Final Documentation
ME310 2012-2013
Clariant
InnoEx
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1 Executive Summary

Clariant is an international leader in specialty chemicals, an industry characterized by increasingly high competition from emerging markets. In need of rapid innovation to stay ahead of the competition, Clariant requested the development of an open innovation platform that would allow them to connect, communicate, and innovate with startups and academics in a new high-tech industry: Printed electronics. Printed electronics (PE) is an emerging technology that uses special inks to print electrical components directly onto various substrates.

There are two common open innovation methods: online platforms and in-person workshops. Online platforms let corporations like Clariant publicly post challenges for a global community of innovators to solve. Workshops bring innovators face-to-face to brainstorm solutions to common problems. Both options require users to reveal potentially valuable ideas in public forums, and thereby forfeit any claim to intellectual property. PE workshops have the additional problems of 1) focusing on existing industry problems and 2) lacking the prototyping tools for turning ideas into believable products.

Our team, composed of four Mechanical Engineering master’s students at Stanford University and two Business Innovation master’s students at the University of St. Gallen in Switzerland, has developed a solution that addresses these critical flaws.

Our solution is InnoEx, a comprehensive innovation experience, which is designed to accelerate the entire printed electronics industry by facilitating interconnection, communication, and innovation. We developed two complementary innovation experiences: InnoEx Online, a privacy-oriented social network and search database, and InnoEx InPerson, a printed electronics prototyping and innovation generation workshop. Although we designed our solution specifically for the PE industry, the concept could easily be translated to any emerging technical industry.

InnoEx Online

InnoEx Online requires users to post only the expertise or resources that they are willing to share with the community. Users can search the global community for people offering expertise or resources they need, shown in Figure 1, and contact those people privately. There is never any need to publicly post potentially valuable ideas.

Figure 1: Search Page (left) and Search Results (right)
This system helps Clariant to stay at the pulse of the technology and enables them to launch new and foster existing relationships within the PE industry. InnoEx Online also provides Clariant with an overview of all interactions and activities in the community and therefore represents a unique tool in the scouting phase of their idea-to-market-process.

**InnoEx InPerson: Featuring the 3D Circuit Printer**

InnoEx InPerson is a workshop concept that revolves around a unique manufacturing and prototyping tool: the 3D Circuit Printer (3DCP), shown in Figure 2. This new technology combines 3D printing with PE inks to produce 3-dimensional circuits fully integrated into any mechanical shape, all without removing the object from the print bed. The 3DCP provides incentive for PE idea generators to attend the workshop, inspiration for new product ideas, and a tool for prototyping them. By meeting to imagine new applications of PE technology rather than existing industry problems, the workshop does not put existing intellectual property at risk.

![Figure 2: The 3D Circuit Printer](image)

Our system helps Clariant stay ahead of the competition by connecting them to the most innovative people in the industry. It also enables collaboration between Clariant and innovators to help them turn their innovations into realities. In this way, InnoEx can accelerate not just Clariant’s innovation process, but illuminate the entire Printed electronics industry.

![Figure 3: Illuminating the Printed Electronics Industry](image)
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1.4 *Glossary*

ABS: Plastic material used in FDM printing

FDM: Fused Deposition Modeling, additive manufacturing technology that lays down layers of melted material to 3D print objects

Hot-end: Part of the extruder made to heat-up the ABS plastic up to 230C and have it extruded through a brass nozzle of 0.35mm

Extrusion / extruder: Extrusion is a process used to create objects of a fixed, cross-sectional profile. In our case the extruders pushed down ABS or conductive material in circular nozzle.

Hackability: Capability of a system to be modified for a different purpose than its original function.

G-Code: Machine commands for manufacturing, usually starting with the letters G or M.

CAM: Computer Aided Machining

TLT: A machine shop on Stanford’s campus

PRL: Product Realization Laboratory, another machine shop on Stanford’s campus
2  Context

2.1  The Design Team

2.1.1  Stanford Group

<table>
<thead>
<tr>
<th>Name</th>
<th>Status: 1st Year M.S. in Mechanical Engineering</th>
<th>Contact</th>
<th>Skills</th>
<th>Computing</th>
<th>Background and Interests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hao Jiang</td>
<td></td>
<td><a href="mailto:jianghao@stanford.edu">jianghao@stanford.edu</a></td>
<td>lathing, milling, CNC processing, craft planning, mechanism design, mechatronics.</td>
<td>Solidworks, AutoCAD, C, MATLAB, Linux</td>
<td>I come from the northeastern part of China. I acquired my Bachelor Degree from Beijing University of Aeronautics and Astronautics, focusing on Manufacturing, Design and Robotics. I really like doing innovative design work and collaborating with people on projects. I am interested in playing acoustic guitar and table tennis (ping pong). And I am also fascinated in Chinese cuisines. I am looking forward to making friends with more people and pursuing our dreams!</td>
</tr>
<tr>
<td>Alexandre Jais</td>
<td></td>
<td><a href="mailto:ajais@stanford.edu">ajais@stanford.edu</a></td>
<td>solid and fluid mechanics, simulation, rapid prototyping, mechatronics</td>
<td>C, C++, Python, Maple, MATLAB, Spaceclaim, Solidworks, CATIA, SIMULINK, Dr Frame 3D, Comsol Multiphysics, Adobe Lightroom, Adobe InDesign, Ableton Live, Max MSP</td>
<td>I was born and raised in the wonderful city of Paris in France (Ah Paris...) and studied at Ecole Centrale Paris. My adventure in Stanford started in September 2012 and my interests include Biomechanics, a bit of Robotics and of course Product and System Design here at Stanford. I am a guitar player, a passionate reader and an amateur photographer.</td>
</tr>
</tbody>
</table>
Scarlett, Si Jiang
Status: 2nd year M.E. Graduate Student
Contact: jiangsi@stanford.edu
Skills: PCB design, signal processing, MEMS design
Computing: C, R, AutoCAD, Altium Designer, MATLAB

I grew up in a village near deserts in Xinjiang Province, the most western part of China. I graduated from Tsinghua University with a Bachelor Degree of Micro-Electronic-Mechanical-Systems. I keep exploring all kinds of possibility of my life, and I am glad to pursue entrepreneurship after graduation. I admire freedoms, the love of people, animal and nature.

Daniel Levick
Status: 1st year M.E. Graduate Student
Contact: dlevick@stanford.edu
Skills: mechatronics, thermal design, rugged design, systems integration
Computing: Solidworks, Solidworks Flow Simulation, Inventor, MATLAB

Born and raised in the Virginia suburbs of D.C., I earned a B.S. in Mechanical Engineering from the University of Virginia in 2010 and worked for two years at a satellite communications firm before coming to Stanford in 2012. I enjoy robots, singing, and singing robots. I also enjoy traveling. My most enjoyable product design experiences have been those that integrate electronics, software, and mechanical design. I am very excited to be studying at Stanford and learning to be a better designer from ME310.
2.1.2 St. Gallen Group

Raphael Thommen
Status: Masters Candidate in Business Innovation
Contact: raphael@thommen-sissach.ch
Skills: communication & media relations, business innovation, marketing, business engineering
Computing: Microsoft Access, Micro Strategy, PowerPivot

I was born in Basel, Switzerland. I received my B.A. in Business Administration from St. Gallen University. I have enjoyed internships at a local newspaper and at Credit Suisse and Swisscom. I also enjoy handball, tennis, journalism, and cooking.

Timo von Bargen
Status: Masters Candidate in Business Innovation
Contact: timovonbargen@web.de

I was born in Ulm, Germany. I received a B.S. in Business and Economics from University of Hohenheim. I have experience from internships at Daimler AG & EnBW AG. I enjoy music, sports, and travel.

2.1.3 Coach: Dr. Vinod Baya
Contact: vinodbaya@gmail.com

2.1.4 Clariant Liaison:

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Clariant International Ltd., Switzerland
Group R+D - R&D Center Colorants - Technology Scouting
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Phone: +49-69-305-2079
Fax: +49-69-331749
2.2 Corporate Partner: Clariant

Clariant is a global leader in specialty chemicals. Specialty chemicals are high value, relatively low production volume chemicals designed for a specific purpose. For instance, Clariant produces a line of chemicals for tanning leather. It also designs and redesigns chemical processes, such as the chemical process for dying blue jeans. Clariant sells its chemicals and processes to business customers that use Clariant’s products to produce finished goods for end consumers.

2.3 The Need for Rapid Innovation

Recent global trends have dramatically increased competition for Clariant. A major reason for this increase is the low-cost production of specialty chemicals in emerging chemical markets. To stay ahead of the competition, Clariant needs to develop new products and technologies that cannot be less expensively replicated by emerging markets. In order to address this need, Clariant requires the ability to rapidly innovate.

Clariant’s innovation practices are currently defined by an inward focus. Only one organization within Clariant appears to communicate directly with customers: the business development unit. The business development unit conducts market research in order to generate requirements and ideas for possible innovations. Otherwise, innovations are born in Clariant’s R&D labs. See Appendix B for a description of current innovation practices.

The concept of open innovation holds great potential for improving Clariant’s ability to innovate. Open innovation attempts to augment traditional market research by interactively capturing needs and ideas from all possible stakeholders and interested parties. The goal of open innovation is to transform innovation networks by not only adding innovation partners but by improving lines of communication between innovators. Most importantly, openness and improved communication could create a sense of community and trust that not only will benefit Clariant, but could make the entire industry more efficient and creative.

2.4 A New Business Unit: Printed Electronics (PE)

At the end of January, Clariant informed us that we would apply our innovation solution to their new printed electronics business unit. Printed electronics (PE) is a revolutionary new technology that uses special inks to print electronic components using traditional printing technologies like inkjet, screen printing, and gravure. Current PE applications are relatively limited. Because the new business unit will be a newcomer to a small but rapidly developing industry, it will have an even greater need to reach out beyond Clariant’s R&D labs into the broader community to form partnerships and collaborations with key players. While Clariant claims to have an excellent network of business partnerships with key players in the printing and electronics industry, these will not necessarily be the key players in the printed electronics industry. To thrive, Clariant’s new business unit must be able to identify, collaborate with, and eventually become one of these key players.
2.5 Problem Statement

Our task is to fulfill Clariant’s need to rapidly innovate by providing them with an open innovation solution targeted at the printed electronics industry. This solution must overcome several major challenges:

1. Lack of awareness: Many potential innovators have never heard of Clariant. This will be even more applicable in the printed electronics industry because Clariant does not currently sell any PE products. It is impossible to include these potential innovators in Clariant’s innovation network without first introducing them to Clariant’s products and values.

2. Lack of trust leads to lack of collaboration: One of the major benefits of PE technology is that its materials and manufacturing methods are very inexpensive. Therefore protecting intellectual property (IP) becomes essential for business success. Fear of IP theft breeds mistrust and severely limits the opportunities for collaboration.

3. A unique incentive: Potential innovators and emerging key players in the PE industry need an incentive to collaborate with Clariant. Clariant has expressed to us that this incentive cannot be acquisition or venture capital. Many other incentives that Clariant could provide, like market intelligence and scale-up process knowledge, are not unique and could be provided by competitors.

Our solution must overcome these barriers in order to add the highest potential innovators to Clariant’s innovation network. Several opportunities exist that we believe will help to meet these challenges:

1. Trust as an incentive: Trust is incredibly valuable in the PE community. If Clariant can gain the trust of innovators, this could be a major incentive for collaboration.

2. Rapidly growing application space: The first PE products are only just coming to market. Most of the hype is focused around flexible OLED displays. This means that there is very little market “pull” for most PE inks at the moment. We see a huge opportunity to imagine and create new applications that will generate this market pull for the benefit of the entire PE industry. Furthermore, there is evidence that exciting applications are powerful incentives for collaboration.
3 Design Requirements

3.1 InnoEx Online

InnoEx Online is designed to address the main flaw in many open innovation online platforms: the requirement to post valuable ideas in public domains. It also includes many features that build user trust and ensure user privacy.

As of this report’s publish date, InnoEx Online is a highly refined proof of concept and user testing platform rather than a website with a functional searchable database. Many functions are simulated with dynamic panels and extensive scripting to provide an extremely realistic user experience. Therefore, while functional requirements have not been satisfied, we have produced physical representations of how each function would be implemented so that it could be quickly implemented by a database architect.

Functional Requirements

<table>
<thead>
<tr>
<th>Index</th>
<th>InnoEx Online Functional Requirements</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Allow users to search for expertise and resources</td>
<td>Removes barriers to innovation by initiating collaboration with high likelihood of utility.</td>
</tr>
<tr>
<td>2</td>
<td>Save search data grouped as “projects” and “connections” and maintain this information on a user profile page</td>
<td>Provides an easy way for users to maintain and keep track of existing connections</td>
</tr>
<tr>
<td>3</td>
<td>Allow a user to contact a potential collaborator</td>
<td>Collaboration cannot happen without communication.</td>
</tr>
<tr>
<td>4</td>
<td>Does not require users to post any intellectual property or publishable ideas</td>
<td>Allows users that do not trust each other to feel secure enough to use the system without fear of idea theft.</td>
</tr>
<tr>
<td>5</td>
<td>Establish a basic level of trust between users by facilitating references from users’ common connections</td>
<td>Interviews indicate that even one reference from a mutual connection can dramatically increase the level of confidence and trust between potential collaborators.</td>
</tr>
<tr>
<td>6</td>
<td>Allow the user to create a profile that can then be added to a searchable database</td>
<td>All other functionality depends on a populated database. The simplest way to populate the database is to have users fill out a form to get access to the website.</td>
</tr>
</tbody>
</table>
Future Opportunities
1. Interviews have indicated a need for a clearinghouse function that validates PE products independently. This would be a great feature to add to the community.
2. Provide metrics of system success including number of profiles, search patterns, and message rates.
3. Give a holistic picture of the PE community – who has/knows what. This must be implemented very carefully so as not to compromise trust and anonymity.

Physical Requirements

Table 2: InnoEx Online physical requirements

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Rationale/Metric</th>
<th>Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractive and professional appearance</td>
<td>Given/Judged yes or no by Clariant</td>
<td>Yes</td>
</tr>
<tr>
<td>Search page displaying searchable items in an intuitive format</td>
<td>Needed for functional requirement 1.</td>
<td>Yes</td>
</tr>
<tr>
<td>Profile creation page that shows what kinds of information a user can or must provide</td>
<td>Needed to demonstrate functional requirements 4 and 6.</td>
<td>Yes</td>
</tr>
<tr>
<td>Profile page that shows a user’s information and current projects</td>
<td>Demonstrates functional requirement 2.</td>
<td>Yes</td>
</tr>
<tr>
<td>Search Result page displaying search results and buttons that facilitate communication</td>
<td>Demonstrate functional requirement 1 and 3</td>
<td>Yes</td>
</tr>
<tr>
<td>Social network view page that shows what kinds of projects another user has as well as any connections users have in common</td>
<td>Demonstrate functional requirement 5</td>
<td>In Development</td>
</tr>
<tr>
<td>Easy to build and maintain</td>
<td>Given/judged yes or no by Clariant</td>
<td>Clariant has expressed willingness to implement it.</td>
</tr>
</tbody>
</table>

3.2 InnoEx InPerson and the 3D Circuit Printer
The InnoEx InPerson workshops are designed to address two problems with common workshop methodology:
- **Focus:** the common focus on solving current industry problems creates an inherent conflict of interest. The solutions to these problems would be immediately valuable; therefore attendees are very unlikely to share them with acquaintances.
- **Prototyping:** the lack of rapid prototyping tools prevents attendees from exploring critical questions about an idea’s feasibility. This creates the perception that ideas that are created in these workshops have very little credibility and that the workshops are not worth attending.
Functional Requirements

Table 3: InnoEx InPerson Functional Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Rationale</th>
<th>Test Results Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspire new application ideas for existing technology rather than solve industry problems.</td>
<td>Addresses the focus problem by removing the conflict of interest. Creates safe, creative, collaborative environment.</td>
<td>20 minute brainstorm at the Test Workshop produced 20 new application ideas. One member of the workshop requested by email a proof of concept for an idea he came up with.</td>
</tr>
<tr>
<td>Enable prototyping the new application ideas.</td>
<td>Addresses the prototyping problem.</td>
<td>The InnoEx puzzle pieces test application demonstrates that the printer could prototype many of the application ideas generated at the Test Workshop.</td>
</tr>
<tr>
<td>Attract PE startups and academics as well as designers from other industries who are interested in using PE in their industry.</td>
<td>Attracting PE startups and academics is given by Clariant. Designers from other industries are critical for broadening the applications of PE.</td>
<td>Test Workshop entry survey results indicate that 4/5 attendees came to see the 3D printer.</td>
</tr>
</tbody>
</table>

Physical Requirements

- Large room with areas for mingling, large presentations, and product demonstrations.
- Prototyping equipment for printing electronics and creating application prototypes.
- Accessible location for a large number of target users.
- Workshop coordinators and leaders for planning the workshop, preparing attendees, and leading brainstorming and prototyping sessions.

Opportunities

- Attract innovators from outside of the PE community that might never otherwise be encountered by PE users. These innovators could be doctors, artists, engineers, etc. that could drive application innovation.

3.2.1 3D Circuit Printer Requirements

Table 4: 3D Circuit Printer Functional Requirements

<table>
<thead>
<tr>
<th>Index</th>
<th>Functional Requirements</th>
<th>Rationales</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR1</td>
<td>Provide a unique feature: print circuits in 3D inside of plastic shapes</td>
<td>Simultaneously fulfills FR3 and all three InnoEx InPerson functional requirements by attracting users with a unique tool, inspiring applications with a unique capability, and enabling prototyping of those applications.</td>
</tr>
<tr>
<td>FR2</td>
<td>Print various PE materials</td>
<td>The printer must be applicable to PE technology.</td>
</tr>
</tbody>
</table>
Table 5: 3D Circuit Printer Physical Requirements

<table>
<thead>
<tr>
<th>Physical Requirements</th>
<th>Derived from...</th>
<th>Test Result Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Print vertical conductive traces</td>
<td>FR1</td>
<td>Vertical traces 6mm in height have been printed.</td>
</tr>
<tr>
<td>Embed silicon electrical components</td>
<td>FR1, FR3</td>
<td>Completed for resistors, SMT LEDs, and coin cell batteries.</td>
</tr>
<tr>
<td>Print ABS plastic in 3D shapes</td>
<td>FR1</td>
<td>Print quality is comparable to commercial FDM printers.</td>
</tr>
<tr>
<td>Pause feature for embedding components by hand</td>
<td>FR1</td>
<td>Implemented.</td>
</tr>
<tr>
<td>Software supporting dual extrusion of different materials and addition of pause feature</td>
<td>FR1</td>
<td>Implemented with open source software and a short post-processing script.</td>
</tr>
<tr>
<td>Replaceable syringe extruder</td>
<td>FR2</td>
<td>Completed and tested/calibrated for 1 PE material, with reasonable assumption that other materials could be printed with different sized syringe tips.</td>
</tr>
<tr>
<td>Print conductive traces at less than .5mm line width</td>
<td>FR3</td>
<td>.5mm line width achieved, which allows discrete SMT components to be connected. Limited by material viscosity.</td>
</tr>
<tr>
<td>Weight easily portable by 2 people; can ship by air</td>
<td>FR5</td>
<td>Weight is 13.6kg – easy to carry between two people and complies with most airline checked baggage restrictions.</td>
</tr>
<tr>
<td>Size easily portable by 2 people; can ship by air</td>
<td>FR5</td>
<td>55cm x 66cm x 46cm outer dimensions are a little awkward to carry and would probably require an oversized carrying case for most airlines.</td>
</tr>
<tr>
<td>Materials cost less than $1500</td>
<td>FR6</td>
<td>Actual materials cost for printer is $1,156.05</td>
</tr>
</tbody>
</table>

**Opportunities**

- Clariant has premium inks so that the printer can make use of them to make the system unique and attractive.
- Clariant has good connections with other big companies, such as HP, that can help them manufacture and improve the printer.
Other PE materials with lower viscosities may allow the incorporation of SMT devices with small pin spacing by lowering minimum trace width.

Adapting a commercial printer may improve resolution and reliability, provided the commercial printer is compatible with our software.

### 3.3 Business Opportunities

- High potential innovators could also be high value potential customers. Adding them to Clariant’s innovation network could easily equate to adding them to Clariant’s customer network.

- Creating an internal open innovation network could create the corporate cultural shift that is necessary to effectively execute external open innovation. This internal network could serve as a pilot and launch point for external open innovation. To create this internal network, our system could be prototyped inside the company between the new PE unit and related business units or personnel.

- Incorporate privacy functions that allow the creation and maintenance of Non-Disclosure Agreements within our system. In a competitive business climate, this may increase the chance that another business will partner with Clariant.
4 Design description

4.1 System overview

InnoEx consist two major complementary innovation experiences two: InnoEx online and InnoEx InPerson. InnoEx Online is a privacy-oriented social network and search database to connect and communicate startups and academics; and InnoEx InPerson is a printed electronics prototyping and idea generation workshop. Inside the workshop, the 3D Circuit Printer (3DCP) works as a unique manufacturing and prototyping tool to facilitate ideas generated in the workshop to become real innovation. An overall system overview is shown in Figure 4.

![InnoEx system overview diagram](image)

**Figure 4: InnoEx system overview diagram**

4.2 InnoEx Online Design Description

InnoEx Online is composed of seven pages and a header, which is at the top of each page and adapts to login information provided by the user. Each page is composed of links, dynamic panels, and static content. It was created in Axure, a software tool for creating semi-functional web application mockups. The following is a list of pages:

1. Header
2. Search
3. Configuration
4. Provide
5. Profile
6. Project Pages
7. Workshops
8. About
4.2.1 Header Description

The header is at the top of each page. It has three states: Login, Sign in, and Logged On. These states are shown in Figure 5, Figure 6, and Figure 7. It provides basic links to different parts of the site and provides a Login function.

![Figure 5: Header, Login state](image)

![Figure 6: Header, Sign In state](image)

![Figure 7: Header, Logged On state](image)

Table 6: Header Link Table

<table>
<thead>
<tr>
<th>Link Description</th>
<th>Link Destination Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>InnoEx logo and “Search”</td>
<td>Search</td>
</tr>
<tr>
<td>“Provide”</td>
<td>Provide</td>
</tr>
<tr>
<td>“Workshops”</td>
<td>Workshop</td>
</tr>
<tr>
<td>“About”</td>
<td>About</td>
</tr>
<tr>
<td>“Sign up here” (Sign In state only)</td>
<td>Provide</td>
</tr>
<tr>
<td>“View Profile” (Logged On state only)</td>
<td>Profile</td>
</tr>
</tbody>
</table>
Table 7: Header Dynamic Panel Table

<table>
<thead>
<tr>
<th>Dynamic Panel Icon</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Login” (Login state only)</td>
<td>Toggles to Sign In state</td>
</tr>
<tr>
<td>“Enter your email” and password fields (Sign In state only)</td>
<td>Takes text input from user</td>
</tr>
<tr>
<td>“Sign In” (Sign In state only)</td>
<td>If email and password fields match a stored profile, clicking toggles to Logged On state. Otherwise displays “Wrong email or password”</td>
</tr>
<tr>
<td>Profile name and picture icon</td>
<td>Displays logged on profile name and picture. Clicking toggles display/hide panel with “View Profile” “Recommend” and “Sign Out”</td>
</tr>
<tr>
<td>“Recommend” (Logged On state only)</td>
<td>Toggles “Recommend a friend” static field</td>
</tr>
<tr>
<td>“Sign Out” (Logged On state only)</td>
<td>Return to Login state and links to homepage</td>
</tr>
</tbody>
</table>

4.2.2 Search Page

The search page allows the user to configure parameters for a search for experts, materials, devices, and facilities. It also provides a banner for advertising.
Table 8: Search Page Link Table

<table>
<thead>
<tr>
<th>Link Description</th>
<th>Link Destination Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Configure my project now!”</td>
<td>If Logged On, links to Configuration</td>
</tr>
<tr>
<td>Scrolling Banner (rotates through 4 photos)</td>
<td>Search/Provide/Workshops/About</td>
</tr>
<tr>
<td>“Sign in” (shown if header is not in Logged On state by clicking “Configure my project now”)</td>
<td>Toggles header to Logged On state if email and password match an existing profile. Otherwise displays “Wrong email or password”.</td>
</tr>
<tr>
<td>“Test InnoEx now!” (shown if header is not in Logged On state by clicking “Configure my project now”)</td>
<td>Configuration</td>
</tr>
<tr>
<td>“Register right away!” (shown if header is not in Logged On state by clicking “Configure my project now”)</td>
<td>Provide</td>
</tr>
</tbody>
</table>

Figure 8: InnoEx Online Search Page

Table 9: Search Page Dynamic Panel Table

<table>
<thead>
<tr>
<th>Dynamic Panel Icon</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Puzzle pieces x 4</td>
<td>Display/Hide checkbox list of resources</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>Checkbox list</td>
<td>Checked boxes feed true to corresponding variables used by the Configuration page.</td>
</tr>
<tr>
<td>“Configure my project now!”</td>
<td>If header state is no logged in: display “Are you a member yet” dynamic panel. Otherwise links to Configuration page.</td>
</tr>
<tr>
<td>“Are you a member yet”</td>
<td>Provides sign in link, email and password fields. Test InnoEx now links to Configuration page. “Register right away” links to Provide page.</td>
</tr>
</tbody>
</table>

### 4.2.3 Configuration Page

The configuration page shows search results based on the search page and login parameters. Search result profiles are displayed based on boxes checked on the configuration page, as shown in Figure 9. If no boxes are checked, the page displays “You didn’t check any boxes” and a link back to the search page. If the user has not logged on, the search results are displayed with anonymous expert and resource names and no contact information with “Register Now” links to the Provide page, as shown in Figure 10.

![Figure 9: Configuration Page - Logged On](image_url)
Each profile listed in the Configuration page (when the user is Logged On) has several dynamic items on the right side of the page that show/hide text input boxes and contact information. Input to the text boxes is stored on a user’s profile. The “References” button also displays a text box and contact information (as shown in Figure 11), and is intended to represent a function that would request references from the profile.

Each profile also contains several placeholders for trust features. The star rating is similar to other websites rating features and would be based on user feedback about each profile about how
trustworthy that profile is. Project history would give an anonymous network view to indicate whether the profile had been active in certain types of projects. Optional links to LinkedIn or other social network profiles can also provide additional trust.

4.2.4 Provide
The Provide page, depicted in Figure 12, contains only static content. Text fields and drop-down menus allow users to add personal information, connections to other social network profiles, expertise, materials, devices, and facilities to their profile.

![Provide page](image)

Figure 12: Provide page

4.2.5 Profile Page
The Profile page displays personalized information and settings. In addition to links and dynamic content listed in Table 10 and Table 11. The Profile page has static placeholder content that demonstrates a number of features. The “Current Availability” indicator would allow a user to adjust how frequently other users could contact them. The ribbon underneath the user’s picture would advertise workshops or other promotional content. The “Configuration History”
field would contain links to previous searches. The “Traffic History” field, similar to other social networks, displays anonymous information about other users’ interaction with your profile.

Table 10: Profile page link table

<table>
<thead>
<tr>
<th>Link Description</th>
<th>Link Destination Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Edit Profile”</td>
<td>Provide</td>
</tr>
<tr>
<td>Scrolling Banner (rotates through 4 photos)</td>
<td>Search/Provide/Workshops/About</td>
</tr>
<tr>
<td>“Solar Application” and “Battery Prototype Testing”</td>
<td>Project Pages</td>
</tr>
</tbody>
</table>

Table 11: Profile page dynamic panel table

<table>
<thead>
<tr>
<th>Dynamic Panel Icon</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture, profile name, and contact information</td>
<td>Displays the logged on user’s picture, profile name, contact information, and trust statistics.</td>
</tr>
</tbody>
</table>
Most of the information in the Communication Box is a static placeholder showing kinds of information that would be displayed: any types of communication with other users. This dynamic panel will also add text a logged on user adds to his profile using the buttons on the Configuration page, and will then allow the user to remove that information with the “X” button.

### 4.2.6 Project Pages

Project Pages are almost entirely static placeholder representations of what a user’s project page could look like, as listed in Table 12. In a functional version the user would have a Project page for each of their projects. The only link currently on the Project Page is “New Search,” which links back to the Search page.

<table>
<thead>
<tr>
<th>Static Field Name</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Project Members”</td>
<td>Includes the users participating in the project and their representation as a provider of expertise, materials, etc.</td>
</tr>
<tr>
<td>“Project Wall”</td>
<td>Provides a private location for project participants to post messages that only other project participants can see.</td>
</tr>
<tr>
<td>“Upcoming Events” and “Suggested Events”</td>
<td>Promotes InnoEx InPerson workshops and other PE community events.</td>
</tr>
<tr>
<td>“Suggested InnoEx Resources”</td>
<td>Suggest other profiles that might be useful to the project, using a matching algorithm</td>
</tr>
<tr>
<td>“Communication and Collaboration Tools”</td>
<td>Lists links to services like Skype, Dropbox, etc. This promotes alternative means of communication to maximize the likelihood that users will communicate.</td>
</tr>
<tr>
<td>“Invite others to InnoEx”</td>
<td>Offers another suggestion to add users to the community.</td>
</tr>
</tbody>
</table>
4.2.7 Workshops Page

The Workshops page provides static content about the InnoEx InPerson workshop, as shown in Figure 15. The only link is labeled “InnoEx InPerson” and directs to the Workshops page.
InnoEx InPerson is a workshop concept that revolves around a unique manufacturing and prototyping tool: the 3D Circuit Printer (3DCP). This new technology is capable of producing 3-dimensional circuits fully integrated into any mechanical shape, all without removing the object from the print bed. It can do this by using printed electronics inks to create products that would be impossible to create before, and therefore provides both an incentive for idea generators to attend the workshop and a starting point for imagining exciting new applications of PE technology. By meeting to imagine new applications of PE technology, the workshop creates a safe, intellectual property-free space. Attendees can share their knowledge, creativity, team dynamics, and other important traits without ever sharing intellectual property or publishable data. Based on this experience, strong relationships are more likely to evolve.

Figure 15: Workshops Page

4.2.8 About Page

The About page provides static content that describes the InnoEx vision, including the promotional video, as well as the list of founders, as shown in Figure 16.
4.3 InnoEx InPerson Design Description

4.3.1 Functional and physical specs
InnoEx InPerson workshops are designed to maximize the benefits of face to face communication for startups and academics that are connected through InnoEx online platform. These workshops provide the attendees with an interactive and proactive way to imagine the future of the industry opportunities by fast prototyping their ideas with the unique fast prototyping tool, which is described as the 3D circuit printer (3DCP)

The first InnoEx InPerson workshop was launched at a conference room in the Stanford d.school. The conference room had large white boards, big tables and also the printer. Besides two of
Stanford team members, five external targeted attendees joined the workshop, one printed electronics startup co-founder, one printed electronics PhD candidate, one fashion designer, one robotic system engineer and one medical school PhD candidate. A group of 3-5 people as a discussion group is ideal for this kind of workshops, since within smaller groups, attendees are easier to exchange deeper thoughts in conversations and build more trustful relationships. The workshop photo is shown in Figure 17.

![First InnoEx InPerson workshop](image)

**Figure 17: First InnoEx InPerson workshop**

The workshop is designed to be 30 minutes long in total, which includes 5 minutes session for introductions, 10 minutes brainstorm session to explore the design space based on the 3DCP and each other’s field of work, followed by 10 minutes brainstorming section on one selected topic from the previous design space exploration section, and then 5 minutes to wrap up. Before and after the main discussion session, the attendees filled an entry surveys and an exit surveys. Detailed workshop itinerary is in the Appendix section.

### 5.3.2 Requirements fulfillments for workshops

The actual workshop took about one hour long. The introduction lasted longer than expected because attendees were actually friends’ friends. And brainstorming session around Printed Electronics industry and the 3DCP took almost half of an hour. So we decided to abandon the second brain storm session. According the observations and surveys from the workshop, the findings are as below (Table 13).

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Test Results Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspire new application ideas for existing technology rather than solve industry problems.</td>
<td>20 minute brainstorm at the Test Workshop produced 20 new application ideas. One member of the workshop requested by email a proof of concept for an idea he came up</td>
</tr>
</tbody>
</table>
Enable prototyping the new application ideas. | The InnoEx puzzle pieces test application demonstrates that the printer could prototype many of the application ideas generated at the Test Workshop.

Attract PE startups and academics as well as designers from other industries who are interested in using PE in their industry. | Test Workshop entry survey results indicate that 4/5 attendees came to see the 3D printer. Three of them quoted like the brainstorming session and two liked the printer demo sessions a lot, also the informational introductions to all the attendees brought their interest to something new.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Fulfillments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large room with areas for mingling, large presentations, and product demonstrations</td>
<td>A conference room with big white boards big tables, enough chairs, which were not good for mingling, but good for brainstorming and presenting</td>
</tr>
<tr>
<td>Prototyping equipment for printing electronics and creating application prototypes.</td>
<td>3DCP was on the center of the table, which was also the center of people eyesight. However the emergency syringe motor broke out right before the day of workshop, so the printer was actually not printing conductive paste. But it printed the ABS plastics.</td>
</tr>
<tr>
<td>Accessible location for a large number of target Workshop coordinators and leaders for planning the workshop, preparing attendees, and leading brainstorming and prototyping sessions.</td>
<td>Yes, the design school conference room located at the first floor of design school, easy to find and had large door. Indoor facilities were fully equipped.</td>
</tr>
</tbody>
</table>

Physical requirements for workshops are as below (Table 14).

**Table 14: Physical Requirements fulfillments**
Opportunities fulfillments
- InnoEx workshops proved to be able to attract both innovators from the PE related innovators and the outside innovators such as fashion designers. The fashion designer heard about the 3DCP and workshop from her sister who is a printed electronics PhD candidate. And the designer came up with good ideas about how to combine the 3DCP with her own field of fashion design. This proved that the workshop had the great opportunity to attract undefined users and drive innovation with their efforts.
- Another important focus is whether the workshop could enhance trust among the attendees. This was hard to measure through this single workshop, since attendees had already built up a trustful relationship with the team member who sent the invitation to them. People are naturally inclined to be friendly to friends of friends. This focus will be tested in future workshops with users who are connected through the InnoEx Online.

4.4 3D Circuit Printer Design Description

4.4.1 Printer Specifications
The detailed design specifications of the 3D circuit printer corresponding to the Design Requirement are given as follows (Table 15, Table 16, and Table 17).

<table>
<thead>
<tr>
<th>Index</th>
<th>Functional Requirements</th>
<th>Design Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR1</td>
<td>Provide a unique feature: print circuits in 3D inside of plastic shapes</td>
<td>Successfully embedded LEDs, resistors, and batteries inside 3D plastic shapes and all the circuits designed worked well.</td>
</tr>
<tr>
<td>FR2</td>
<td>Print various PE materials</td>
<td>The printer could be able to print several conductive materials such as conductive Bare ink and Silicone silver paste.</td>
</tr>
<tr>
<td>FR3</td>
<td>Create useful circuits with PE materials</td>
<td>So far could use SMT components to make really functional circuits, but chips were not tested yet.</td>
</tr>
<tr>
<td>FR4</td>
<td>Attract PE startups and academics, and other industry designers</td>
<td>As tested in several workshops, the printer aroused great interest among Printed Electronics startups, researchers, robotics industry, educational industry, and even fashion design industry.</td>
</tr>
<tr>
<td>FR5</td>
<td>Portable</td>
<td>13.6kg for the whole printer so it is portable.</td>
</tr>
<tr>
<td>FR6</td>
<td>Low investment from Clariant</td>
<td>The total cost for the printer with some printing material is approximately $1,000.</td>
</tr>
</tbody>
</table>
Table 16: Design Specifications for Physical Requirements.

<table>
<thead>
<tr>
<th>Physical Requirements</th>
<th>Derived from…</th>
<th>Design Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Print vertical conductive traces</td>
<td>FR1</td>
<td>Vertical traces of 6mm in height have been proved and printed.</td>
</tr>
<tr>
<td>Embed silicon electrical components</td>
<td>FR1, FR3</td>
<td>Completed for resistors, SMT LEDs, and coin cell batteries.</td>
</tr>
<tr>
<td>Print ABS plastic in 3D shapes</td>
<td>FR1</td>
<td>Print quality is comparable to commercial FDM printers.</td>
</tr>
<tr>
<td>Pause feature for embedding components by hand</td>
<td>FR1</td>
<td>Implemented with a G-code command &quot;@pause&quot;</td>
</tr>
<tr>
<td>Software supporting dual extrusion of different materials and addition of pause feature</td>
<td>FR1</td>
<td>Implemented with open source software Slic3r, Repetier Host, Marlin and a short post-processing script.</td>
</tr>
<tr>
<td>Replaceable syringe extruder</td>
<td>FR2</td>
<td>Completed and tested/calibrated for 1 Printed Electronics material, with reasonable assumption that other materials could be printed with different sized syringe tips.</td>
</tr>
<tr>
<td>Print conductive traces at less than .5mm line width</td>
<td>FR3</td>
<td>.5mm line width achieved, which allows discrete SMT components to be connected. Limited by material viscosity.</td>
</tr>
<tr>
<td>Weight easily portable by 2 people; can ship by air</td>
<td>FR5</td>
<td>Weight is 13.6kg – easy to carry between two people and complies with most airline checked baggage restrictions.</td>
</tr>
<tr>
<td>Size easily portable by 2 people; can ship by air</td>
<td>FR5</td>
<td>55cm×66cm×46cm Outer dimensions are a little awkward to carry and would probably require an oversized carrying case for most airlines.</td>
</tr>
<tr>
<td>Materials cost less than $1,200</td>
<td>FR6</td>
<td>Actual materials to reproduce a printer cost $1156.05</td>
</tr>
</tbody>
</table>

And Table 17 shows the detailed mechanical, electrical, and software specifications of the printer.

Table 17: Printer Specifications

<table>
<thead>
<tr>
<th>Mechanical Specifications</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Dimensions</td>
<td>550mm×660mm×460mm</td>
</tr>
<tr>
<td>Shipping Weight</td>
<td>13.6kg</td>
</tr>
</tbody>
</table>
### 4.4.2 Printer Cost and Bill of Materials

The 3DCP consists two main parts: the Reprap 3D printer kit and an additional syringe dispensing system. Due to the limited budget, instead of ordering the more expensive pre-assembled Replicator, which may cost $2,000 for one unit, we purchased a cheaper Reprap kit from Makerfarm, which cost us $617.68 including tax and shipping fees. Since the set came with only the motor sets and gears, other essential mechanical support such as steel rods, and electrical equipment such as power supply were also needed to purchase. For the syringe dispensing system, the precision linear motor and syringe supporter which was manufactured by the 3D printer at the PRL (products realization lab at Stanford) needed extra expenses.

In Table 18, the calculations aimed at the cost to reproduce another printer the same as the 3DCP the team has already built. In this way, this table excluded the spare parts the team actually bought or replaced for the printer, also excluded the consumables parts, such as the printing materials, see Table 19. Therefore, the cost of the printer is different from the real budget the team had for the project’s printer.
Table 18: Bill of materials for 3D circuit printer

<table>
<thead>
<tr>
<th>Content</th>
<th>Vendor</th>
<th>Unit</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Stepper motor</td>
<td>Haydon Kerk</td>
<td>1</td>
<td>$211.53</td>
</tr>
<tr>
<td>2 Rep Rap</td>
<td>Makerfarm</td>
<td>1</td>
<td>$617.68</td>
</tr>
<tr>
<td>3 Stepper driver</td>
<td>Makerfarm</td>
<td>1</td>
<td>$9.75</td>
</tr>
<tr>
<td>4 Kapton tape1/2 inch for hot end</td>
<td>Amazon</td>
<td>1</td>
<td>$4.00</td>
</tr>
<tr>
<td>5 Heat bed glass</td>
<td>Walmart</td>
<td>1</td>
<td>$9.37</td>
</tr>
<tr>
<td>6 Syringe supporter</td>
<td>PRL</td>
<td>1</td>
<td>$9.75</td>
</tr>
<tr>
<td>7 Printer support-steel rods</td>
<td>Home depot</td>
<td>12</td>
<td>$65.49</td>
</tr>
<tr>
<td>8 Printer base stand</td>
<td>Tap plastics</td>
<td>3 cut to size</td>
<td>$138.23</td>
</tr>
<tr>
<td>9 Power supply</td>
<td>Fry’s</td>
<td>1</td>
<td>$50.00</td>
</tr>
</tbody>
</table>

Prices includes tax & shipping fees

Total $1,156.05

Consumables cost:

Table 19: Consumables bill of materials

<table>
<thead>
<tr>
<th>Content</th>
<th>Vendor</th>
<th>Unit</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>10cc clear polyethylene syringe barrel;</td>
<td>Nordson</td>
<td>30</td>
<td>$140.60</td>
</tr>
<tr>
<td>Syringe Piston; Neoprene; 10cc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Abs filament</td>
<td>Makerfarm</td>
<td>1kg</td>
<td>$31.43</td>
</tr>
<tr>
<td>3 Conductive ink</td>
<td>Silicon Solutions</td>
<td>1oz</td>
<td>$279.23</td>
</tr>
</tbody>
</table>

Prices includes tax & shipping fees

Total $451.26

4.4.3 Printer System Overview
The 3D circuit printer is a modified Mendel Prusa V2 3D Printer with a customized dual extrusion print-head.

- Dimensions: 55cm x 66cm x 46cm outer dimensions
- Weight: 13,6kg
- Build Space: 10cm x 18 cm x 10 cm
- Linear axis speed: up to 300 mm/s
4.4.4 Components Descriptions

- MakerFarm Mendel Prusa V2 Frame: 3D printer frame open source design. See the RepRap website for more info about the Mendel Prusa 3D Printer design.
- X-carriage: Plate translating on the x-axis used for supporting the extruders
- Hot-end: Part of the extruder made to heat-up the ABS plastic up to 230°C and have it extruded through a brass nozzle of 0.35mm
- Temperature sensor: Used for giving the RAMPS a feedback on the temperature of the hot-end for closed loop temperature control of the hot-end.
- RAMPS Board: Composed of an Arduino Mega Board and the RAMPS shield. Brain of the 3D printer, it communicates with a PC to command all the features of the printer, including the LCD screen and the heating systems. Uses stepper drivers to control up to 3 degrees of freedoms and 2 extruders.
- Stepper Motors: NEMA 17 Standard Stepper Motors – used for actuating the linear degrees of freedom and the plastic extruders
- Haydon Kerk Size 11 Non Captive Shaft Hybrid Stepper – used for the syringe extruder
• ATX Power Supply: PC power supply providing 12v inputs with a maximum power of 450W
• USB interface: On the Arduino Board, used to communicate with a CAM solution installed on a computer
• Endstops: Electro-mechanical components used to detect the extreme positions on each of the linear degrees of freedom.

![Endstop](image1.png)

**Figure 21 Endstop**

• LCD Interface: Displays information about the current status of the printer and allows the user to control the printer without the need to being plugged in a computer. Has an SD card slot for direct loading of g-code.
• Build Plate: 8” x 8” x ¼” acrylic plate used as a printing surface

**Extrusion System detail**

![Extrusion System](image2.png)

**Figure 22 Extrusion System Overview**
Figure 23 CAD Model of the dual extrusion system

**Syringe Extruder**

Figure 24 CAD Model of the dual extrusion system
Attachment system

Figure 25 In White is the acrylic plate used for attaching both extruders on the printer

Figure 26 Laser Cut Design for the dual-extruder adaptation system
Cover

Cover dimensions: 18” x 18” x 4.3”
Material: Glossy White Acrylic ¼” thick

![Figure 27 Final rendering for the printer cover Mk2](image)

**Power supply support**

**LCD screen support**

**Plastic Spool Holder**

![Figure 28 Laser Cut Cover Parts first batch](image)
4.4.5 Printing Process Description

The typical printing process from the user side consists of four steps. First, use CAD software such as Solidworks or SpaceClaim to provide the 3D CAD model and save it in .stl file version. Second, load the CAD .stl file in CAM software called Slic3r and generate G-code. Third, load the G-code into the central controlling software called Repetier Host. Finally, turn on the machine and start the printing. Specifically, for the first step, there should be wells reserved for filling in with ink and small cavities reserved for filling in with electric components, which is shown in Figure 30. Table 20 provides the detailed information for designing a circuitry-embedded plastic part. For the second step, after importing the .stl CAD model file and choosing the right configuration, click on "Export G-code", which is shown in Figure 31. The basic idea behind this software is to slice the CAD model to tens to hundreds of layers and make the nozzle traverse along each layer to complete the whole printing process. For the third step, Repetier Host is an open source central controlling software that could load the G-code and send G-code command to the printer. Click on "Connect" to connect with the printer, "Load" the generated G-code, start preheating the extruder, double check the Z-axis home position and leveling of the two printhead, make sure that the syringe nozzle tip could extrude smoothly without clogging, and put the desiccant box cap back on the tip. And finally hit the "Run Job" button to start printing.

Figure 29 Laser Cut Cover Parts second batch
Figure 30: A typical circuitry-embedded CAD design.

Table 20: Detailed CAD design references.

<table>
<thead>
<tr>
<th>Features</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductive traces</td>
<td>1.2mm × 0.4mm for cross-section</td>
</tr>
<tr>
<td>Plastic wells to contain conductive traces</td>
<td>2mm × 0.6mm for cross-section</td>
</tr>
<tr>
<td>Cavities to hold SMT LEDs</td>
<td>4.3mm × 1.2mm × 1.1mm</td>
</tr>
<tr>
<td>Cavities to hold regular resistors</td>
<td>7.6mm × 2.8mm × 3.5mm</td>
</tr>
<tr>
<td>Cavities to hold 3 parallel male pin headers</td>
<td>9.5mm × 3.5mm × 3mm</td>
</tr>
<tr>
<td>Cavities to hold 3 parallel female pin headers</td>
<td>9.2mm × 3.2mm × 8.9mm</td>
</tr>
<tr>
<td>Cavities to hold 2025 button batteries</td>
<td>Φ21mm × 5.8mm</td>
</tr>
</tbody>
</table>

Figure 31: Using Slic3r to import CAD model and generate G-code.

During the printing process, the printer will first print the plastic base part and leave some cavities as designed in the CAD software. Then printer will pause and park to a side position waiting for the user to insert components inside the cavities. Next remove the desiccant box cap, resume the printing job and use the syringe extruder to print conductive materials to connect
those components. Then the printer will pause again to wait the user to put the desiccant box cap back and get ready for the next tool change. Finally the plastic extruder will work again to print plastic covers on top of the circuits to seal it and make it completely embedded.

4.4.6 Printer Software Description

There are together four software modules used in the whole printing process, known as the CAD design software such as Solidworks, CAM software with a G-code generator such as Slic3r or Skeinforge, the central controlling user interface such as Repetier Host or ReplicatorG, and onboard software/firmware such as Marlin. G-code typically contains the speed and position information of the printhead and print-bed motions. And the firmware like Marlin could translate the G-code into control signals to drive the stepper motors to rotate and achieve the motions. The software system diagram is shown in Figure 32. Specifically a list of tuned Slic3r parameters is shown in Table 21. A list of tuned Repetier Host parameters is shown in Table 22. And a list of tuned Marlin parameters is shown in Table 23.

![Software System Diagram](image)

**Table 21: Tuned Slic3r parameters.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer Height</td>
<td>0.2mm</td>
</tr>
<tr>
<td>First Layer Height</td>
<td>0.35mm</td>
</tr>
<tr>
<td>Minimum Perimeters</td>
<td>2</td>
</tr>
<tr>
<td>Fill Density</td>
<td>1</td>
</tr>
<tr>
<td>Fill Pattern</td>
<td>Rectilinear</td>
</tr>
<tr>
<td>Top/Bottom Fill Pattern</td>
<td>Rectilinear</td>
</tr>
<tr>
<td>Infill Every # Layers</td>
<td>1</td>
</tr>
<tr>
<td>Solid Infill Every # Layers</td>
<td>1</td>
</tr>
<tr>
<td>Fill Angle</td>
<td>0</td>
</tr>
<tr>
<td>Perimeter Speed</td>
<td>60mm/s</td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Small Perimeter Speed</td>
<td>10mm/s</td>
</tr>
<tr>
<td>External Perimeter Speed</td>
<td>70%</td>
</tr>
<tr>
<td>Infill Speed</td>
<td>60mm/s</td>
</tr>
<tr>
<td>Solid Infill Speed</td>
<td>60mm/s</td>
</tr>
<tr>
<td>Top Solid Infill Speed</td>
<td>60mm/s</td>
</tr>
<tr>
<td>Support Material Speed</td>
<td>60mm/s</td>
</tr>
<tr>
<td>Bridges Speed</td>
<td>60mm/s</td>
</tr>
<tr>
<td>Gap Speed</td>
<td>60mm/s</td>
</tr>
<tr>
<td>Non Printing Speed</td>
<td>130mm/s</td>
</tr>
<tr>
<td>First Layer Speed</td>
<td>30%</td>
</tr>
<tr>
<td>Skirt Loops</td>
<td>2</td>
</tr>
<tr>
<td>Skirt Distance from Objects</td>
<td>6mm</td>
</tr>
<tr>
<td>Skirt Height</td>
<td>1 Layer Height</td>
</tr>
<tr>
<td>Support Material Pattern</td>
<td>Rectilinear</td>
</tr>
<tr>
<td>Support Material Pattern Spacing</td>
<td>2.5mm</td>
</tr>
<tr>
<td>Support Material Pattern Angle</td>
<td>0</td>
</tr>
<tr>
<td>Default Extrusion Width</td>
<td>0.4mm</td>
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<tr>
<td>First Layer Extrusion Width</td>
<td>300%</td>
</tr>
<tr>
<td>Plastic Filament Diameter</td>
<td>2.96mm</td>
</tr>
<tr>
<td>Plastic Extrusion Multiplier</td>
<td>0.95</td>
</tr>
<tr>
<td>Plastic Extrusion Nozzle Temperature</td>
<td>230°C</td>
</tr>
<tr>
<td>Plastic Extrusion Print-bed Temperature</td>
<td>0</td>
</tr>
<tr>
<td>Syringe Filament Diameter</td>
<td>7.358491</td>
</tr>
<tr>
<td>Syringe Extrusion Multiplier</td>
<td>4</td>
</tr>
<tr>
<td>Syringe Extrusion Nozzle Temperature</td>
<td>0</td>
</tr>
<tr>
<td>Syringe Extrusion Print-bed Temperature</td>
<td>0</td>
</tr>
<tr>
<td>Print-bed Size</td>
<td>150×200</td>
</tr>
<tr>
<td>Printer Center</td>
<td>40×40</td>
</tr>
<tr>
<td>Number of Extruders</td>
<td>2</td>
</tr>
<tr>
<td>Z-offset</td>
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</tr>
<tr>
<td>Plastic Extruder Retraction Length</td>
<td>0.5mm</td>
</tr>
<tr>
<td>Plastic Extruder Retraction Speed</td>
<td>6mm/s</td>
</tr>
<tr>
<td>Tool Change Retraction Length for Plastics</td>
<td>0.5mm</td>
</tr>
<tr>
<td>Syringe Extruder X-offset</td>
<td>-48.5mm</td>
</tr>
<tr>
<td>Syringe Extruder Y-offset</td>
<td>-0.8mm</td>
</tr>
<tr>
<td>Syringe Extruder Retraction Length</td>
<td>0.001mm</td>
</tr>
<tr>
<td>Syringe Extruder Retraction Speed</td>
<td>1mm/s</td>
</tr>
<tr>
<td>Extra Extrusion on Restart for Syringe</td>
<td>0.01mm</td>
</tr>
<tr>
<td>Tool Change Retraction Length for Syringe</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 22: Tuned Repetier Host parameters.
### Table 23: Tuned Marlin parameters.

<table>
<thead>
<tr>
<th>Configuration.h</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>X_ENDSTOPS_INVERTING</td>
<td>FALSE</td>
</tr>
<tr>
<td>Y_ENDSTOPS_INVERTING</td>
<td>FALSE</td>
</tr>
<tr>
<td>Z_ENDSTOPS_INVERTING</td>
<td>FALSE</td>
</tr>
<tr>
<td>INVERT_X_DIR</td>
<td>TRUE</td>
</tr>
<tr>
<td>INVERT_Y_DIR</td>
<td>FALSE</td>
</tr>
<tr>
<td>INVERT_Z_DIR</td>
<td>TRUE</td>
</tr>
<tr>
<td>INVERT_E0_DIR</td>
<td>FALSE</td>
</tr>
<tr>
<td>INVERT_E1_DIR</td>
<td>FALSE</td>
</tr>
<tr>
<td>INVERT_E2_DIR</td>
<td>FALSE</td>
</tr>
<tr>
<td>X_HOME_DIR</td>
<td>-1</td>
</tr>
<tr>
<td>Y_HOME_DIR</td>
<td>-1</td>
</tr>
<tr>
<td>Z_HOME_DIR</td>
<td>-1</td>
</tr>
<tr>
<td>X_MAX_POS</td>
<td>150</td>
</tr>
<tr>
<td>Y_MAX_POS</td>
<td>190</td>
</tr>
<tr>
<td>Z_MAX_POS</td>
<td>100</td>
</tr>
<tr>
<td>DEFAULT_AXIS_STEPS_PER_UNIT</td>
<td>{80, 80, 2350, 1100}</td>
</tr>
<tr>
<td>DEFAULT_MAX_FEEDRATE</td>
<td>{250, 250, 2, 30}</td>
</tr>
</tbody>
</table>

#### 4.4.7 Printed Parts Description and Methodology

There are four CAD designs for demonstration of circuitry embedded printing, known as the LED embedded circuit design, the vertical trace circuit design, the battery embedded circuit design, and the puzzle pieces circuit design. The LED embedded circuit design is a 34mm×30mm×15mm plastic cube with an LED, a regular resistor, and a three-pin female pin header embedded inside, which has been shown in the Printing Process part. The vertical trace circuit design contains the same electric circuit components as the LED circuit but the LED and the resistor are in different layers and connected with a vertical/sloped conductive trace, which is shown in Figure 33. The battery embedded circuit design contains two 2025 button batteries in serial. Two conductive traces lead the two polar out and further will be connected with a two-pin male pin header, which is shown in Figure 34. The dimension for this design is 35mm×30mm×11mm. Figure 35 shows the plugging in effect of the vertical trace LED circuit and the battery circuit. The puzzle consists of 4 pieces, known as the Clariant "C" piece with a planar conductive trace and two female pin headers embedded, the light bulb piece with an LED.
circuit, a resistor and two male pin headers embedded, the "InnoEx" piece with two 2025 button batteries in serial and two male pin headers embedded, and the "SUHSG" piece with a vertical conductive trace and two female pin headers embedded, where SUHSG stands for Stanford University and University of St. Gallen (in German). Each puzzle piece was a $50mm \times 50mm \times 12mm$ cuboid with a convex semicircle and a concave semicircle to make it easy to assemble like a puzzle. All the semicircles have a radius of 12mm. The whole puzzle is shown in Figure 36 and Figure 37.

Figure 33: LED and vertical trace embedded circuit design.

Figure 34: Battery embedded circuit design.
Figure 35: Plugging effect of the LED vertical trace circuit and the battery circuit.

Figure 36: CAD model of the puzzle pieces.

Figure 37: Plugging in effect of the printed puzzle pieces.
5  Design Development

5.1  InnoEx Overview

As stated in the Design Requirement section, the final goal of the whole project is to facilitate better connection, communication, and innovation between Clariant and other startups and researchers. There are some open innovation platforms such as OpenIDEO and InnoCentive where people help each other by developing ideas and solutions to the posted problems and broadcast them online. However, most of the high tech startups that the team interviewed were reluctant to join those open innovation platforms. The team spent 9 month exploring the most pertinent issues among startups and university researchers in high tech of printed electronics. We found that the biggest gap preventing people from collaborating is the fear of losing Intellectual Property (IP) and revealing business secrets. People are much more interested in getting ideas published and making own cutting-edge product than sharing ideas with peers. This is especially severe for online open innovation platforms, where the trust issue is the most critical part when sharing novel ideas. Moreover, for physical workshops, especially those focusing on promoting innovation in high tech industries, solely brainstorming new ideas is typically not enough. The team tested several workshops and found that simply brainstorming on the future technology and industries could not get people truly engaged. And there is always an extremely long way to go to make those ideas real. What is needed in this case is basically using prototyping tools to prove the concepts and realize the ideas. For the prototyping tool, the team built printed electronics stickers, a 3D surface printer, and a 3D circuit printer, among which the team chose the last one.

With the above thinking and user testing, the team came up with a whole new open innovation platform called InnoEx, which stands for Innovation Experience. It consists of two parts, known as InnoEx Online and InnoEx Inperson. InnoEx Online is an online website that only focuses on high tech industries like printed electronics to help people find experts, materials, devices, and facilities to collaborate with each other, come up with new ideas, and form a team to make those ideas real. The most important feature of this website is that users do not need to provide any crucial information about their companies and ideas. Once the users get interested in other users and get connections, they could meet with each other face to face to further discuss about potential collaborations and even attend InnoEx InPerson workshops to work together and make ideas come true. During the InnoEx InPerson workshops, some unique prototyping tools like a 3D Circuit Printer will be provided to help people brainstorm, design, prototype, and make early stage products. In this way, workshops are truly functional and can really help people work together and realize their ideas. Specifically, one of the prototyping tools used in the InnoEx InPerson workshop is a 3D circuit printer that can print 3D circuitry inside a plastic part.

5.1.1  InnoEx Logo Development

The initial logo was developed during a train trip from Luzerne to St. Gallen during spring break. InnoEx standing for innovation experience, we wanted to emphasize both the idea generation aspect as well as the networking potential of the whole platform. This lead to the idea of combining a light bulb with the network representation.
This first logo iteration was given to the Media Agency working with the University of St. Gallen that came back to us with several design propositions.

After this first batch of logo we decided to keep the Eurostile Bold font, but have more iterations on the light bulb.
We found our final logo in the next batch and eventually decided to remove the dot after InnoEx. This resulted in the logo beneath and the following variations for the InPerson and Online side of the project.
5.2 InnoEx Online Design Development

5.2.1 Initial Prototype and Benchmarking
The core values of InnoEx Online were finalized at the global team summit in Switzerland over the Stanford student’s spring break in March 2013. The initial website prototype search page is shown in Figure 42.

![InnoEx Online Prototype Search Page](image)

Figure 42: InnoEx Online Prototype Search Page

After the initial prototype, we conducted numerous interviews to refine the concept. Here is a list of interviews:
- Startups: e.g. Cynor, Technopark Zurich, and Celeroton
- Non-core-team Clariant employees: Dr. Martin Vollmer (CTO), Dr. Volker Laska (CIO), Dr. Carsten Schauer (Head of Electronic Materials), Dr. Richard Haldimann (Head Innovation Excellent), Dr. Alexander Rösch (Manager New Business Development)
- Prof. Mark Cutkosky about the web-platform plus the combination of the two parts of the solutions in a video conference with Stanford students
- Weekly testing of respective updates/releases of the platform with academics and startups to generate various feedback loops

We also did extensive benchmarking of features on commercial websites. Here is a list of benchmarking endeavors:
- Matching process: Itunes, Amazon, Zalando, Eat.ch
- How others manage to create trust in the internet: Parship.ch, Match.com, edarling.de, eharmony.com, linkedin.com, xing.com, etc.
- Matching display: Mouser.com, Amazon.com, Beatport.com
- Search criteria: OEA register (Organic electronics association), interviews;
- Promotion of workshops via project overview page: Google Adds, Amazon
- Tool to develop Final Prototype: drupal, wordpress, wix $\rightarrow$ decision for AxureRP (wireframing tool to generate html-mockups $\rightarrow$ see
- wikipedia.com)
- Tools to support the organizational process of projects in the project phase (potential API’s): Doodle, Ical, Outlook Cal, GoogleDocs, Google Drive, Mindstorm, Freemind, Evernote, CloudOn, Notability, Dropbox,

5.2.2 Critical Decisions
We made several critical decisions over the course of the development process, summarized in Table 24.

<table>
<thead>
<tr>
<th>Critical Decision</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employment of Marcel Weisheit, a graphic designer from Berlin.</td>
<td>An experienced graphic designer was able to help make the search page much more intuitive and scalable. High emphasis on an attractive outcome also justified this decision.</td>
</tr>
<tr>
<td>Employment of 22degree, a web and media design firm.</td>
<td>This firm was indispensable in the graphic design and implementation of the platform in Axure, as well as for completing our promotional video.</td>
</tr>
<tr>
<td>Choice of Axure as an implementation platform.</td>
<td>Axure seemed like the perfect balance between functionality and ease of implementation. It is designed as a semi-functional mockup tool. However, the functionality we achieved is beyond the scope of what Axure was built for and took considerable manual coding of condition blocks in scripts. Axure support was invaluable during this process.</td>
</tr>
<tr>
<td>Employment of Stefan Lendi, professional speaker.</td>
<td>A professional voice actor was able to give weight and credibility to our promotional video.</td>
</tr>
<tr>
<td>Reduction of profiles to provided expertise resources and only bare minimum of contact information</td>
<td>Interviews with potential users indicated that filling out redundant profiles was an annoyance. Instead, we provided optional interfaces to other social networks.</td>
</tr>
<tr>
<td>Cannot search directly for a user profile or</td>
<td>This functionality would have overlapped with</td>
</tr>
<tr>
<td>company name.</td>
<td>other social networks and also reduced the needs-based aspect of the search function. Without this ability, users have some guarantee that other users that contact them are actually interested in what they have to provide.</td>
</tr>
<tr>
<td>Cannot buy products/services directly from the platform, but rather have to contact the associated user profile.</td>
<td>The platform should connect people to form collaborations. This again removes overlap with other services where users can directly buy products/services.</td>
</tr>
<tr>
<td>Change of search page layout from square to purchasing puzzle piece chain.</td>
<td>Gives the user more intuition about what can be searched for. This layout is also more scalable because of extra white-space below the search categories.</td>
</tr>
</tbody>
</table>

### 5.2.3 User Testing

We visited one of the largest tradeshows in the PE industry, the Printed Electronics Berlin 2013 (April 16-17th). We tested the current version of the prototype with more than 20 start-ups from all over the world, in different development stages, with totally different needs and backgrounds. We allowed testers to directly interact with the prototype with one team member guiding the through the process and the other observing. Feedback was overwhelmingly positive.

### 5.3 InnoEx InPerson Development

#### 5.3.1 Why Workshops?

The motivation for InnoEx InPerson is the result of a combination of benchmarking and interview results. One of our team members attended a workshop hosted by StartX, a non-profit startup accelerator for Stanford-based companies. StartX is an attractive benchmarking target for two reasons: it has deep knowledge of what startups need to succeed and it is an entity that startups trust with their ideas. Clariant desires both of these qualities.

During the course of the quarter, a startup weekend was organized at Stanford by StartX. This event, which happened during the course of a weekend, gathered a group of approximately a hundred people willing to work fifty hours straight to get a first draft of a prototype and a business plan for a start-up.

![StartX Med logo](image)

Figure 43: StartX Med logo

There were several key findings from this experience:
• A sort of pre-pitch phase of the different projects happened on the event LinkedIn and Facebook pages a few day before the event, with each participant describing his profile, his idea, and what he could offer to a potential team, but most importantly what kind of competence he *needed*.

• The face to face interaction happening at the event allowed a deep level of connection between the participants beyond the level of the professional encounter. Many teams formed during the event felt very involved and kept on meeting after the event.

• The outcome of the process was a host of refined designs and business plans.

The finding that face to face interaction is powerful for forming collaborative relationships agrees well with interview results. In interviews of PE startups, PE academics, and non-PE academics, we found that face to face interaction is regarded as the best way to initiate collaboration. But despite the success of the StartX workshop, many interviewees in the PE field said that they generally did not attend workshops. In comparing workshops in the PE field to the startup weekend, we found two main differences:

• **Focus**: most workshops are not focused on creating new products or companies; they focus on brainstorming ideas for current specific industry problems. The solutions to these problems would be immediately valuable. Therefore attendees are very unlikely to share them with acquaintances.

• **Prototyping**: the lack of rapid prototyping tools for printed electronics prevents attendees from exploring critical questions about an idea’s feasibility. This creates the perception that ideas that are created in these workshops have very little credibility and that the workshops are not worth attending.

These differences present an enormous opportunity for Clariant to fill a void in an emerging industry. Entrepreneurs and academics crave face to face interaction but are dissatisfied with many of their current options. Providing a unique alternative could attract these entrepreneurs and academics to Clariant. Note especially the business focus of startup weekends. Clariant is in a unique position to provide business knowhow to startups at a PE startup weekend.

### 5.3.2 Role of the 3D Circuit Printer

A startup weekend-style workshop could be implemented with traditional PE prototyping tools. However, including the 3D Circuit Printer (3DCP) in a workshop accomplishes three critical tasks that ordinary prototyping tools cannot: it provides a concrete and obvious reason for users to try out a new kind of workshop, shifts the focus from current industry problems to new products and applications, and allows users to rapidly prototype those new products and applications.

Clariant is new to the printed electronics industry but wants to become an innovation hub. Experts in the PE field will take some convincing to believe that Clariant can be this hub, and until they are convinced they are less likely to attend Clariant workshops. The 3DCP removes all necessity to convince these experts. Clariant can simply market the new workshop as a chance to try out a new and exciting prototyping technology.
Because it is a new type of prototyping technology, the 3DCP inherently inspires new types of applications. Startups and academics in the PE field are already familiar with existing prototyping techniques and are accustomed to using them to solve existing problems. Introducing a new prototyping technique forces users into the mindset of new applications, rather than reminding them of old problems.

New applications inspired by the 3DCP are easy to prototype with the 3DCP. Prototyping applications that include electronics and functional inks embedded in a plastic matrix using other methods would be prohibitively time-consuming and expensive. The 3DCP enables rapid and frequent iteration on a design, even over the course of a two-day workshop.

For these three reasons, the 3DCP is an invaluable (but not irreplaceable) part of the InnoEx InPerson workshop concept. Its ability to quickly create previously unimaginable or infeasible products is what makes our workshop concept truly unique. We validated these ideas with user testing.

5.3.3 User Testing

Exploratory Testing

User testing fell into two phases: early exploratory testing and concept validation testing. Our early exploratory testing occurred in winter quarter. The initial goal was to check how Printed Electronics technology in a prototyping lab could facilitate idea generation. The schematic of the lab is shown in Figure 44.

The team set up a prototyping lab environment with an incredible (but fake) 3D printer that can print electronic circuits and components directly into or onto mechanical components. However, instead of using a real 3D circuit printer, the team asked test subjects to do the job of the 3D printer by hand (and thereby design a new product) by putting paper cutouts of different components on objects in the lab space. Then the team watched and recorded the whole process of how they could unleash their creativity and if they could come up with interesting products using simulated rapid prototyping.

The simulated workshop had two phases:

1. Education: The team provided the test subjects with background information of Printed Electronics and the testing scenario.
2. Prototyping: Given the paper cutouts of a large variety of components, the test subjects were asked to pick up any 3D object and use tape to stick the paper components to the 3D object to augment the functions of the object.
We found that this experience promoted not only creativity but better engineering. People had a great time imagining product ideas using our system. Being able to rapid prototype their ideas really unleashed the creativity of some test subjects. One of the test users invented an augmented tennis racket that has a camera system and a force feedback sensor. Another typical invention is an augmented ruler with batteries, LCD screens, and temperature sensors. It can be seen that a large number of new applications of Printed Electronics were exploited with the help of prototyping lab and the fake 3D printer, which contribute tremendously in idea generation and sharing.

Mocking up the actual electronic components on our devices (simulating rapid prototyping) encouraged subjects to think through and flesh out the functions of the object/system. Given the paper components, the subjects reflected that they thought more about the requirements of the 3D object; i.e. how they can improve the functions of the object, which turned out to be really useful for idea generation and sharing.
Concept Validation Testing Discussion

Once we had explored the new workshop concept and developed a real 3D Circuit Printer (3DCP), we were able to do some initial testing of the workshop. A detailed description of this test and its results can be found in the Design Description section. Due to time constraints, we were unable to replicate a StartX startup weekend for Printed Electronics. Instead, we chose to host a short workshop to gage interest, user reaction, and the printer’s ability to inspire ideas. By these metrics, our test workshop was a great success.

However, several important questions remain unaddressed. If Clariant rather than Stanford hosts the workshop, what effect will this have? How will Clariant develop the methodology to run stellar workshops? What changes need to be made to the printer to allow users to effectively prototype with it at workshops? We attempt to provide a roadmap to answering these questions in the next section.

5.3.4 Implementation Roadmap

We envision an overlapping three phase implementation scheme for InnoEx InPerson. In its current form, the printer is perfectly suitable as a showcase device at an exhibition or at business introduction meetings. While these create hype around the printer, Clariant can develop sound workshop methodology around the printer at short workshops similar to the kind we tested. Finally, full startup weekends can be implemented once the printer has been appropriately refined.

For each of the phases, two general strategies could make them especially effective. First, begin each phase as an internal exercise within Clariant. Not only will this promote an internal open innovation culture and break down barriers within Clariant business units, it will allow Clariant to inexpensively prototype and refine the workshop experience while keeping a low profile. The Printed Electronics business unit would also benefit from increased awareness across the company, new ideas, collaborations, and a reputation as an innovation leader from the start.

Second, take advantage of the printer’s natural association with the Maker Movement. The Maker Movement is widely perceived as a major source of innovative new hardware startups, and Time magazine describes it as the potential future of the US economy [1]. 3D printers, and especially RepRap projects like the one the 3D Circuit Printer is based on, are some of the most high-profile tools in the Maker Movement. Identifying with the Maker Movement creates an association with innovative startups, but it also gives Clariant an even more crucial opportunity: the chance to shift toward a philosophy of frequent lower-resolution prototypes. This is contrasts many large companies’ approach of perfecting a prototype internally before exposing it to users, and is also a crucial component of design thinking.

Phase 1: Exhibition Showcase

At no additional investment besides transportation costs, Clariant could use the 3D Circuit Printer as a (internal or external) showcase device to attract interest in the Printed Electronics business unit and promote future workshops. As demonstrated at Stanford’s EXPE product exhibition and by the high level of interest we have received from PE startups and academics, the printer is very effective at attracting attention and inspiring new ideas.
We anticipate that one possible argument against bringing the 3DCP to exhibitions is that its appearance and general lack of refinement may reflect badly on Clariant as a professional, high-quality company. It is capable of making functional but not professional-quality items. However, if presented as an avatar of the Maker Movement, as discussed above, the printer will give the impression that Clariant is taking radical, innovative steps. It will be associated with innovation, not lack of quality or professionalism.

**Phase 2: Introduction and Brainstorming Workshops**

With some investment in event planning but no additional investment in the printer, Clariant could host workshops similar to those described in the Design Description section. This would buy time to refine the printer while simultaneously obtaining new application ideas that would inform the printer’s design. It would also give Clariant practice at hosting workshops and provide material for the development of best practices.

**Phase 3: Startup Weekend**

With a more substantial amount of investment in event planning and refining the printer, Clariant could host its own startup weekend. At this point, the printer would need to be refined to a level that could quickly and reliably prototype new applications within the span of several hours. The user interface would need to be refined to a level that would allow for flexibility and speed in application design.

While this phase requires the most investment, it also has the highest potential payoff. Startups will be formed out of these workshops, and Clariant will be with them from the very beginning of their design process. There is no earlier time to get involved in new products and no better way to stay at the cutting edge of technology than by creating the environment where that technology is invented.

**5.3.5 Potential future applications of the 3D Circuit Printer**

**From the workshop**

The printer working as a catalysis tool for idea generation, the members of our workshop came up with extremely cool ideas. A robotics’ expert decided to exploit the sealing potential of 3D printing to create waterproof enclosure for his robot’s circuits. A fashion designer came up with the idea of using a 3D circuit printing technique to create mannequins that would be using integrated pressure sensors to detect zones where the fabric is too tight on a model. Lastly a printed electronics expert proposed to use this machine to prototype handheld devices that would use the flexible screens produced by his company.

**Beyond**

We detected several area of interests for the applications of this printer:

- Aero/Astro
- Architecture
- Medical Devices
- Military
An example of devices that could be prototyped with this iteration of the printer came up when a start-up developing electronic bracelets for prisoner tracking approached us, as our printer could be used to rapid-prototype their device. Further development of the printer with a better precision for the electronic extrusion system, controlled atmosphere for better print quality, addition of an automatic pick and place system or bigger build size could lead to fully automated printing process, high precision electronics or again prints that could lead to a fully printed power system for a car or even a house. One of the most exciting application could be the replacement of the plastic material with biomaterial leading up to electronics embedded into biological systems, with great applications in the medical world with a new generation of prosthetics tissues, organs or limbs.

5.4 3D Circuit Printer Development

5.4.1 Choice of printer

After the initial shift at the beginning of April from an Electronic Surface Printer, that would print conductive material on 3D surfaces to a 3D Circuit Printer, which prints the conductive material inside a 3D plastic object that is being printed at the same with a second extruder. There were several key requirements for this printer:

- Resolution of the positioning system
- Reliability
- Hackability of the system
- Price
- Availability

The first candidate for our project appeared to be the MakerBot Replicator (Figure 46)
Figure 46 Makerbot Replicator [2]

The replicator featured a build volume of about 5 liters (225 x 145 x 150 mm), dual extrusion capability and a vertical resolution of 0.2mm (layer thickness). It came assembled for about 2000$.

This 2000$ price after much discussion appeared to be very high considering the remaining project’s budget. The fact that this printer came fully assembled and calibrated could not justify endangering the project’s finances. Moreover MakerBot shift’s to a closed-source business model put some doubts on the replicator’s hackability that would prove fundamental for the integration of the conductive paste extruder.

We decided to look into open source 3D printing kits and especially the RepRap projects [3], famous for several open source designs that use 3D printed components for building of their 3D printers.
We decided to order a Makerfarm Prusa V2 kit (Figure 47, Figure 48), which contained all the materials and electronics needed to set up a 3D printer. This kit includes the following:

- Complete Printed V2 Linear Prusa Parts with Greg's Accessible Extruder (Printed in ABS Plastic)
- Complete MakerFarm V2 Linear Prusa Hardware Set
- Complete Greg's Extruder Hardware Set
- Complete J-Head MKIV-B Hot End Kit (Prints using both ABS and PLA Filament). The extruder
- Complete MK1 Heated Bed Kit
- Laser Cut Electronics Mounting Kit
- 5 x Nema 17 Stepper Motors Pre wired with Molex Connectors Pre-installed

In addition we had to purchase steel smooth rods and threaded rods at home depot for the building of the frame as well as a power supply (450W ATX PC power supply). We chose RAMPS (Figure 49) electronics for it could be easily adapted for dual extrusion. The RAMPS Board controls the printer, the 3 linear degrees of freedom, two extruders and the heating system. The RAMPS Board is a shield that adapts on an Arduino MEGA board.
5.4.2 Building the printer

We will go through the main steps of the building but for more details please refer to the instruction manual provided by Makerfarm.
The first step consisted in cutting the threaded rods (Figure 50) and the smooth rods to the right dimensions.
The 5/16-18 Threaded Rods:
6 at 371mm
7 at 295mm
2 at 440mm
The 5/16” smooth rods:
2 at 384mm
2 at 394mm
2 at 335mm

The Makerfarm kit comes with 3D printed parts that make the structure of the 3D printer. The assembly process starts with building the triangle that keep the structure rigid. The assembly of the frame requires the 3D printed parts to be filed as the process of 3D printing makes either irregular or suppresses any clearance required to assemble the parts (Figure 51). For further versions using the Prusa designs, better resolution or better printing technique would help during the assembly process.
The X and Y axis use a belt and gears to position the print bed and the extruder. The Z axis uses two threaded rods coupled with stepper motors.

The building of the printer lasted approximately one week (Figure 52).

5.4.3 Build Area Development

The parts are printed on a build plate that translates on the y-axis while the extruders move with the x and z axis. The build area consists of a PCB board where most of the surface consists of a heating resistor whose role is to uniformly heat up the bottom of the printed parts.
For the plastic material to stick better on the build area, a few techniques are recommended by
the maker community. The one we initially tested consisted of the heated bed that was covered
by a glass plate coated with Kapton tape (Figure 53), a polyimide tape that resists to high
temperature and provides a smooth surface for the print. This technique proved very successful
for plastic printing but unfortunately caused very fast clogging of the conductive material.

It was later decided not to use the heating system but replace the glass plate and the Kapton tape
by an acrylic plate with the same dimensions (Figure 54). Cleaning this acrylic plate with
acetone before each print or ABS glue (ABS dissolved in acetone) guaranteed to have a very
good adhesion of the first layers of print.
5.4.4 Syringe Extruder Design Development

The design of the syringe extruder is inspired by the syringe extruder used by the Fab@Home [5] project at Cornell which open sourced the designs of the first two iterations of their printer.

Figure 55 Extruder used in the fab@home project

This design was adapted to fit in the circular hole on the extruder carriage of the Prusa (Figure 56).

Figure 56 x-carriage for the Prusa V2

The main components of the system are a syringe support, a syringe with a piston, and a stepper motor with a non-captive screw shaft (Haydon Kerk Size 11 (Figure 58)). When the motor runs the non-captive screw translate instead of rotating. This stepper can directly be controlled through the RAMPS board of the printer adding an additional stepper driver. The first iteration was printed on a Makerbot Replicator found in the TLTL at the school of Education, and a first syringe system can be seen on Figure 57. To guarantee the translation, a bar that was forced to translate inside a slot was clamped on the screw.
The main problems with this initial version of this syringe support, was first its fragility and secondly a lack of access to the syringe that made the reloading of the syringe difficult. The next iteration was then made using thicker walls and a bigger space between the top of the syringe and the steppers to facilitate the removal of the syringe. Syringes Mk2 and Mk3 were printed using the TLTL Makerbot Replicator. We tested those versions and eventually a better quality MK4 was printed with Room 36’s ProJet 3D printer (Figure 59). This version was integrated on the printer for the rest of our tests.
Right before EXPE we decided to reinforce the syringe support again, and came up with an Mk5 that features reinforced walls. A printed translation system was also added to the system.

5.4.5 Attachment of the dual extrusion system

The main challenge in integrating both extruders was to adapt the plastic extruder and the syringe extruder on the carriage. A first idea we had was to put keep the hot end on the carriage but put the stepper motor on the side to keep some space on the x-carriage (Figure 61). We will call this system the remote stepper system. It is inspired by this design found on Thingiverse (http://www.thingiverse.com/thing:16523).
In order to adapt the hot-end on the printer x-carriage (Figure 62) we had to laser cut in an 1/4“ acrylic plate a piece made to provide support for the hot end and the syringe extruder (Figure 26).

**Figure 61 CAD model of the printer with remote stepper**

**Figure 62 Hot-End Extruder**

**Figure 63 Laser Cut Design for the dual-extruder adaptation system**
We eventually found out that the dual extrusion caused some problems, because of the additional distance between the hot end and the steppe motor. After additional tests we eventually decided to put the stepper motor back on the x-carriage, on top of the hot-end, next to the syringe carriage (Figure 64).

![Final dual extrusion assembly](image)

Figure 64 Final dual extrusion assembly

### 5.4.6 Cover design
We wanted to present at EXPE a printer that would be agreeable to look at but also demonstrate the technical capabilities of the printer.

Our initial design iterations revolved on a complete cover that would hide most of the printer’s parts. We will call this design the “gem” design (Figure 65).

![Rendering for the “gem” design.](image)

Figure 65 Rendering for the “gem” design.

The printer renderings indeed looked great but the main problem of this kind of cover resided in the manufacturing of this object. We asked Prototype Plus a quote for this kind of object and it appeared that manufacturing this kind of object would have cost us approximately $3000. Moreover it was objected that this kind of design would hide most of the internal components of
the printer forcing us to remove it as soon as we wanted to show how this printer worked at EXPE.
As a result we decided to go to a simpler design. A simple white and glossy base that would hide most of the electronics and cables, incorporate the screen, the plastic spool and serve as a presentation stand for EXPE (Figure 27).

Figure 66 Final rendering for the printer cover Mk2
The parts for the manufacturing of this cover were made out of 1/4” thick glossy white acrylic plates, laser-cut at the TLT and glued together with acrylic cement (Figure 67).

Figure 67 Finished 3D Circuit Printer

5.4.7 Common problems
Many problems occurred during the building of the printer and I am going to list the major recurring problems here.
A first problem that caused us a lot of trouble was connection problem with the RAMPS board, as an error when plugging pins in the machine caused the destruction of one of our Arduino boards.

A second recurring problem occurred with the temperature sensors that sometime did not return any readable value to the board causing the printer to stop.

A third issue with this printer was the mechanical end-stop positioning especially for the z-axis. Those end-stops are the parts of the printer that indicate when the maximum or the minimum position is reached. This end-stop happened to have to be recalibrated very often for the prints to be of a good quality.

Lastly, while the 3D printed components happened to stay really strong with time, some of the gear on the x-axis motor especially broke repeatedly.

Figure 68 Broken Motor Gear
5.4.8 Printer Software Selection

The printer software has four main components shown in 5.4.8 Figure 69. Most CAD modeling software can produce STL files, so this was not a major source of investigation. Printer firmware for our choice of RAMPS electronics was fairly limited, so we defaulted to the widely recommended Marlin firmware since it can support multiple extruders. The most important development decisions were our choices of G-code generator and User Interface.

![Figure 69: Printer Software System Diagram](image)

The main problem with most User Interfaces (or integrated user interface and g-code generator programs) is lack of configurability. We experimented with Cura and ReplicatorG. Neither allowed the configurability of Repetier-Host. Repetier-Host has a built-in g-code editor, a g-code terminal for direct communication with the printer firmware, and most importantly it gives direct access to the G-code Generator software. Other user interfaces instead provide dumbed-down configuration options that are then passed to G-code Generator software. Neither ReplicatorG nor Cura appear to support different size plastic filaments, for instance. Without this level of configurability, it would have been extremely difficult to print our two very different materials. For a good comparison of RepRap-compatible software, see [http://reprap.org/wiki/CAM_Toolchains](http://reprap.org/wiki/CAM_Toolchains).

Repetier-Host supports two G-code Generators, Slic3r and Skeinforge. Skeinforge is notoriously difficult to configure and one of the slowest G-code Generators available. Slic3r is much easier to configure, supports separate configurations for multiple extruders, and supports post-processing scripts for modifying g-code output.
5.4.9 Calibration Process

After the 3D circuit printer is fully assembled, the team spent two weeks calibrating all of the physical and software parameters to guarantee a good and robust printing quality. The calibration consists of two parts: the plastic printing calibration and conductive material printing calibration.

Plastic printing physical calibration includes leveling the print-bed, settling default Z-axis home position, and using Acetone to clean the acrylic print-bed. Leveling the print-bed can be done by manually or electrically moving the printhead to the four corners of the print-bed to ensure that the distances between the printhead nozzle tip and the print-bed are the same. If the distance changes along X-axis movement, one can rotate one of the Z-axis screw rod to make it all the way same. If the distance changes along Y-axis movement, one can tune the angle of the Y-axis slot to make it all the way same. Setting default Z-axis home position can be done by manually moving the Z-axis end-stop switch button until the distance between nozzle tip and the print-bed is less than the thickness of one sheet of paper. Using Acetone to clean the acrylic print-bed could make the ABS plastics better adhere to the print bed and guarantee non-warping bottom surface of printed parts.

Plastic printing software calibration includes layer height, infill percentage and pattern, printing speed, skirt, bridging, support material, line width, filament diameter, nozzle diameter, printing area, and temperature settings. We used a 20mm by 20mm by 10mm solid cube CAD model to do most of the software calibration and tune the parameters according to the printing quality and efficiency.

- For the layer height, the first layer is 0.35mm high and other layers are 0.2mm high, which is shown in Figure 70. The amount of materials extruded out of the nozzle is not dependent on the layer height, so if the layer height is too small, the nozzle might get blocked; whereas if the layer height is too big, the melted material could not adhere well with the previous layer and sometimes the printing lines were even wiggly.

- The infill percentage and pattern determines the solidness of the printed parts and the printing time. In order to guarantee a good printing quality with enough intensity, we chose 100% infill and rectilinear pattern, which is shown in Figure 71. Using 30% infill and a honeycomb pattern could provide a faster printing process.

- Printing speed is another factor influencing the printing speed. By default the speed was 60mm/s, which is shown in Figure 72. Larger speed could decrease the printing quality and increase noise and vibration. Particularly the first layer speed was 30% of the general speed, and the speed for small perimeters or structures is 10mm/s. Z-axis was especially different from X-axis and Y-axis because it was a worm drive system. Larger speed could cause the motor spinning so fast that the coupler could slip. We limited the Z-axis to be within 200mm/min.

- Another interesting speed parameter was the extrusion speed, i.e., the amount of materials extruded in a certain period of time. Even though the extrusion speed was a function of the X-axis and Y-axis speed and the line width, there was also a coefficient controlling the extrusion speed. This coefficient was set in the configuration.h file in Marlin firmware and was set to be 1100.
- Skirts are surrounding lines outside the printed parts at the first layer in order to make the extrusion smooth before really printing the parts. The parameters for skirts are the same as first layer and the number of lines is two.
- Bridging and support material are used for dealing with gaps or hollow structures. Line width was set to be 0.4mm and first layer 300%, which is shown in Figure 73.
- Filament diameter was 2.96mm and nozzle diameter was 0.35mm according to the physical measurement. The extrusion multiplier was used for extrusion speed minor tuning and we set it to be 0.95.
- The printing area was 150mm by 200mm with a printing center at 40mm by 40mm. For temperature settings, we used 230°C to better melt the ABS plastics, and we disenabled the print-bed heating to better prevent the nozzle clogging of the syringe extruder for conductive material, which is shown in Figure 74.

![Figure 70: Layer height settings.](image)
Figure 71: Infill percentage and pattern settings.

Figure 72: Printing speed settings.
For the conductive material printing calibration, there are two steps. Because the conductive material was 98% silver and it was extremely expensive, the team decided to use peanut butter to substitute for material for printing test due to the similar viscosity. After that we shifted back to the conductive material and achieved great printing quality. For both steps, the calibration includes leveling Z-axis height, filament diameter, nozzle diameter, extrusion multiplier, X and Y offsets, customized G-code, retraction settings, and post-processing scripts.

- Leveling Z-axis was mainly done by adding washers to the syringe holder and rotating the nozzle screw. As homing Z-axis, one can easily tell whether the syringe nozzle tip is the same height as the plastic extruder or not.
• For the filament diameter tuning, the basic idea is to make the syringe system extrude the same amount of material as the plastic extruder does with the same command. The team did the following experiment. Sending the command to extrude 10mm will cause the piston to move 2.183mm. Because the software did not allow for changing the extrusion speed individually for both printhead, i.e., the number of steps per millimeter, we had to change the filament diameter to “fool” the printer. The filament diameter was settled to be 7.358491mm, which is shown in Figure 75.

• After this, the team chose a large variety of nozzle tips to both ensure a smooth extrusion and a high enough resolution. The team found out that a nozzle tip with less than 0.61mm inner diameter was not able to print continuous lines due to the high viscosity with air seal, and finally chose 0.84mm nozzle tip diameter. With the above filament and nozzle diameter settings, the team experimented printing peanut butter cube, and got satisfactory printing quality, which is show in Figure 76.

• The extrusion multiplier has the similar function as the plastic extruder for minor extrusion tuning. In this case we set it to be 4.

• X and Y offsets are used for promoting the printing quality to make the two materials relative position more precise. After several experiment of printing peanut butter lines in certain plastic wells, the X offset was set to be -45.8mm, and Y offset was set to be -0.8mm, which is shown in Figure 77. The CAD model and real printing results for offset calibration is shown in Figure 78 and Figure 79. The customized G-code is mainly used during the extruder change.

• Since the nozzle tip frequently got clogged for both peanut butter and conductive material, the team made a hollow box full of desiccant to prevent moisture curing. Thus when the extruder is working the desiccant box should be removed, and when it shifted back to the plastic extruder, the box should be put back on the tip. Therefore when changing the extruders, the printer needed to pause and go to a parking position for taking off and putting back the desiccant box. An @pause command was used in this case to facilitate the pause motion during tool change, and correspondingly there was a line of G-code command “G1 X100 Y10 Z20 F200” running during the pause to make the printhead go to the parking position.

• Retraction settings were more useful for peanut butter printing because it was much more heat curing than moisture curing, as was the case for conductive material. For peanut butter, we did not need the desiccant box but instead retract 5mm every time it was not printing and extrude back again when it started to print.

• The last tuned parameter was the individual printing speed of the plastic extruder and the syringe extruder, which was done in a Perl post-processing script that is included in the Appendix section. With the post-processing speed the conductive material could be printed in a comparatively low speed to guarantee a good quality while the plastics the same as 60mm/s as mentioned before.
Figure 75: Filament and temperature settings for syringe extrusion.

Figure 76: Printed peanut butter cube before melting.

Figure 77: X-axis and Y-axis offsets settings.
5.4.10 Choice of the conductive materials
The conductive material is a key element to link the 3DCP with printed electronics aspects in this design challenge. The targeted conductive material should be highly conductive in a robust way, should be in a form factor, which is easy to be dispensed by the currently available dispensing tool that fits the 3DCP. Also the material shouldn’t be too expensive to purchase, or not available in the market in the near future and also shouldn’t be hazardous at all.

From the starting point, we first tested the conductive inkjet ink we bought for the benchmarking materials last quarter. It is a PEDOT ink, full name is Poly (3,4-ethylenedioxythiophene)-poly (styrenesulfonate) from Agfa, as shown in the Figure 80 below.
The ink is a liquid form factor, which can be dispensed by the inkjet print head. The resistance 75-120 Ω/sq>80% visible light transmission (40 μm wet). See Appendix section for the specification sheet. As this ink is directly used in the printed electronics industry, it will create a good proof of concept of fast prototyping tool if the 3D printer could print this ink. While the form of this ink is liquid proved to be too low well-controlled, the ink will flow all the way down before it dries, so as a result, it’s difficult to deposit a continue line in the vertical directions. And we tested this on the surface printed by the 3D printer and the resistance of a 70mm length ink is about 200ohms. In this way, we discovered the ideal conductive materials we use should be able to self-sustaining to create the vertical trace, which is able to connect different layers of components in the 3D circuits. In this way, a more viscous but also conductive material should be our next step.

Bare conductive paint (show in Figure 81) was the second ink tested. From the winter quarter’s prototype, instead of printing it on the paper, bare conductive paint was directly deposited by syringe along then channels printed by the 3D printer in the TLT lab at Stanford. The 70mm trace with 2mm width measured to be about 700ohms. Benefits are the channels helped the ink deposit uniformly than normally painted on the surface of paper, and the heated print bed of 3D printer also heats the ink, which makes it dry faster. Since the pure bare conductive paint is too viscous and difficult to dispense using the 10cc syringe and 16 gauge tips, the paint is diluted with water. Adding more water will lengthen the time to solidify, but it benefited more to dispense smoothly by the syringe.
Therefore, because the resistance of the bare conductive ink is still too high, so this material not appropriate to act as electrically conductive wiring materials.

Then we tested the silicon solutions, SS-26F (as shown in the Figure 82). It is an electrically conductive silicone RTV (room temperature vulcanizing). When cured, the elastomer resists weathering, ozone, moisture, UV and high temperatures. And when it is wet, the viscosity is really high so it can self-support when we draw vertical lines.

- Viscosity, cps 500,000
- Consistency : thixotropic paste
- Working time, mins. @ R.T.: 15
- Tack Free Time, mins. @ R.T.: 30
- Cure time 24 Hrs. @ R.T.
- Durometer, Shore A 70
- Volume resistivity, Ohms/cm 0.005
- Conductive filler silver
A single line drawn by hand using a syringe onto the surface was shown in the picture below Figure 83. The line has a resistance of 0.3 ohms about 2 mm width, and 30 mm length.

Temperature, moisturizer and air flow are three main factors which influence the cure process. And the resistance will be low enough after it cures. So under the 3D printer circumstance, when the ink was deposited as a single line exposed to the open airflow, the resistance dropped significantly after 5 minutes. After 15 mins, the resistance was onto 0.3 ohms. When it dries, it forms like a rubber like trace, easy to peel and self-support.

Because we didn’t have time to actually measure the resistance, quoting from the paper at Cornell University [8], see, with the cross sectional area of 0.8 mm * 1.2 mm, the resistance is about 0.192 ohms/m which is almost the same as the standard copper wire, ID 0.078 mm.

We tested several gauge of tips, the appropriate one is gauge 16 tip, which has an inner diameter about 0.84 mm (shown in Error! Reference source not found.).
Pushing the tips with smaller diameters is finally pushing out the silicone extracted from the materials, and leaves the dried silver inside. Since the printer is trying to connect components with printed wiring traces, since the distance between chips package has certain limitations, the thinner line the materials can form the better. And by using the 16 tip, it’s able to draw traces at 0.84mm width, which is narrow enough to connect the different foot size of electrical components, e.g., the foot size of regular resistors is 0.4mm*0.4mm for cross-section, and the SMT chips normal package the foot pin distance is 2.54mm. So SS-26F could be appropriate conductive materials for the 3DCP, especially for the syringe dispensing print head. Below figure shows what we drew by hand to deposit uniform lines in the channels, both horizontal and vertical, and also in slope.

So, SS-26F is selected to be the conductive material used by the 3DCP in this project.
6 Project Planning

6.1 Overview of spring quarter activities

Spring quarter was mainly three parts: the first two weeks length to finish function X, which was one critical part the final prototype/product, the following six weeks to penultimate, which was the second last milestone that all the functions of the final prototype/product were finished, and the last 2 weeks preparing for EXPE, which is the final exhibition. Here are some important milestones and dates describing the whole quarter’s activities.

April 2 2013 through April 18, 2013-Function X finished
The first two weeks challenged the whole team to finish one non-trivial part in the final system, and by this point, this part or functions should be able to working all the way down to the final EXPE without extra efforts.

Our function X was to completely assemble the frame of a Rep-rap Prusa Model 3D printer. This process took literally 10 days day and night to assembly the printer. And there was also a little delay than expected because the PCard was out of order for quite a while. These purchases were big deals and it’s difficult to go through any individual’s reimbursement process. So this process held the whole team for at least 3 days. It reminded the team to plan the purchase in advance in case.

Function X was finished on time with the printer mechanical parts and also the syringe was able retract water and dispense water in either way.

April 18 2013 through May 23 2013-Penultimate
Figure 86 showed the manufacturing plan after function X was finished. Since the spring quarter’s deliverables main depended on how can the team successful execute the schedule on time. So we have a detailed manufacturing plan as below (Figure 86).
Figure 86: Spring quarter manufacturing plan—April 25th---May, 12th
Figure 87: Spring quarter manufacturing plan-May 2nd-May 16th
Figure 88: Spring quarter manufacturing plan-May 12th—May 29th
As we can see from Figure 86. After April 18\textsuperscript{th}, major tasks were "Calibrate printer for Scarlett prints", "Integrate Syringe Extruder into Printer", "Print Flat Traces", "Finalize Syringe Extruder Design, Print Circuit in 2 Planes".

The calibration and integration part went well and met the schedule with late night work at the loft. Also it took long time to tune the syringe to extrude the peanut butter in a certain scale and also print the 3D structure using the peanut butter, which served as a substitution for the expensive ink.

The whole above process was a little late than the schedule (May, 2\textsuperscript{nd}, 2013). Actually around May, 12\textsuperscript{th}, 2013, we tested the syringe with real conductive materials. After that, the clogging problem held the schedule a little bit; changing tips frequently was strongly stopping the project moving forwards. Afterwards, there was a breakthrough that we changed the tips from conic ones to vertical ones, and added a cap to prevent the tip from contacting the air.

May15\textsuperscript{th}, the team successfully printed two circuits with both SMT LEDS and regular resistors.
By then it fell behind the schedule for almost about one week’s work because it was difficult to adjust the offset of the syringe printhead and cost a lot of time to figure out how to slow down the syringe printhead by manually modifying the according G-code.

Then it took about another week to print and test the 2 planes traces, and in this way we still need another week to print the EXPE showcase circuits. In this way, it cut off the PCB comparison parts from the planning, which was not designed and tested before EXPE.

Though printing the current circuits, it’s not hard to imagine the printer could prototype 3D circuit boards with chips and the wiring width could be as small as 0.5mm. It could be a pity not printing actual working circuits with chips on time.

So we had an updated version of schedule, which cut off some parts that was not completed before penultimate. So please find the revised reschedule as below (Figure 90).

**May, 23 through June 6—Two weeks to EXPE**

Since its two weeks before EXPE, printing showcase puzzle pieces for showcase application, making the cover for the printer, documentation for the final presentations, designing and building the booth were our main goals during this time. Global team arrived one week before the EXPE, and Clariant’s liaison Tobias arrived four days in advance of the final EXPE. Many things achieved within these two weeks. See Figure 90 for detailed information.

### 6.2 Process Reflections

**Alexandre Jais**

The Magic of ME310 and of Mechanical engineering was even more blatant for me during this quarter. Where the ideas turned tangible with early prototyping, functional later on, become actual products. Solutions that could be released (almost) into the wild with a level of detail that impresses a crowd of 500 expert builders and makers. The road or should I say the race to EXPE is part of the thrill of this whole quarter. It really is a stress test for both our mechanical engineering skills and our organizational skill, and I am glad that our team made some of the Jungian team dynamics surveys lie.

The past few months were also the most international of my life. The amount of progress made during our travel time in Switzerland made us do considerable progress in our reflection, and I think that gathering the whole team at that point helped us to take the key-decisions at a key moment of the project.

This also the quarter where we start to get even more attached to our ideas and team. With a strong will at least from my side to push the experience beyond the flight simulator. The feeling of having external validation from a variety users is maybe the best creative confidence booster ever seen, especially when companies see an interest for your technology. 310 is even more with that perspective in mind a life shaping experience and I am proud to fully be part of it now.
Scarlett Jiang

Spring quarter plus the spring break travelling was all-together a busy quarter than the past two quarters. I am also glad to feel the team was working more efficient as an entity. Within the Stanford local team, we were not actually good at working according to schedules. With these 10 weeks practices, we became more structured and built more awareness of scheduling. We drew a clear manufacturing plan in details to make sure the we were on the right track. It was not as fun as to be just creative and do whatever comes to our mind, and it took some time for the team to follow the plans. Also it needs some techniques or thoughts to throw on the time estimations of each part. It’s a little pity that actually there were about 10 days delay in the schedule, though the boys were working so late at night for the printer, while tuning the syringe was harder than expected. And for myself, since without the tangible tools working in my hand, it’s hard for me to plan in details and prepare well enough for solve the problems in advance. In this case, preventing clogging was something I should pay attention in advance before even the syringe was not actually working with the real conductive ink. I underestimate the importance of what clogging can influence the printing process.

In the teamwork process, everyone was designated to certain tasks, and could work individually. But instant discussions about the problem as soon as possible with the teammates greatly accelerated the thinking process, even though he or she may not doing anything related. Effective communication really saves time and brings sparkling insights.

It’s almost the end of the whole project, I am graduating now, and the only one in the team! Sad, and don’t want to leave at all. It’s hard to tell people what I have learned in terms of hardcore skills, but I am obviously more confident to face challenges and solve problems. And for sure, I learnt so much through ME310, our adorable team, TTteam and the whole class. Having teammates of Hao, Alex and Dan are amazing. I will miss them a lot.

Hao Jiang

It has been a fantastic quarter to work with the whole team to finally realize our ideas and make our final prototype/product! I could still remember that at the beginning of the spring quarter every team member was quite passionate but also a little bit worried about how much we could accomplish by the end of this quarter. We spent a lot of time choosing a good 3D printer to modify and further assembling and calibrating it. It was great fun that we used peanut butter to substitute for the expensive conductive paste to test dual printhead printing. Though a lot of late night printing and discussions, the we enjoyed so much on what we have been working on. The global team also got great accomplishments that made the website real and truly functional. We were really excited about that. As a result, by the end the quarter, we successfully delivered our combined final product InnoEx Online and InnoEx Inperson and got quite positive feedbacks from target users! So far it is not only a huge and successful project, but also great friendships and design thinking skills. It has been an amazing year and truly honored to work with all the people in the global design thinking class!
Daniel Levick
It’s been a thrilling roller coaster ride with a wonderful team and many wonderful memories. I feel as though we have really accomplished something special. The diversity on the team really contributed to the quality of our product. Everyone brought something very different, but everyone also strived to communicate effectively, and I think it was the combination of these two things that made us a strong team. Many thanks to my parents, friends, the teaching team, all of our startup and academic contributors, and my wife Grae!

6.3 Budget report and planning
This section covers the money spent with the Stanford team on this project. For the spring quarter, there were $4,000 dollars allotted plus $ 2,368.97 rolled over from spring quarter for the Clariant project, total $6,368.97. By the end of this quarter, Stanford team used $5,043.11 and the remaining $905.6036.
Figure 90: Two weeks before EXPE schedule
Stanford Budget
Most of the budget of this quarter was spent on the 3D circuits printer and related materials, including the Rep-rap printer, motors, syringe design, and relatively expensive conductive materials. A small portion of the budget was spent on the spare parts for the printer itself and electronic components for printing applications. Shipping fees could also be a portion of the spending, since different parts of speed the projects linked together, whenever emergency happened, the team needed to respond and repair the part as soon as possible, in case of influencing the whole projects. So some next air shipping fees were not negligible. Generally, the team was able to spend the money efficiently and smartly. In general, the team spent less than the budget allotted for this quarter, and also save money from the budget by applying promotion code to reach discount, and by ordering expensive stuff earlier to avoid big shipping fees.

At the beginning of spring quarter, we drew up the budge below to roughly estimate how much money we can spend on each part, as below Table 25.

Table 25: Spring quarter budget

<table>
<thead>
<tr>
<th>Vendor Name</th>
<th>Description of Expense</th>
<th>Pre-tax Amount</th>
<th>Quantity</th>
<th>Shipping &amp; Handling (if any)</th>
<th>Amount Incl Sales Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D printer</td>
<td>Prototype</td>
<td>$535.00</td>
<td>1</td>
<td>$70.00</td>
<td>$649.81</td>
</tr>
<tr>
<td>conductive inks/paste</td>
<td>250/100grams</td>
<td>$250.00</td>
<td>4</td>
<td>$60.00</td>
<td>$1,143.75</td>
</tr>
<tr>
<td>Plastic filament</td>
<td>31/gram</td>
<td>$31.00</td>
<td>10</td>
<td>$50.00</td>
<td>$385.96</td>
</tr>
<tr>
<td>Customized printhead</td>
<td>3 iterations, manufacturing fee</td>
<td>$200.00</td>
<td>3</td>
<td>$50.00</td>
<td>$700.25</td>
</tr>
<tr>
<td>Motor</td>
<td></td>
<td>$134.28</td>
<td>1</td>
<td>$145.50</td>
<td>$134.28</td>
</tr>
<tr>
<td>Syringe Barrel, Syringe Piston; Neoprene; 10cc</td>
<td></td>
<td>$95.06</td>
<td>1</td>
<td>$103.00</td>
<td>$95.06</td>
</tr>
<tr>
<td>Cleaning system</td>
<td>electronics, manufacturing</td>
<td>$500.00</td>
<td>1</td>
<td>$100.00</td>
<td>$500.00</td>
</tr>
<tr>
<td>Rubber Cap</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other electronics</td>
<td>LED, mounted chips</td>
<td>$500.00</td>
<td>1</td>
<td>$500.00</td>
<td></td>
</tr>
<tr>
<td>Arduinio boards</td>
<td></td>
<td>$70.00</td>
<td>2</td>
<td>$140.00</td>
<td></td>
</tr>
<tr>
<td>Spare parts kit</td>
<td></td>
<td>$200.00</td>
<td>1</td>
<td>$200.00</td>
<td></td>
</tr>
<tr>
<td>EXPE decorations</td>
<td>Candy, cookie</td>
<td>$50.00</td>
<td>1</td>
<td>$50.00</td>
<td></td>
</tr>
<tr>
<td>EXPE</td>
<td>Shirt</td>
<td>$35.00</td>
<td>4</td>
<td>$140.00</td>
<td></td>
</tr>
<tr>
<td>Expe</td>
<td>Jo-Ann Fabric</td>
<td>$100.00</td>
<td>1</td>
<td>$108.38</td>
<td></td>
</tr>
<tr>
<td>Team dinner</td>
<td>Team dinner when liason comes</td>
<td>$25.00</td>
<td>7</td>
<td>$189.66</td>
<td></td>
</tr>
<tr>
<td>EXPE poster</td>
<td>posters for expe</td>
<td>$144.00</td>
<td>2</td>
<td>$288.00</td>
<td></td>
</tr>
</tbody>
</table>
And below are the actual expenses.

### Table 26: Spring quarter actual expenses

<table>
<thead>
<tr>
<th>Date</th>
<th>Vendor Name</th>
<th>Description of Expense</th>
<th>Unit Price</th>
<th>Unit</th>
<th>Shippin &amp; Handling (if any)</th>
<th>Amount Incl Sales Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/12/2013</td>
<td>HyHaydon Kerk</td>
<td>Who: Alex using Pcards What: Stepper motor Why: Prototype, Syringe Control</td>
<td>$134.28</td>
<td>1</td>
<td>$66.00</td>
<td>$211.53</td>
</tr>
<tr>
<td>4/12/2013</td>
<td>Nordson</td>
<td>Who: Alex using Pcard What: Syringe Barrel, Syringe Piston; Neoprene; 10cc Why: Syringe system for prototype</td>
<td>$95.06</td>
<td>1</td>
<td>$35.00</td>
<td>$140.60</td>
</tr>
<tr>
<td>4/12/2013</td>
<td>Makerfarm</td>
<td>Who: Alex using Pcard What: Reppap 3d printer Why: Prototype</td>
<td>$569.95</td>
<td>1</td>
<td></td>
<td>$617.68</td>
</tr>
<tr>
<td>4/12/2013</td>
<td>Makerfarm</td>
<td>Who: Alex using Pcard What: Stepper driver Why: Drive the stepper motor</td>
<td>$9.00</td>
<td>1</td>
<td>$0.00</td>
<td>$9.75</td>
</tr>
<tr>
<td>4/12/2013</td>
<td>Makerfarm</td>
<td>Who: Alex using Pcard What: 3d printing abs filament Why: 3D printing materials</td>
<td>$29.00</td>
<td>1</td>
<td>$0.00</td>
<td>$31.43</td>
</tr>
<tr>
<td>4/12/2013</td>
<td>Silicon solutions</td>
<td>Who: Scarlett using Pcard What: Silicone Solutions, 1oz Why: Conductive paste</td>
<td>$205.19</td>
<td>1</td>
<td>$74.04</td>
<td>$279.23</td>
</tr>
<tr>
<td>4/18/2013</td>
<td>Amazon</td>
<td>Who: Scarlett using Pcard What: Kapton tape 1 inch Why: Taping the 3D printer&quot;</td>
<td>$24.18</td>
<td>1</td>
<td>$0.00</td>
<td>$26.30</td>
</tr>
<tr>
<td>4/22/2013</td>
<td>Walmart</td>
<td>Who: Scarlett using Pcard What: Touch Gloves (was cancelled), box frame Why: Experiments safety, and decorations for the 3D printer</td>
<td>$7.98</td>
<td>1</td>
<td></td>
<td>$8.68</td>
</tr>
<tr>
<td>4/23/2013</td>
<td>Radio Shack</td>
<td>Who: Hao using his money</td>
<td>$64.99</td>
<td>1</td>
<td>$0.00</td>
<td>$70.68</td>
</tr>
<tr>
<td>Date</td>
<td>Store</td>
<td>Who</td>
<td>Description</td>
<td>Price</td>
<td>Quantity</td>
<td>Total</td>
</tr>
<tr>
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<td>-------------------------------</td>
<td>---------------------------------------------------------------</td>
<td>--------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>4/25/2013</td>
<td>Makerfarm</td>
<td>Alex out of pocket</td>
<td>Arduino boards, 3D printer control</td>
<td>$139.00</td>
<td>1</td>
<td>$139.00</td>
</tr>
<tr>
<td>4/25/2013</td>
<td>Warmart</td>
<td>Scarlett using Pcard</td>
<td>glass box frame, decorations for the 3D printer</td>
<td>$7.97</td>
<td>1</td>
<td>$7.97</td>
</tr>
<tr>
<td>4/29/2013</td>
<td>Amazon</td>
<td>Scarlett using Pcard</td>
<td>Green ABS 3mm filament, returned</td>
<td>$36.00</td>
<td>1</td>
<td>$36.00</td>
</tr>
<tr>
<td>4/29/2013</td>
<td>Bookstore</td>
<td>Scarlett using Pcard</td>
<td>Charcoal Vine thin, Trowell palette knife, Supercapacitor</td>
<td>$7.78</td>
<td>1</td>
<td>$7.78</td>
</tr>
<tr>
<td>4/29/2013</td>
<td>Tresidder</td>
<td>Scarlett using Pcard</td>
<td>Peanut Butter, Ink substitution</td>
<td>$3.89</td>
<td>1</td>
<td>$3.89</td>
</tr>
<tr>
<td>5/1/2013</td>
<td>Makerfarm</td>
<td>Alex out of pocket</td>
<td>T2 Gears, Parts of the printhead</td>
<td>$10.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/6/2013</td>
<td>Silicon solutions</td>
<td>Scarlett using Pcard</td>
<td>Ink-3Oz, 3D printing materials</td>
<td>$512.23</td>
<td>1</td>
<td>$512.23</td>
</tr>
<tr>
<td>5/6/2013</td>
<td>Unixsurplus INC</td>
<td>Scarlett using Pcard</td>
<td>1.75mm ABS filament, 3D printing materials return to the tlt Lab</td>
<td>$36.00</td>
<td>1</td>
<td>$36.00</td>
</tr>
<tr>
<td>5/6/2013</td>
<td>Repraper Tech Co.ltd</td>
<td>Scarlett using Pcard</td>
<td>1.75mm ABS filament, 3D printing materials return to the tlt Lab</td>
<td>$41.00</td>
<td>1</td>
<td>$41.00</td>
</tr>
<tr>
<td>5/8/2013</td>
<td>PRL</td>
<td>Alex out of pocket</td>
<td>3D Printing parts, Parts of the printhead</td>
<td>$50.00</td>
<td>1</td>
<td>$50.00</td>
</tr>
<tr>
<td>5/12/2013</td>
<td>Homedepot</td>
<td>Alex out of pocket</td>
<td>Frame for the printer, Parts of the printer</td>
<td>$60.08</td>
<td>1</td>
<td>$60.08</td>
</tr>
<tr>
<td>5/12/2013</td>
<td>Makerfarm</td>
<td>Alex out of pocket</td>
<td>Gears and belts, Peniultramite Prototype</td>
<td>$70.00</td>
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</tr>
<tr>
<td>5/13/2013</td>
<td>Makerfarm</td>
<td>Scarlett using Pcard</td>
<td>Hot end, Sparepart</td>
<td>$54.95</td>
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<td>$54.95</td>
</tr>
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<td>5/9/2013</td>
<td>Costco</td>
<td>Dan out of pocket</td>
<td></td>
<td>$100.00</td>
<td>1</td>
<td>$100.00</td>
</tr>
<tr>
<td>Date</td>
<td>Company</td>
<td>Who</td>
<td>What</td>
<td>Why</td>
<td>Amount</td>
<td>1.</td>
</tr>
<tr>
<td>------------</td>
<td>---------------</td>
<td>--------------------------</td>
<td>--------------------------------</td>
<td>---------------------------------</td>
<td>--------</td>
<td>----</td>
</tr>
<tr>
<td>5/21/2013</td>
<td>Fry's</td>
<td>Pcard</td>
<td>Pizza</td>
<td>SUDS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/20/2013</td>
<td>RadioShack</td>
<td>Dan out of pocket</td>
<td>Power supply and electronics</td>
<td>3D printing</td>
<td>$80.00</td>
<td></td>
</tr>
<tr>
<td>5/23/2013</td>
<td>Tap plastics</td>
<td>Dan out of pocket</td>
<td>Plastics</td>
<td>Components</td>
<td>$42.34</td>
<td></td>
</tr>
<tr>
<td>5/27/2013</td>
<td>Tap plastics</td>
<td>Scarlett out of pocket</td>
<td>Plastics</td>
<td>EXPE 3D printer stand</td>
<td>$138.23</td>
<td></td>
</tr>
<tr>
<td>5/28/2013</td>
<td>Haydon Kerk</td>
<td>Scarlett out of pocket</td>
<td>Stepper motor</td>
<td>3D printer motor</td>
<td>$209.11</td>
<td>1.</td>
</tr>
<tr>
<td>5/28/2013</td>
<td>Home Depot</td>
<td>Hao out of pocket</td>
<td>Wood stud, foam insulation</td>
<td>EXPE 3D printer booth</td>
<td>$128.35</td>
<td></td>
</tr>
<tr>
<td>5/29/2013</td>
<td>Haydon Kerk</td>
<td>Scarlett</td>
<td>Stepper motor</td>
<td>Linear acuator</td>
<td>$200.33</td>
<td>1.</td>
</tr>
<tr>
<td>5/30/2013</td>
<td>Makerfarm</td>
<td>Scarlett</td>
<td>Prusa Motor set</td>
<td>Spareparts for the printer</td>
<td>$94.14</td>
<td>1.</td>
</tr>
<tr>
<td>5/30/2013</td>
<td>Amazon</td>
<td>Scarlett</td>
<td>LED power, flexible LED strip light, 3V batteries</td>
<td>Booth design, and expe applications</td>
<td>$91.78</td>
<td>1.</td>
</tr>
<tr>
<td>5/30/2013</td>
<td>Haydon Kerk</td>
<td>Scarlett</td>
<td>Linear acuator</td>
<td>Spare parts for syringe</td>
<td>$200.33</td>
<td>1.</td>
</tr>
<tr>
<td>5/30/2013</td>
<td>Working Meal</td>
<td>Whole Team</td>
<td>working meal</td>
<td>Liaison comes</td>
<td>$63.13</td>
<td></td>
</tr>
<tr>
<td>5/30/2013</td>
<td>Tap Plastics</td>
<td>Scarlett</td>
<td>plastics parts for booth</td>
<td>booth design</td>
<td>$105.58</td>
<td>1.</td>
</tr>
<tr>
<td>5/30/2013</td>
<td>Newark</td>
<td>Scarlett</td>
<td>Dialight LED, Red,yellow,green,resistor</td>
<td>Booth design</td>
<td>$80.83</td>
<td></td>
</tr>
<tr>
<td>5/30/2013</td>
<td>Newegg</td>
<td>Scarlett</td>
<td>Thermaltake TR2 TR-500 500W ATX12V</td>
<td>Spare power supply</td>
<td>$38.34</td>
<td>1.</td>
</tr>
<tr>
<td>5/30/2013</td>
<td>Home Depot</td>
<td>Scarlett</td>
<td>corner brace zinc</td>
<td>Booth design</td>
<td>$34.54</td>
<td></td>
</tr>
<tr>
<td>6/1/2013</td>
<td>Home Depot</td>
<td>Scarlett out of Pocket</td>
<td>Bolts, nuts, washers, blockx</td>
<td>Booth design</td>
<td>$38.34</td>
<td></td>
</tr>
<tr>
<td>6/3/2013</td>
<td>Amazon</td>
<td>Scarlett</td>
<td>Blue LED, Powersource</td>
<td></td>
<td>$34.54</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Store</td>
<td>Who</td>
<td>What</td>
<td>Why</td>
<td>Quantity</td>
<td>Amount</td>
</tr>
<tr>
<td>----------</td>
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<td>------------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>6/1/2013</td>
<td>Moo.com</td>
<td>Alex</td>
<td>Namecard</td>
<td>EXPE</td>
<td>6</td>
<td>193.64</td>
</tr>
<tr>
<td>6/1/2013</td>
<td>Zazzle</td>
<td>Dan out of pocket</td>
<td>T-shirts</td>
<td>EXPE</td>
<td></td>
<td>225.23</td>
</tr>
<tr>
<td>6/4/2013</td>
<td>Jo-Ann Facric</td>
<td>P Card</td>
<td>Table Cloth</td>
<td>EXPE</td>
<td></td>
<td>55.18</td>
</tr>
<tr>
<td>6/4/2013</td>
<td>Tap Plastic</td>
<td>Pcard</td>
<td>Acrylic plastic</td>
<td>EXPE</td>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td>6/4/2013</td>
<td>Copy of America</td>
<td>Pcard</td>
<td>Posters</td>
<td>EXPE</td>
<td>1</td>
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<td>PCard</td>
<td>Silicone inksSS-26F</td>
<td>EXPE 3D printer ink</td>
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7 Works Cited


8 Appendices

8.1 Appendix I

Workshop Itinerary

1. Please take 5 minutes to fill out the entry survey (on the reverse side of this page)! ~5min
2. Meet and Greet: ~10 min
   • We will go around and each person should introduce themselves and maybe include the following information:
     a. Your name
     b. Where you’re from
     c. What you do/what are you interested in
     d. Favorite food
     e. How familiar are you with printed electronics and its applications?
3. Introduction to the 3D circuit printer ~10min
4. 3D circuit printer applications brainstorming session ~15min
5. Application design session (we will pick one application and discuss it in a little more detail) ~10min
6. Exit Survey ~5min

Total: about 55 mins
8.2 Appendix II

Properties of Conductive Inkjet Ink

Product Specification

Product Name: Poly[3,4-ethylenedioxythiophene] - poly(styrenesulfonate) - 0.8% in H2O, conductive inkjet ink

Product Number: 739316

<table>
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<th>TEST</th>
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<tr>
<td>Appearance (Color)</td>
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<tr>
<td>Appearance (Form)</td>
<td>Liquid</td>
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<tr>
<td>Infrared spectrum</td>
<td>Conforms to Structure</td>
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<tr>
<td>Proton NMR spectrum</td>
<td>Conforms to Structure</td>
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<tr>
<td>pH</td>
<td>1.5 - 2.5</td>
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<tr>
<td>Viscosity</td>
<td>7 - 12</td>
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<tr>
<td>cP at 22°C</td>
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<tr>
<td>Miscellaneous Assay</td>
<td>75 - 120</td>
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<tr>
<td>Resistivity, Ohm/sq</td>
<td></td>
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<tr>
<td>Note</td>
<td>Product of Agfa-Gevaert N.V.</td>
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</table>

Sigma-Aldrich warrants, that at the time of the quality release or subsequent retest date this product conformed to the information contained in this publication.

The current Specification sheet may be available at Sigma-Aldrich.com. For further inquiries, please contact Technical Service. Purchaser must determine the suitability of the product for its particular use. See reverse side of invoice or packing slip for additional terms and conditions of sale.
Properties of Bare Conductive Paint

Bare Paint Jar (50ml) - Bare Conductive

Bare Paint is the first consumer-liquid conductive paint available to consumers today. This unique DIY-friendly material is designed for anyone of all ages to explore and learn about electronics with an inclusive, easy-to-use material.

Bare Paint provides a dramatically different method of innovating with electronics as it can be applied to almost any surface, including cardboard, paper, wood, wallpaper, walls, textiles, and some plastics.

Bare paint can be used to replace conventional acid etching, making it a great electronics prototyping tool. Non-toxic and water-based, Bare Paint can be used without gloves or mask. The paint dries quickly at room temperature, and can be removed with soap and water.

Application Methods include: painting, screen printing & assay painting among others.

1 jar of Bare Paint is enough material to cover approximately 1 square meter.

Price: £18.99

Buy Now!
8.4 Appendix IV

Properties of Silicone Solutions SS-26

SS-26

Product Description

SS-26 is an electrically conductive, moisture curing silicone RTV. SS-26 is a 1-Part silicone that when applied to the substrate allows handling of the assembly within an hour. When cured, the elastomer resists weathering, ozone, moisture, UV and high temperatures. SS-26 works well in manual and automatic dispensing equipment.

Product Features

- Very high electrical conductivity
- Fast R.T. cure
- Thixotropic paste
- High temperature resistant
- Non-corrosive
- Very high thermal conductivity

Typical Applications

- Form in place gaskets
- Electrically conductive sealant
- EMI/RFI silicone shielding

Color: Silver-Tan
(custom colors available upon request)

Service Temperature

-45 to 260°C

Electrically Conductive Silicone RTV

Typical Properties

- Viscosity, cps: 500,000
- Specific Gravity: 3.06
- Consistency: thixotropic paste
- Working time, mins. @ R.T.: 15
- Tack Free Time, mins. @ R.T.: 30
- Cure time: 24 Hrs. @ R.T.
- Durometer, Shore A: 70
- Volume resistivity, Ohms/cm: 0.005
- Conductive filler: silver

Method of Application

Dispense sealant onto part and mate parts. Be sure not to squeeze all of the product out of flange assembly. Allow to cure.

Chemical cure system

Oxime cure system

Solids

98% solids, contains no solvents
Curing

Cure speed can be accelerated with increased humidity to very rapid cure times. Typical utilization involves dispensing in open air and after exposure to ambient humidity, a room temperature cured rubber with electrically conductive properties is formed.

Adhesion

Primerless adhesion to most plastics, metals and typical substrates.

Limitations

Do not use product in solvent or fuel immersion applications. Allow to fully cure before putting assembly into service. Ensure enough product remains between flanges to be effective in an assembly.

Packaging

SS-26 is available in 10.3 oz. cartridges and 40 lb. pails. This product is also available in customer defined packaging sizes, upon request.

Handling and safety

For maximum shelf life, keep containers sealed when not in use. Keep out of the reach of children. Uncured sealant can irritate eyes and skin. Refer to MSDS.

Limited warranty

All recommendations, statements and technical data herein are based on tests we believe to be reliable and correct, but accuracy and completeness of said tests are not guaranteed and are not to be construed as warranty, either expressed or applied. User shall rely on his own information and tests to determine suitability of the product for the intended use, and the user assumes all risk and liability resulting from the use of this product. Manufacturer’s sole responsibility shall be to replace that portion of product of the manufacturer proves to be defective. Manufacturer shall not be liable to the buyer or any third party for injury, loss or damage directly or indirectly resulting from the use of, or inability to use, the product. Recommendations or statements other than those contained in a written agreement signed by an officer of the manufacturer shall not be binding by the manufacturer.

This product has not been tested for, and is therefore not recommended for, uses for which prolonged contact with mucous membranes, abraded skin, or blood is intended; or for uses which implantation within the human body is intended.

**Customized versions available upon request**
8.5 Appendix V

Slic3r post-processing Perl code

#!/usr/bin/perl
#
# A little postprocessing script to adapt Slic3r [http://slic3r.org] gcode output
# for a Techzone Huxley [http://reprap.org/wiki/TechZoneHuxley].
#
# Copyright 2012 Guy 'DeuxVis' P.
#
# This program is free software: you can redistribute it and/or modify
# it under the terms of the GNU General Public License as published by
# the Free Software Foundation, either version 3 of the License, or
# (at your option) any later version.
#
# This program is distributed in the hope that it will be useful,
# but WITHOUT ANY WARRANTY; without even the implied warranty of
# MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
# GNU General Public License for more details.
#
# You should have received a copy of the GNU General Public License
# along with this program. If not, see [http://www.gnu.org/licenses/].

use strict;
use warnings;
use English '-no_match_vars';
use File::Temp qw/ tempfile /; # use the tempfile function from the File::Temp package
use File::Copy qw/ move /;

# You can change those to suit your machine capabilities.
#my $Z_start_speed = "80.0";
#my $Z_full_speed = "110.0";
my $syringe_speed = "300.00"; #mm/min syringe extruder speed
my $T1_flag = 0; # used in loop to indicate whether we're in a syringe extrusion block
my $before = "";
my $after = "";
my $file_in = $ARGV[0] or die( "Need gcode file name as first argument !");
my ($file_out_h, $file_out_name) = tempfile() or die( "Cannot open temp work file !"); #use the tempfile function to create a temporary file in the two variables

while (<>) { #this while loops through each line of the gcode file just created by Slic3r, one line at a time until we run out of lines

    #reset T1_flag to 0 if we’re going into a T0 block
    if ($_ =~ /^M190/){
        print $file_out_h "$_;";
    }

    if ($_ =~ /T0/){ #the $_ is the current line of the gcode file we’re leading. It’s a weird default variable where everything gets stored in Perl without anyone saying anything. Shh it’s a secret!
        $T1_flag = 0; #the =~ compares $_ to the expression inside the // marks. There are tons of special rules and tricks for what goes inside the //.
        print $file_out_h "$_;";
    }

    #set the T1_flag when we see a T1 to indicate we’re in a T1 block
    elsif ($_ =~ /T1/){
        $T1_flag = 1;
        print $file_out_h "$_@pause Extrude until you see extrusion begin.\n";
        # print $file_out_h "@pause Extrude until you see extrusion begin.";
    }

    #only if we’re sure we’re in a T1 block, change speeds
    elsif ($T1_flag){
        if ($_ =~ /^G1 X(\d+).\d* Y(\d+).\d* F(\d+).\d* E(\d+).\d*)/){
            $_ =~ m/F/;
            $before = $`;
            $_ =~ m/E/;
            $after = $’;
            print $file_out_h "$before"."F$syringe_speed E$after";
        }
    }

    elsif ($_ =~ /^G1 X(\d+).\d* Y(\d+).\d* E(\d+).\d*)/){
        $before = $`;
    }
}
$after = $'
print $file_out_h "$before"."F$syringe_speed E$after"
}

elsif ($_ =~ /^G1 E\(\d+\.\d*\)/) {
    $before = $'
    $after = $'
    print $file_out_h "$before"."F$syringe_speed E$after"
}

else {
    print $file_out_h "$_"
}
}

else {
    print $file_out_h "$_"
}

# I do manual heatup - not sure my firmware does M109 properly anyway.
# if ($_ =~ /"M109/)
#    print $file_out_h ";$_"

# Z movements use their own speed
# } elsif ($_ =~ /"G1 Z\(\d+\.\d*\) F\(\d+\.\d*\).*/)
#    print $file_out_h "G1 F$Z_start_speed\n"
#    print $file_out_h "G1 Z$1 F$Z_full_speed\n"
#    print $file_out_h "G1 F$2\n"

# Monotronics old firmware doesn’t know that G1 lines starting with a F
# means "starting speed", so we set a separate line for that.
# Commented out as next step will also do that.
#} elsif ($_ =~ /"G1 F\(\d+\.\d*\) (.+)/
#    print $file_out_h "G1 F$1\n"
#    print $file_out_h "G1 "$2\n"
# Let firmware do non-Z acceleration, all movements will start at
destination speed.
# } elsif ($_ =~ /^\G1(.*) F(\d+)(.*)$/) {
  # print $file_out_h "G1 F$2\n";
  # print $file_out_h "G1$1$3\n";

# Comment out anything suspicious - ie _BRIDGE_FAN_END bug in slic3r 0.7.0.
# } elsif ($_ ne "\n" and $_ =~ /^s*[^GM;]/) {
  # my $displayLine = ";
  # chomp( $displayLine);
  # my $warnMsg = "$PROGRAM_NAME found and commented out suspicious GCode
    '$displayLine';
  # warn( $warnMsg );

# You can change those to suit your machine capabilities.
#my $Z_start_speed = "80.0";
#my $Z_full_speed = "110.0";
# print $file_out_h ";$;

# Anything else passes through unmodified.
# } else {
#   # print $file_out_h "$_";
# }
#}

close $file_out_h;
move( $file_out_name, $file_in );