LCD screen configuration
- User interface to set the dimensions of the bonding area to fit within the flow cell
- Design a microfluidic system to flow nucleotides through the flow cell and across the LCD screen where it can be exposed to UV light
- Integrate the microfluidic system and user interface to autonomously flow each of the required nucleotides and chemicals in order to produce a DNA strand
- Design the entire system so that it can synthesize the DNA strands at a relatively high rate
- Make the system adaptable to a range of array sizes

***Constraints:***

- Ensure the DNA is synthesized accurately to store and maintain the integrity of the digital information
- Make a bug free, user-friendly user interface to synthesize the desired micro arrays
- Use affordable parts to fulfill this expensive task
- The LCD screen is connected to the user interface via an HDMI connection

## 2.3 Engineering Standards

- IEEE 802.11 - Wireless Networking "WiFi": This standard will be applied to our project because we will be using wireless networking to communicate between our computer application, the software controller (raspberry pi), and the 3D printer itself.
- IEEE 260.1 - Standard Letter Symbols for Units of Measurement: This standard applies because we are working with a microfluidic system to make a DNA microarray. This means we will be working with very miniscule amounts of liquid pushed through holes that may just be a few millimeters wide.
- IEEE 830 - Software Requirements Specifications: We apply this standard because our project has certain parameters that we must abide by, so we have certain software requirements we must follow to develop our software to meet our specifications.
- IEEE 1588 - Precision Time Protocol: This standard is applied through our use of a 3D printer. The fluid must be applied to create the microarray at specific intervals to avoid mistakes and actually create an accurate end product.
- IEEE 802.6 - Standards for information exchange between systems: This standard is applied to our project because we will use a Raspberry PI to transfer data to a LCD and a nucleotide fluid dispenser.
- IEEE 1074 - Software Development Life Cycle: We apply this standard to our project because we will need to create a UI and a program to control the LCD and nucleotide fluid dispensation system. This code we create for this task will need togo through the Software Development Life Cycle.
- IEEE 1471 - Software Architecture / System Architecture: We apply this standard through the development of our application that the user will be interacting with as well as the system that communicates between the 3D printer and software controller. Good architecture will help immensely in the runtime of our application and how easy it will be to implement.

## 2.4 Intended Users and Uses

***Users***

- Geneticists
- Data Analysts
- Pathologists
- Biologists

***Uses***

- Synthetic DNA genes can be used for characterization of a genome
- Synthesized DNA is used as a form of digital data storage
- Synthetic DNA can be used for disease research
- The system can be used to simulate the naturally occurring process

# 3 Project Plan

## 3.1 Project Management/Tracking Procedures

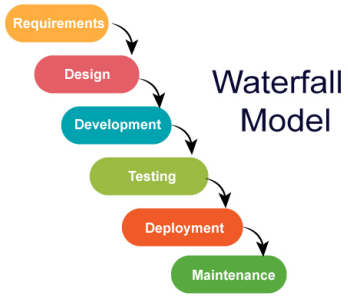
### *a. Project Management*

The project management style we adopted for our design is waterfall. Due to the technical nature of our project we require a well thought out process and series of steps which allows for the best progression of our project. In order to fulfill the necessary requirements for DNA synthesis, we need to first have a method of controlling where and how the DNA oligomers bond on the microarray. Then we need to create a process which allows for the flow of DNA molecules into the system to complete the DNA synthesis. Since these steps are complex and dependent upon previous steps, we needed to create deadlines to be completed in sequential order.

### *b. Tracking Procedures*

To keep track of our progress we utilized a few mediums. First, we communicate as a group with our advisor through Slack. As well, we use Google Drive to take weekly meeting notes. This helps us keep track of our weekly discussions in regards to tasks to be worked on for the given week. It also helps us store knowledge we gather from our advisor. We have made use of Git throughout the progression of the development of programming our user interface.

Figure 1: Summary of Waterfall Management Model



## 3.2 Task Decomposition

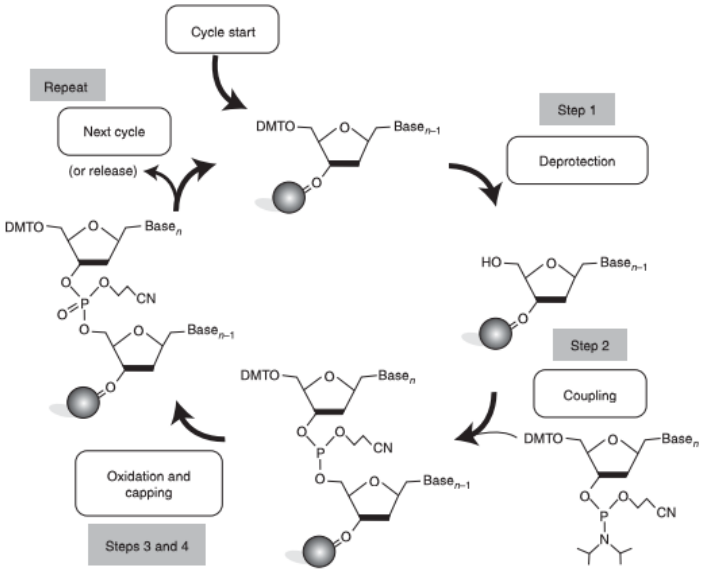
***Tasks:***

- Controlling the LCD
- Developing the microfluidic system
- Coding a GUI

***Subtasks:***

- Research biology principles of DNA synthesis
- Creating/coding a microarray to be displayed on the LCD
- Communicate with LCD screen via created code

Figure 2: Summary of DNA Synthesis Process



## 3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Table 1: Description of Project Milestones

| **Milestone** | **Measure Progress** |
|---|---|
| Connect to the LCD | Proper, stable connection and ability to display/mirror our display to the desired LCD. |
| Develop Microfluidic System | DNA synthesis is completed according to provided code with accuracy of 85% |
| Coding a microarray | DNA is accurately sequenced based on input from GUI |
| Coding a GUI | Proper coding connection to display and ability to project image to desired LCD. |
| Communicate with LCD via created code | When the GUI application is run, the desired images are displayed on the LCD. |

## 3.4 Project Timeline/Schedule

Figure 3: Project Schedule


1. Understanding biology behind DNA synthesis (2 weeks)
2. Research DNA Materials (2 weeks)
3. Dismantle 3D Printer to Interact with LCD (1 week)
4. Research LCD (3 weeks)
5. Connect to LCD (3-4 weeks)
6. Create GUI for LCD Screen (3-4 weeks)
7. Testing GUI (3-4 weeks)

## 3.5 Risks And Risk Management/Mitigation

Table 2: Risks and Mitigations

| **Task:** | **Risk:** | **Risk Factor (1-10): 1 = Low, 10 = High** | **Resolution or Explanation:** |
|---|---|---|---|
| Displaying to the LCD | LCD does not display what is intended | 2 | Replace LCD, or use a different way to connect to the LCD |
| Developing microfluidic system | Trying to understand the biology behind this task and implement it | 7 | Further understand task and get access to required |
| Modifying 3D printer | Breaking printer component | 3 | Component would be easy to fix or reorder |
| Coding GUI | Code does not work | 4 | Debugging |
| Communicating with LCD screen | GUI and LCD screen are not compatible and do not communicate | 8 | Change how we communicate with the LCD or use a different process behind the GUI |

## 3.6 Personnel Effort Requirements

Table 3: Allocated Project Hours

| Task | Hours |
|---|---|
| Biology/DNA Research | 20 |
| Connect/Research LCD | 15 |
| Creating Microarray | 10 |
| Coding GUI | 20 |
| Communication between LCD and Created Code | 10 |

| | |
|---|---|
| Developing Microfluidic System | 30 |
| TOTAL | 105 |

### 3.7 Other Resource Requirements

- HDMI to MIPI adapter for connection between computer and LCD
- Fabrication technology for flow cell
- DNA oligomers to be used in microfluidic system
- Use of ETG for manufacturing of various components

# 4 Design

## 4.1 Design Context

### 4.1.1 Broader Context

Table 4: Ethical Design Considerations

| **Area** | **Description** | **How our Project Relates** |
|---|---|---|
| Public health, safety, and welfare | How does your project affect the general well-being of various stakeholder groups? These groups may be direct users or may be indirectly affected (e.g., solution is implemented in their communities) | This method of DNA synthesis uses UV light to break down and bond the DNA. If not regulated the UV light could be too intense and prolonged exposure could lead to potential harm of users such as geneticists or other scientists |
| Global, cultural, and social | How well does your project reflect the values, practices, and aims of the cultural groups it affects? Groups may include but are not limited to specific communities, nations, professions, workplaces, and ethnic cultures. | Development of DNA synthesis technology assists with researchers who are attempting to keep up with the increasing data storage demand year to year. DNA can be a viable solution for containing copious amount of data in a single structure |

| | | |
|---|---|---|
| Environmental | What environmental impact might your project have? This can include indirect effects, such as deforestation or unsustainable practices related to materials manufacture or procurement. | Data centers are currently used to hold the digital information for companies such as Amazon or Facebook. DNA storage capabilities could reduce the required space and therefore the required energy to store data, from the size of a data center to the size of a small room. |
| Economic | What economic impact might your project have? This can include the financial viability of your product within your team or company, cost to consumers, or broader economic effects on communities, markets, nations, and other groups. | This product reduces the cost of current DNA synthesis by using simpler components. This would allow bioinformatics personnel the opportunity to budget more resources towards storing data in DNA. This process could also eventually be used by geneticists for patients who require some form of gene therapy. |

### 4.1.2 User Needs

- Geneticists need a cheaper way to synthesize DNA that will end up saving them money and time in the end.
- Data analysts need a long term alternative for digital information to keep up with the increasing demand of a digital world
- Pathologists need a method of studying disease causing genes without needing to extract these molecules from a human sample

### 4.1.3 Prior Work/Solutions

There are no DNA 3D printers on the marketplace currently. Although, there are a few companies that can perform DNA synthesis. The first of these companies are San Diego-based Molecular Assemblies, Ansa Biotechnologies, and Paris-based DNAScript. Currently a single character in a genetic sequence costs roughly $1 to print, or $1 per base pair. In perspective, if you wanted to print the entire sequence of a human, it would cost around $2 billion.

### 4.1.4 Technical Complexity

1. The design consists of three major systems, each consisting of multiple components working in tandem to complete the desired function.
    a. Anycubic Photon Mono 3D Printer
        i. Monochromatic LCD screen
        ii. UV light module with magnifying lenses

   b. Microfluidic System
      i. Flow cell fabrication
      ii. Fluigent controller and switches
      iii. DNA oligo pools
      iv. Air compressor
   c. Software/GUI
      i. WPF
      ii. C#
      iii. XAML
2. The DNA synthesis process requires the use of several scientific principles which can be realized using the above components.
   a. UV light polarization via control of liquid crystal display
   b. DNA oligomer denaturing via UV light
   c. DNA phosphoramidite synthesis
3. The problem scope contains multiple challenging requirements that match or exceed the current solutions or industry standards.
   a. More affordable alternative to the current industry processes
   b. Accuracy of DNA sequencing to reflect the current industry standard
      i. Minimal substitutions, omissions, or additions of DNA base pairs during sequencing
      ii. Proper dispersion of UV light exposure to all regions of the flow cell
   c. User friendly interface to allow for ease of use
      i. Variability in DNA strand array size
      ii. Easy input of desired sequence

## 4.2 Design Exploration

### 4.2.1 Design Decisions

1. Connection between the LCD and the computer will be made via an HDMI to MIPI adapter connection.
2. The variables users will have control over within the software will consists of array size, individual position size, and position spacing
3. The sequence of DNA base pairs as well as the selection of intermediate chemical compounds used for cleaning the surface of the flow cell will be determined once the setup of the microfluidic system is complete.

### 4.2.2 Ideation

Several considerations were taken into account when determining the best course of action for the connection and control of the LCD screen. The ideas were generated through brainstorming sessions during team meetings and new ideas continued to be generated as we gained more background information from our advisor. The following options were considered for this decision in the design:

1. Connection to the 3D printer directly via USB port
2. Connect to a Raspberry Pi or the 3D printer itself through the Wifi capabilities of both
3. Use of a Raspberry Pi to control the LCD and connect via MIPI port
4. Connection between the LCD and computer via an HDMI to MIPI adapter
5. Various alternative LCD screens with built in HDMI connections

### 4.2.3 Decision-Making and Trade-Off

For each of the options we went through and researched the current products available on the market to determine its viability. We also took into account financial considerations since one of the major goals of our project is to create an affordable design. The different variations of LCD screens were more expensive than our current screen so we wanted to find a method to make it work without the need for a new part. Research was done on the wifi connection and USB connections to the 3D printer and it became evident that extensive reconfiguration of the microcontroller would be required to control the LCD and allow for an image file to be passed through the printer to the LCD. This option was mainly in consideration because it did not require us to dismantle the printer. The Raspberry Pi option was appealing because it had the simple software available. The only issue was that it required an adapter and it required introducing an additional part to our system. We determined the best option was to go with the HDMI to MIPI adapter which could connect the LCD directly to the computer and cut out any additional controllers, secondary components, or difficult software reconfigurations. This option allows for the LCD screen to essentially act as a second monitor to our computer and we can project any image we want to the screen for the purposes of DNA synthesis.

## 4.3 Proposed Design

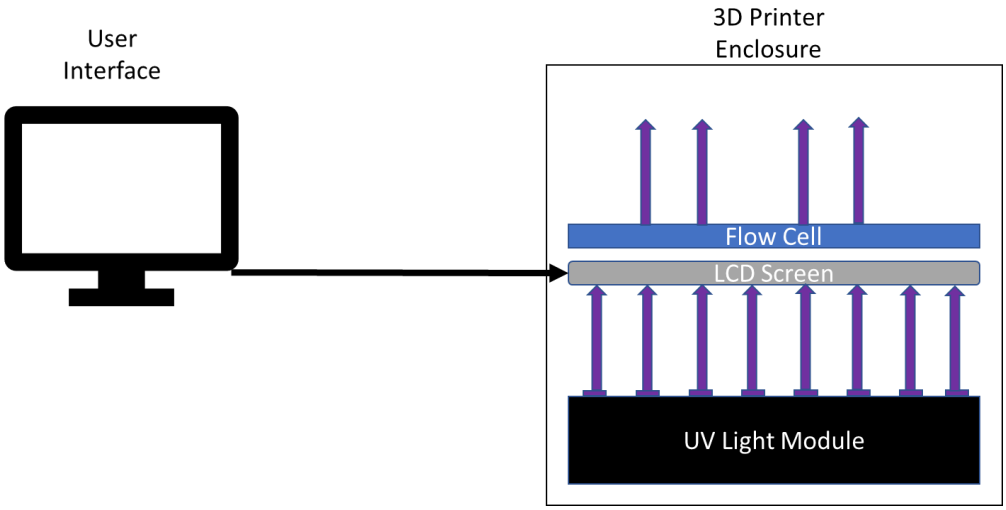
Being able to successfully perform DNA synthesis with the use of a modified Photon Mono 3D printer that will satisfy a new medium of digital storage to keep up with increasing demand at an affordable price. Our design will consist of three major sub-components. Those being the LCD screen and UV light control, the user interface, and the microfluidic system.

### 4.3.1 Design Visual and Description

The diagram below depicts the interaction between the user interface and the LCD screen. The array parameters and digital information are uploaded into the designed software. The digital information will be divided up into two-bit segments, each of which will be correlated to any given DNA base pair based on its value. The software will then break the string of data down into relatively equal segments to fill each of the positions on the array. The segments will be parsed layer by layer in each of the array locations and an image will be generated to be passed to the LCD screen. The images will configure the

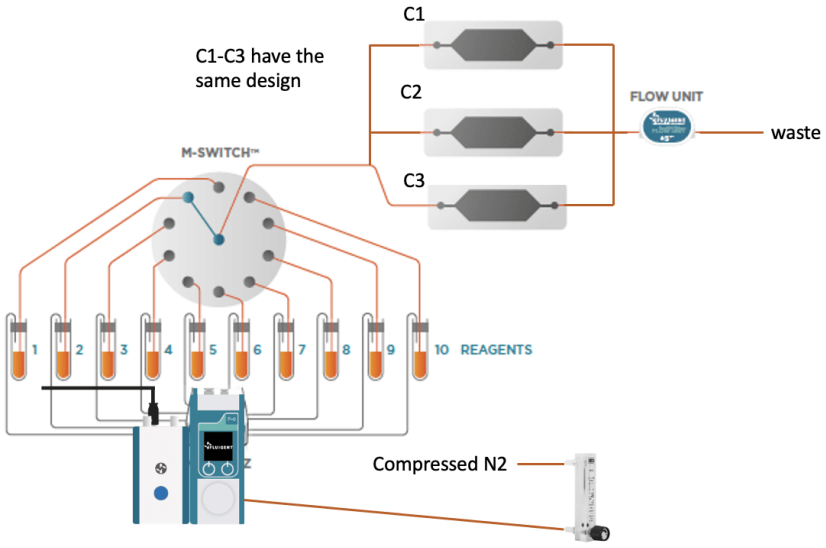
LCD screen in a way which selectively lets the UV light through and into the flow cell where it will initiate the bonding between the DNA base pair and the growing DNA segment.

Figure 4: Integration of User Interface and LCD Screen



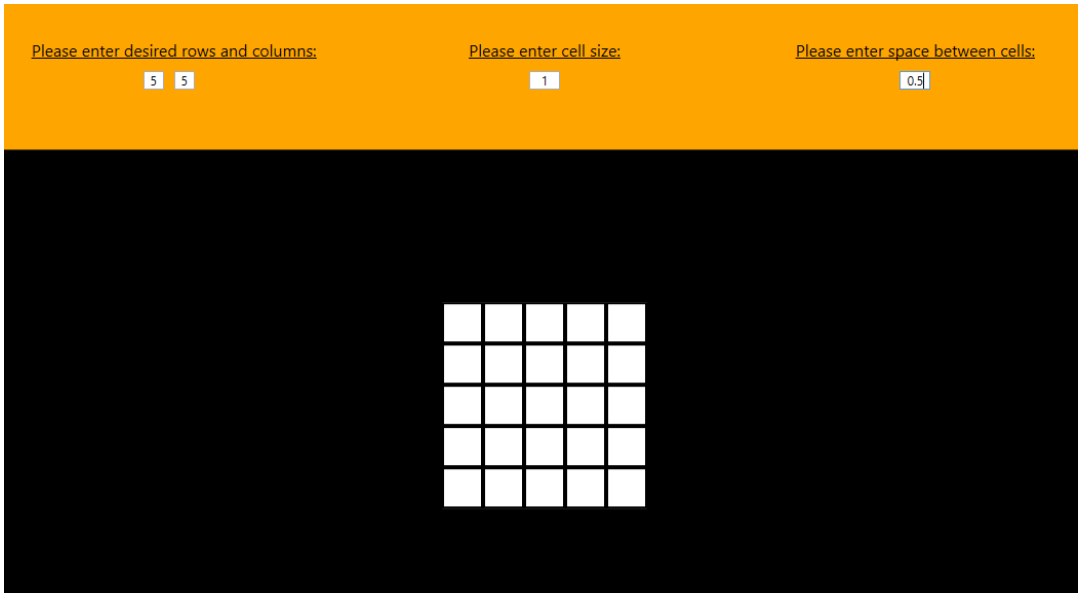

The microfluidic system is shown in the image below. There will be a total of ten chemical compounds which will be used throughout the bonding process of each layer of the DNA segments. The rotating M-Switch in the middle of the diagram will rotate at each step and open up the channel between the reagents and the flow cells. During that time the other wells will be replenished. The flow cells are the components labeled C1-C3 and will be the location where the bonding will occur. The entire system will be operated using a vacuum and compressed air to push the reagents through the system.

Figure 5: Diagram of Microfluidic System




Primitive example of the User Interface. This is just a simple look of what we are basing our current code off of. Each cell in the matrix will eventually be separated (surrounded by black to match the background) and also be able to switch colors to completely blend in with the background. Also, as mentioned above, we are currently working towards receiving user input to allow the entire matrix to be customizable to the DNA standards that they want.

Figure 6: Example of User Interface Dimension Selection



### 4.3.2 Functionality

The DNA synthesis is initiated by a user dictating the array size, which is the number of DNA segments created, position spacing, and size for their desired sequence. The digital information which is to be encoded by the DNA is translated by assigning a two-bit value to each of the four base pairs. Each time a different base pair is introduced to the flow cell a new black and white image will be displayed on the LCD screen. The white locations will allow UV light to pass through and thus allow bonding to occur between the current base pair and the DNA strand being synthesized in that position of the array. This process will be repeated for each base pair at any given level until the desired strand length is reached. Once completed the individual strands can be bonded together to create one coherent strand containing all of the digital information.

The current design has not reached its fully functional form, but in theory once all of the components are integrated together it should be able to perform the task. The accuracy of the DNA synthesis is still in question and some alterations may need to be made in order to correct this issue.

### 4.3.3 Areas of Concern and Development

One of the major areas of concern is the accuracy of the DNA synthesis process. Bonding errors, such as omissions, additions, or substitutions, are potential issues to arise if the surface of the flow cell is not properly cleansed between each base pair being introduced or insufficient light allowing for the activation of the bonding reaction. This issue will be addressed by determining the best compounds to use as intermediate fluids to cleanse the surface of each DNA base pair. Extensive testing will also be done to determine the accuracy of the process and where errors are occurring. These solutions will come in the late stages of the project as we are currently working on integrating each subsystem together.

## 4.4 Technology Considerations

Table 5: Evaluation of Technology Utilized

| Technology | Strengths | Weaknesses | Trade-offs |
|---|---|---|---|
| LCD Screen | Compatible with HDMI to MIPI adapter<br><br>Significant difference in UV intensity between white and black regions<br><br>Easy control of image produced through HDMI connection | Lifespan of RGB screen<br><br>Required removal of reflective backing<br><br>Not compatible with resolution settings of all PCs | Shorter lifespan compared to monochromatic, but improved UV intensity difference<br><br>Although it does not match the resolution of every PC it is able to work with the adapter to make for ease of information transfer |
| Software | C# capable of encompassing all requirements for project<br><br>Fluigent's OxyGEN built in commands for microfluidics<br><br>OxyGEN easily integrated with C# | Requires application to run and be connected through a computer | Program being run through the computer makes the design simpler and cheaper but makes setup more complex. |
| Microfluidics | All components are compatible<br><br>Simple assembly<br><br>Autonomous capabilities<br><br>Components are easily replicable | Expensive components<br><br>Self manufactured components with sealing concerns | Saved money by manufacturing some of our own components, but found issues with sealing to ensure no pressure leaks |

### Design Alternative Suggestions:

The potential for alternative solutions from those outlined above could relieve some of the concerns and weaknesses described. A different model of adapter could be designed to be compatible with a monochromatic LCD screen which would alleviate the lifespan concerns associated with an RGB LCD screen. In regards to the microfluidic components, manufacturing our own versions of the normally expensive components has saved us money, but resulted in insufficient sealing when placed under pressure. In order to resolve this issue we have revised our design from using an epoxy sealant to designing the components with threaded ferrule fittings.

## 4.5 Design Analysis

In the current state of our design, we have been able to reach several of the individual milestones, but have yet to integrate them as one unit. The preliminary testing of the user interface and LCD screen has proven to be successful in that we are able to replicate an input image on the screen. The LCD screen is still being tested to improve the UV light exposure intensity passing through any given region. The microfluidic system is still experiencing pressure leaks at critical points which have inhibited it from performing as expected. Manufacturing is in progress for new components which are expected to resolve these issues. These final modifications will lead us into the next phase of the project which is integrating all systems together and testing of the overall system.

## 4.6 Design Plan

The current design has been broken down into three major sub-components. Those being the LCD screen and UV light control, the user interface, and the microfluidic system. Each member of the group has been designated a role in designing at least one of these components.

### LCD Screen/UV Light Control:

The different iterations of LCD screen control methods we have tried have been outlined in the above sections. We have tested the LCD screen with HDMI to MIPI adapter and found this method of interfacing with the LCD screen works well. Further testing is being done to determine the intensity of UV light being produced by the light module when it passes through the LCD. This will be an important factor in determining the time of exposure for the DNA base pairs when they pass through the system. The UV light is the catalyst for the bonding reaction so the testing will ensure it has enough energy to break the protective molecules on the DNA which prevent it from bonding uncontrollably.

### User Interface:

For the software application that users will visually interact with we decided to go with a WPF framework application that uses C# for the backend functionality and XAML for the GUI. Currently, it displays a white matrix on a black background as this is the basis for what our project will look like and what we will base the rest of our code on. We are in the process of implementing/testing receiving user input that will be used to determine the size of the matrix, size of the individual cells, as well as a few other minor aspects.

### Microfluidic System:

This subsystem is still in the early stages of development and has been heavily research based. A schematic for the overall design of the microfluidic system has been sketched out to be referenced during assembly. Most of the parts have been obtained, but the flow cell is required to be custom fabricated. A 3D rendering of the model is currently being developed and the goal is to fabricate it in the early weeks of next semester.

# 5 Testing

## 5.1 Unit Testing

- UV Light Wattage - We will be using a power meter to measure this. It is necessary to assure enough light is getting through the LCD screen in order to synthesize DNA.
- LCD Screen Resolution - We will test this screen to make sure that the UI from our code is properly displayed on the LCD. We will test this by ensuring the screen stays properly displayed throughout the computer; alters the image, changes tabs, and a device is plugged into the computer.
- Systems Software - We will need to make sure all of the different software components within the system work in tandem with each other. To make sure this works, we will first analyze each system individually. We will perform simulating plausible user input into our software and confirming if the response is what we desire.

## 5.2 Interface Testing

We have a user interface that formulates a matrix to the specifications that the user desires. This is used to replicate a microarray. The interface will request and accept user input and with this data it will initialize another interface that is then sent to the 3D printer to be used. Testing will be quite simple because we can just enter possible user input and then see how each interface reacts.

## 5.3 Integration Testing

Integration of the user interface with control of the LCD screen. This is critical for the design because the user interface will allow for the control of the LCD screen to selectively control where the UV light passes through to catalyze the bonding reaction between DNA base pairs. This integrated system can be tested by passing information from the user interface to the LCD screen. The image sent will be compared to the final

output image. A power meter will be used to verify the proper amount of UV light is being blocked or allowed through by the opaque and transparent region, respectively.

Integration of the microfluidic system with the combination of the LCD and user interface. The main functionality for this integration will be to ensure the clock cycles are synchronous so that the flow controller initiates the flow of a given compound at the proper time for it to receive sufficient UV exposure when the light module is activated. Testing will be done by checking the percentage of bonding which takes place during one cycle of the system. Changes may need to be made to verify the amount of exposure each chemical is receiving as it flows across the LCD screen and flow cell.

## 5.4 System Testing

System testing can be seen as complete end to end testing for a specific system. The two main systems that require testing are the user interface and the microfluidic system.

***User interface:***

The user interface will require testing on multiple aspects. We will need to create Unit Tests that inject user inputs to test and see if we get the desired output. When creating these tests and inputs we will need to make sure we don't forget the corner cases. We also will need to perform some automation tests to assure the image is properly rendered.

***Microfluidic system:***

The microfluidic system will require testing of the flow rates of each of the chemicals being used. Pressure within the flow cell will also need to be tested and monitored as part of the flow rate testing. The adhesion rate of the molecules to the designed substrate will also be tested. All of these variables can be observed using a software designed by Fluigent known as OxyGEN.

## 5.5 Regression Testing

Any new additions we have, such as a new LCD screen, we immediately test with our system to make sure everything functions. This testing is required since each step builds off one another, so if the screen does not work then the rest of the project will not work. Testing the UV light with the power meter with the LCD screen also gives us crucial data regarding the cellular bonding of DNA.

In regards to the user interface code, we are continually making more and more branches with plenty of commits. This will ensure we do not lose any critical progress as well as ensuring we are able to revert back to a working version whenever we like.

## 5.6 Acceptance Testing

- Demonstrate physically that the user interface works as intended in our weekly meetings with the client.
- Successfully and accurately print DNA with correct coding

## 5.7 Results

- The results of our testing should follow our acceptance testing in that we successfully synthesized DNA with the correct coding that we input.
- For the user interface, the results of our testing will be checking if the output that is presented to us is the one that we are expecting. Because the nature of our project allows us to know what the output should look like before entering any input, we can simply see how the program reacts to what we enter into it.

Table 6: Example of User Interface Dimensioning

| Input → | 10, 10 | 1 cm | 10 nm |
|---|---|---|---|
| Matrix Size | A matrix with 10 rows and 10 columns will appear | | |
| Cell Size | | Each cell will measure 1 centimeter across | |
| Space Between Cells | | | The space between each cell of the matrix will measure to 10nm |

# 6 Implementation

The implementation plan for next semester will be to integrate each subsystem together to form our final product. The LCD screen and UV light control will be integrated with the user interface first in order to ensure everything functions as intended prior to adding the flow system. The user interface will be designed to sequentially send images to the LCD screen for a set period of time and also control the operation of the UV light module. The time at which a given image is displayed on the LCD screen and the time at which the UV light is activated will need to be synced in order to maximize exposure time. Once the timing and performance of the system is sufficient we will be able to integrate the microfluidic system. The user interface will also be able to control when to activate the pressure controller and valve in order to push the desired fluid through the system at the time when the image is present on the screen and the UV light is active.

# 7 Professionalism

## 7.1 Areas of Responsibility

Table 7: Application of Standards to Professional Responsibilities

| Area of responsibility | Definition | NSPE Canon | IEEE | Explanation [brief description, how they differ from NSPE canon] |
|---|---|---|---|---|
| Work Competence | Perform work of high quality, integrity, timeliness, and professional competence | Perform services only in areas of their competence; Avoid deceptive acts | 6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations<br>5. to improve the understanding of technology; its appropriate application, and potential consequences | These two descriptions relate to work competence in that they describe improving the knowledge of current technology being used as well as only doing the work one is qualified for.<br><br>They differ from NSPE by not mentioning anything to do with performing deceptive actions but they go further in depth into what one's area is determined as. |
| Financial Responsibility | Deliver products and services of realizable value and at | Act for each employer or client as faithful agents or trustees | 4. to reject bribery in all its forms | To reject bribery relates directly to financial responsibility because it pertains to performing work honestly despite other |

| | | | | |
|---|---|---|---|---|
| | reasonable costs | | | potential benefits.<br><br>The IEEE code is a very broad description whereas the NSPE code describes what the role of the employee is in relation to the work they perform for either the employer or client |
| Communication Honesty | Report work truthfully, without deception, and understandable to stakeholders | Issue public statements only in an objective and truthful manner; Avoid deceptive acts | 3. to be honest and realistic in stating claims or estimates based on available data<br>2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist | The two IEEE codes relate to communication honesty because they focus on disclosing all information honestly to both the general public and to employers.<br><br>These differ from NSPE because they mention that communication honesty not only encompasses disclosing information to the public, but also disclosing conflicts of interest to an employer. |
| Health, Safety, Well Being | Minimize risks to safety, health, and well-being of stakeholders | Hold paramount the safety, health, and welfare of the public | 1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment | This IEEE code correlates directly to Health Safety and Well-being in that it states we should make these things an absolute priority when developing a product and that the public should be made aware of any risks associated with it.<br><br>There is not much of a difference between the IEEE and NSPE with the exception of the IEEE code mentioning taking responsibility as well as disclosing information. They both portray the same value in safety, however. |
| Property Ownership | Respect property, ideas, and information of clients and | Act for each employer or client as faithful agents or trustees | 9. to avoid injuring others, their property, reputation, or employment by false or malicious action | Code 9 from the IEEE code of ethics is very similar, saying that one should avoid injury to others and property and their reputation. |

| | | | | |
|---|---|---|---|---|
| | others | | | This differs from the NSPE code since it does not directly mention any client or information. |
| Sustainability | Protect environment and natural resources locally and globally | Adhere to principles of sustainable development to protect the environment for future generations | | There was no similar code found in the IEEE code of ethics which related to sustainability more than another area of responsibility. |
| Social Responsibility | Produce products and services that benefit society and communities | Conduct them honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession | 8. to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression<br>7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others<br>10. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics | There were three different codes we found in the IEEE code of ethics that apply to Social Responsibility. 8, 9, and 10 all mention some form of treating others fairly, conducting work honestly, and supporting peers and co-workers<br><br>These differ from the NSPE code since the IEEE codes do not directly say to benefit society or communities. |

## 7.2 Project Specific Professional Responsibility Areas

Table 8: Application of Professional Responsibilities to the Project

| Area of responsibility | Team Performance | Application & Justification |
|---|---|---|
| Work Competence | High | Work competence is crucial to our projects professional context because timeliness and high quality are of necessity. During this semester, we need to focus and work timely to make sure we are able to complete what we want before next year. Along with this, we want to make sure the work we do is of high quality so we don't have issues down the road and have to repeat steps. Also, when printing DNA properly, there can be no little lazy mistakes. |
| Financial Responsibility | Low | Currently, although our project gives us a $5,000 budget, our supervisor provided us with the necessary photon printer. This semester, we will most likely not need any additional parts of tools to complete what we want, so financial responsibility is currently of low concern. For next year, when we need to buy more parts to physically print, this area of responsibility may be moved to a medium. But I don't believe we will reach near our budget, so this shouldn't be a huge concern. |
| Communication Honesty | Medium | This area of responsibility is of medium concern due to the group doing individual work. When assigned work to do weekly, it is important that work is properly communicated as well as done, honestly. It would be easy to tell our advisor/stakeholder we did certain work that is not currently done, which is never wanted or desired. This could potentially happen due to miscommunication or someone trying to cover up for not doing the work they are supposed to. |
| Health, Safety, Well Being | Low | When looking into health and safety, we are mainly concerned with the health and safety of the users. Within our project, the only dangers so far that we could run into are within the 3D printer itself. |
| Property Ownership | High | This category is of high concern due to a few reasons. There are a few ways to go about solving every problem whether it's coding, hardware, or theoretical. While asking for guidance from our mentor, as well as working in a team, we all need to make sure we are respectful to each other and their ideas. More importantly, our mentor gave us access to a photon 3D printer, which is not only expensive, but also is his property. Due to both of these facts we must be respectful by taking care of and properly storing the printer. |
| Sustainability | Low | Our project doesn't have many earth harming parts to it. The main component is the photon 3D printer which prints nucleotides one at a time until we create DNA. We will also use a computer to control the 3D printer. None of these things are too harmful to the environment or global resources. The worst part would be the printer potentially using a |

| | | |
|---|---|---|
| | | small amount of electricity to constantly run while it prints. |
| Social Responsibility | High | This area of responsibility is important to our project due to the end goal of it. In the end, hopefully, we will be able to successfully print DNA which will benefit society. Printing DNA will help with antibody-based drug development, donor DNA synthesis, metabolic pathway engineering, and gene therapy. All of these things will be highly beneficial to society. |

## 7.3 Most Applicable Professional Responsibility Area

We believe that the most applicable professional responsibility area in regards to our project is Work Competence. What this means to our project is very important because the work that we are doing is very involved and complicated. Everyone must complete their work with confidence and competence because the nature of our project can lead a very small error to grow or develop into a major error later on. 0A high quality of work is a necessity when printing DNA because if one individual nucleotide inserted on the Oligos is improper, the entire strand of DNA will need to be repeated. So we need to precisely add the proper nucleotide to the proper oligos upon printing. On top of high quality of work, we need to be timely with our work as well. During this semester we have several goals we want to reach. This includes; communicating with the printer, coding the user interface, and controlling/calibrating the LCD. To make sure we get all of this done, we must complete our high quality work in a timely fashion. A way we can help make sure this gets done is by our weekly reports and team meetings.

# 8 Closing Material

## 8.1 Discussion

The current state of our project has resulted in the ability to control images displayed on an LCD screen via the user interface we designed. We have been able to slightly modify the LCD screen by removing an aluminum reflective film on the back of it, thus increasing the amount of UV light able to pass through the screen by a factor one hundred. The user interface is also able to control the dimensions of the microarray to serve as a control for bonding locations in the flow cell. The microfluidic system has not reached full functionality yet as there were some pressure leaks in a few components, but a majority of the system is assembled. Those issues are being resolved with a new design for these components which is expected to provide a tighter seal.

Figure 7: Current Status of Microfluidic System

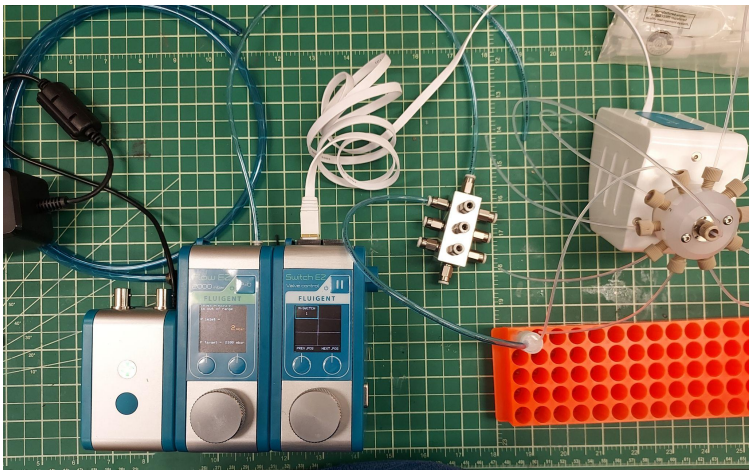
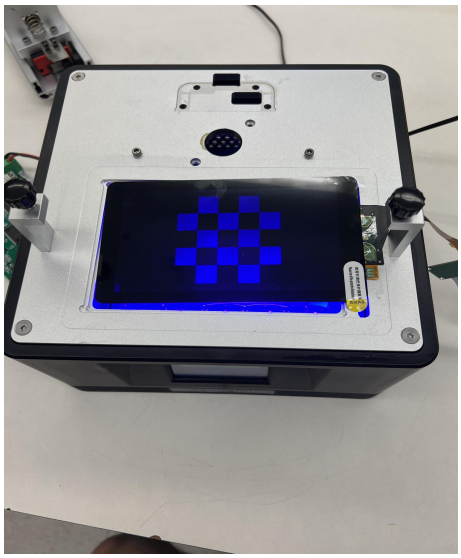


Figure 8: Displayed Image on LCD Screen



## 8.2 Conclusion

In conclusion, the goal for our project is to create a system which can autonomously synthesize DNA for the purpose of digital data storage. The system has been developed through the use of an LCD screen, UV light module, user interface, and microfluidic system. The choice of LCD screen allowed us to use an HDMI to MIPI adapter so that we can transmit images from our user interface to the LCD screen. Based on the white and black regions of the screen, UV light is able to selectively pass through the screen and will be the catalyst for nucleotide bonding. The microfluidic system has been designed using parts from Fluigent and a simple flow cell created with the assistance of ETG.

Setbacks that came up throughout the development of the design included component malfunctions such as the initial LCD screen circuitry shorting and pressure leaks in the reagent tubes of the microfluidic system. Software also faced some challenges in that there were specific bugs and errors which took some time to resolve while still maintaining the desired functionality. These setbacks caused delay as we needed to complete testing to verify the issues were present and then evaluate potential solutions before ordering new components. We have been able to determine a feasible solution for the LCD screen and solutions for the pressure leaks are currently being manufactured. The software development continues to require consistent debugging as to prevent any other major setbacks

As the individual components are being completed, the next steps in the process will be to integrate them and create the final system. This system will be able to take an input of digital information and translate it into a DNA sequence by correlating two bit values to a specific base pair. The DNA sequence will then be divided into segments which can be used to produce images representative of the structure of each segment at any given layer. The user interface will also control the microfluidic system by activating the pressure controller to flow each of the base pairs sequentially through the flow cell. As we integrate the parts, a majority of our work will be focused on testing to ensure the functionality of our system is as intended.

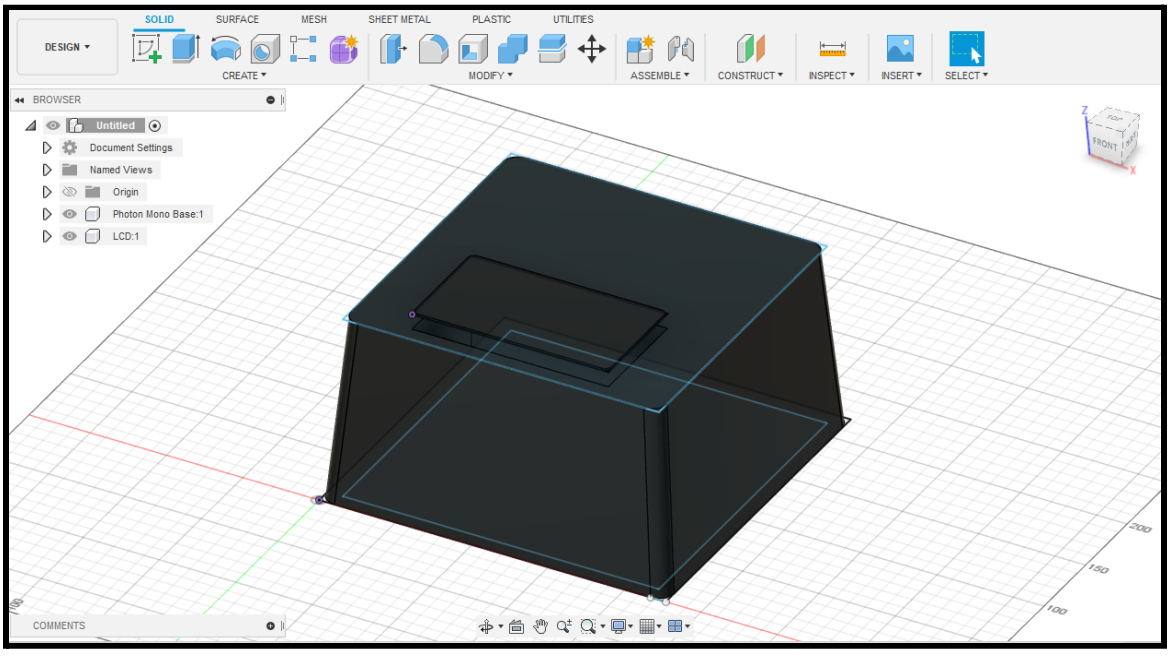
.

## 8.3 References

[1] Bleugh, “Anycubic Photon Mono Teardown 3,” Bleugh.Biz Blog Thingy, 16-Jan-2021. [Online]. Available: https://bleughbleugh.wordpress.com/2020/10/18/anycubic-photon-mono-teardown-3/amp/. [Accessed: 24-Apr-2022].

[2] “Shaping the future,” Fusion 360 Tutorials. [Online]. Available: https://warwick.ac.uk/fac/sci/wmg/about/outreach/resources/fusion_tutorials/. [Accessed: 24-Apr-2022].

## 8.4 Appendices



## 8.4.1 Team Contract

**Team Name** Creating DNA from scratch for DNA-based data storage

**Team Members:**
1) Connor Larson 2) Kyle Riggs
3) Brandon Stark 4) Lucas Heimer
5) Nathan Armstrong

**Team Procedures**

1. Face-to-face weekly meetings, Wednesday @9am in Coover 2222
2. Communicate over email, Slack, or group chat with our team
3. Decision-making policy based on majority vote
4. Record keeping through documents on a shared Google Drive.

**Participation Expectations**

1. Team members are expected to make all team meetings and participate in discussion unless they informed the group ahead of time
2. Members are expected to have team assignments done on time or ahead of time. If this is not possible ample time must be given as a heads up to other team members.
3. Team members are expected to be open with and communicate effectively especially on matters of assignments before they are due.
4. Members should be vocal in team decisions and give their input. Also, if a task is not being done right a team member should speak up and address it.

**Leadership**

1. Connor Larson leads team organization although all team members are expected to stay organized and help each other coordinate tasks. He will also focus on the firmare side of the project. Kyle Riggs will lead the frontend GUI development for receiving and sending user input. Brandon Stark will lead client interaction in regards to the electrical engineering aspect of the project. Lucas Heimer will lead the component design of the electrical engineering part of the project and will work closely with the 3D printer. Nathan Armstrong will focus on the testing aspect of the project and develop unit tests to test our progress as we go.
2. We will make weekly goals and closely follow our weekly reports. We will also consult with our advisor weekly to have him help guide us on what the next steps should be.
3. Contributions from team members will be recognized through group lab hours and weekly group meetings with our advisor.

**Collaboration and Inclusion**

1. Skills and Expertise

a. Kyle Riggs brings an extensive background in Java and C# programming with a focus on the frontend development needed for this project. He has also worked in a diverse team during an internship with electrical, software, computer, and mechanical engineers.
b. Brandon Stark has experience working with multiple programs/coding languages: These programs/languages include: LTSpice, Matlab, Simulink, Virtuoso, and Excel. He also has experience working with circuit design and testing and has knowledge of simple digital systems. Over the summer he worked with the university at the communications building regarding IT infrastructure. He collaborated and worked alongside multiple engineering students, electricians, contractors, and IT supervisors.
c. Connor Larson has experience in Java, Python, C, and MySQL. During one of my internships I worked to teach myself Python and develop an API that used AWS to extract information from legal pdf documents. Another summer at a different internship I worked to implement radars/sonar within Python. For this project I will be focused on working with programming the UI/LCD for the 3d printer.
d. Lucas Heimer has experience in programs such as: LTSpice, Virtuoso, and Matlab. He also has a minor in biomedical engineering which will be useful in contributing to the biology background of the project. He has worked with circuit design and semiconductor design.
e. Nathan Armstrong has experience with various softwares, such as MATLAB, simulink, LTSpice, excel, and others. He also has experience with C coding and a little in python. Nathan has experience with multiple personal projects involving circuit design, building, and testing, as well as simulating said projects in previously mentioned software programs. He will be focusing on the hardware aspects of the 3D printer.

2. Communication. This aspect of group project development is supremely important. If a team member is not contributing to the discussion enough it is up to the other members to ask them what they are thinking as well as how they would address the particular problem.

3. Individual members should bring issues up with the entire team during team meetings. Resolutions and compromises will be agreed upon via majority vote decision on the best path moving forward.

**Goal-Setting, Planning, and Execution**

1. Program the 3d printers UI/LCD.
2. Set weekly goals with both group lab time and individual work.
3. Hold each other accountable by making sure everyone reaches their goals and attends what they are supposed to.

**Consequences for Not Adhering to Team Contract**

1. For minor offenses that happen more than twice the team member who did the infractions will be talked to and addressed by the team as a whole. If these offenses continue/escalate we will bring the issues up to our team's advisor as a next step.
2. If infractions continue and don't get better after being confronted by the team as a whole, then the advisor as well, we will bring the issue to the instructor.

**********

a) I participated in formulating the standards, roles, and procedures as stated in this contract.

b) I understand that I am obligated to abide by these terms and conditions.

c) I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.

1) _____ DATE 2/9/2022

2) _____ DATE 2/9/2022

3) _____ DATE 2/9/2022

4) _____ DATE 2/9/2022

5) _____ DATE 2/9/2022