**Amino**

*A Domestic System for Synthetic Biology and Continuous Culturing*

Julie Legault
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Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning, in partial fulfillment of the requirements of the degree of

**MASTER OF SCIENCE IN MEDIA ARTS AND SCIENCES**

at the **MASSACHUSETTS INSTITUTE OF TECHNOLOGY**

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Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning on May 8th, 2015, in partial fulfillment of the requirements of the degree of Master of Science in Media Arts and Sciences at the Massachusetts Institute of Technology.

**Abstract**

With the ability to transfer a trait from one creature to another purposefully, synthetic biology is advancing across unforeseen domains. From algae cells that convert carbon dioxide to fuel, bio-cementation bacteria to terraform mars, and lab-grown meat, synthetic biology offers new materials for designers, technologists, and artists to explore, and yet, public opinion lags behind these scientific advancements.

Anytime science advances faster than our ability to apprehend it, it produces progress but also fear, suspicion and uncertainty. *Amino* — an object that allows direct interaction with microorganisms to experiment with biology as material— sets out not simply to educate but to also be part of the early culture that metabolizes the changes underway.

*Amino* is a design driven mini-lab that allows users to carry out a bacterial transformation and enables the subsequent care and feeding of the cells that are grown. Inspired by Tamagotchis, the genetic transformation of an organism’s DNA is performed by the user through guided interactions, resulting in their synthetic organism for which they can care like you would a pet. *Amino* is developed using low cost ways of carrying out lab-like procedures in the home and is packaged in a suitcase-sized continuous bioreactor for cells.

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Amino
A Domestic System for Synthetic Biology and Continuous Culturing
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The following served as a reader for this thesis

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A Domestic System for Synthetic Biology and Continuous Culturing

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*To Hope, because there is no point in living without.*

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*And because it is sometimes easier when a bear says it, Thank you Funfetti & co.*
For Kamal
and the Bobtail Squid
# Table of Content

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgments</td>
<td>5</td>
</tr>
<tr>
<td>Table of Content</td>
<td>7</td>
</tr>
<tr>
<td>List of Figures</td>
<td>9</td>
</tr>
<tr>
<td>Introduction</td>
<td>10</td>
</tr>
<tr>
<td>1.1 Overview</td>
<td>11</td>
</tr>
<tr>
<td>1.2 Aims</td>
<td>12</td>
</tr>
<tr>
<td>1.3 Contributions</td>
<td>12</td>
</tr>
<tr>
<td>1.4 Outline</td>
<td>12</td>
</tr>
<tr>
<td>Background</td>
<td>14</td>
</tr>
<tr>
<td>2.1 Synthetic Biology</td>
<td>15</td>
</tr>
<tr>
<td>2.1.1 History</td>
<td></td>
</tr>
<tr>
<td>2.1.2 Public Perception</td>
<td></td>
</tr>
<tr>
<td>2.2 Design for Public Acceptance</td>
<td>19</td>
</tr>
<tr>
<td>2.2.1 The Role of Design</td>
<td></td>
</tr>
<tr>
<td>2.2.2 Design Strategies</td>
<td></td>
</tr>
<tr>
<td>Motivation</td>
<td>26</td>
</tr>
<tr>
<td>3.1 Impact of Synthetic Biology</td>
<td>27</td>
</tr>
<tr>
<td>3.1.1 Distributed bioengineering</td>
<td></td>
</tr>
<tr>
<td>3.1.2 Bioengineering in the home</td>
<td></td>
</tr>
<tr>
<td>Related Works</td>
<td>32</td>
</tr>
<tr>
<td>4.1 Overview</td>
<td>33</td>
</tr>
<tr>
<td>4.2. Life Sciences</td>
<td>34</td>
</tr>
<tr>
<td>4.2.1 Ambio</td>
<td></td>
</tr>
<tr>
<td>4.2.2 Bento Lab &amp; OpenPCR</td>
<td></td>
</tr>
<tr>
<td>4.2.3 Tardigotchi</td>
<td></td>
</tr>
<tr>
<td>4.3 Cultural Significance</td>
<td>37</td>
</tr>
<tr>
<td>4.3.1 Tamagotchi &amp; Furby</td>
<td></td>
</tr>
<tr>
<td>4.3.2 Boîte-en-Valise</td>
<td></td>
</tr>
<tr>
<td>4.3.3 Little Bits</td>
<td></td>
</tr>
<tr>
<td>4.3.4 150-in-One</td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>40</td>
</tr>
<tr>
<td>5.1 Purpose and System</td>
<td>41</td>
</tr>
<tr>
<td>5.2 User</td>
<td>41</td>
</tr>
<tr>
<td>5.3 Materials and Methods</td>
<td>42</td>
</tr>
<tr>
<td>5.3.1 Overview</td>
<td></td>
</tr>
<tr>
<td>5.3.2 Aesthetics / Experience</td>
<td></td>
</tr>
<tr>
<td>5.3.3 Organism</td>
<td></td>
</tr>
<tr>
<td>5.3.4 Transformation</td>
<td></td>
</tr>
<tr>
<td>5.3.5 Continuous Culturing</td>
<td></td>
</tr>
<tr>
<td>Evaluation</td>
<td>52</td>
</tr>
<tr>
<td>6.1 Design Development</td>
<td>53</td>
</tr>
<tr>
<td>6.1.1 Materials</td>
<td>53</td>
</tr>
<tr>
<td>6.1.2 Interface</td>
<td>57</td>
</tr>
<tr>
<td>Conclusion</td>
<td>61</td>
</tr>
<tr>
<td>7.1 Future Work</td>
<td>62</td>
</tr>
<tr>
<td>7.1.1 Development of the System</td>
<td></td>
</tr>
<tr>
<td>7.1.2 Commercial Applications &amp; Others</td>
<td>62</td>
</tr>
<tr>
<td>7.2 Concluding Remarks</td>
<td></td>
</tr>
<tr>
<td>References</td>
<td>63</td>
</tr>
<tr>
<td>Appendix</td>
<td>66</td>
</tr>
<tr>
<td>9.1 Violacein Datasheet</td>
<td>67</td>
</tr>
<tr>
<td>9.2 Transformation in Amino</td>
<td>68</td>
</tr>
<tr>
<td>9.3 LaserCut files for Amino</td>
<td>75</td>
</tr>
<tr>
<td>Appendices</td>
<td></td>
</tr>
<tr>
<td>Violacein Datasheet</td>
<td>67</td>
</tr>
<tr>
<td>LaserCut files for Amino</td>
<td>75</td>
</tr>
</tbody>
</table>
List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sample Genetic Circuit</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>E.E. Assisted Gardening</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Mech. E Planter</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Productivity in DNA Synthesis and Sequencing Graph</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>Cost per base pair of DNA for Synthesis and Sequencing Graph</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>GMO Corn Comic</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>GMO Protesters, 2010</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>Bacterial Litmus Paper</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td>GFP Bunny</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>Victimless Leather</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>Desirability vs. Complexity Graph</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>Genspace Lab Bench</td>
<td>21</td>
</tr>
<tr>
<td>13</td>
<td>Instructional Scaffolding</td>
<td>24</td>
</tr>
<tr>
<td>14</td>
<td>Kitchen Biohacking, 2014</td>
<td>27</td>
</tr>
<tr>
<td>15</td>
<td>Kitchen Biohacking, 2014</td>
<td>27</td>
</tr>
<tr>
<td>16</td>
<td>Kitchen Biohacking, 2014</td>
<td>27</td>
</tr>
<tr>
<td>17</td>
<td>Biobuilder Curriculum Sample</td>
<td>28</td>
</tr>
<tr>
<td>18</td>
<td>Biobricks</td>
<td>29</td>
</tr>
<tr>
<td>19</td>
<td>Biobricks construction standards</td>
<td>29</td>
</tr>
<tr>
<td>20</td>
<td>Arctic Apple</td>
<td>30</td>
</tr>
<tr>
<td>21</td>
<td>Ecovative’s Mycellium Packaging</td>
<td>30</td>
</tr>
<tr>
<td>22</td>
<td>Faber Future’s Dye</td>
<td>31</td>
</tr>
<tr>
<td>23</td>
<td>Modern Meadow’s lab grown beef</td>
<td>31</td>
</tr>
<tr>
<td>24</td>
<td>Bacterial Radio by Joe Davis</td>
<td>33</td>
</tr>
<tr>
<td>25</td>
<td>Jurassic Park still, 1993</td>
<td>33</td>
</tr>
<tr>
<td>26</td>
<td>Island of Dr. Moreau Film poster</td>
<td>33</td>
</tr>
<tr>
<td>27</td>
<td>Resident Evil Game sleeve</td>
<td>33</td>
</tr>
<tr>
<td>28</td>
<td>Moyasimon</td>
<td>34</td>
</tr>
<tr>
<td>29</td>
<td>Ambio Lamp</td>
<td>34</td>
</tr>
<tr>
<td>30</td>
<td>BentoLab</td>
<td>35</td>
</tr>
<tr>
<td>31</td>
<td>OpenPCR</td>
<td>35</td>
</tr>
<tr>
<td>32</td>
<td>Tardigotchi</td>
<td>36</td>
</tr>
<tr>
<td>33</td>
<td>Furby</td>
<td>36</td>
</tr>
<tr>
<td>34</td>
<td>Tamagotchi</td>
<td>36</td>
</tr>
<tr>
<td>35</td>
<td>Duchamp’s Boîte-en-Valise</td>
<td>37</td>
</tr>
<tr>
<td>36</td>
<td>LittleBits</td>
<td>38</td>
</tr>
<tr>
<td>37</td>
<td>150-in-One by RadioShack</td>
<td>39</td>
</tr>
<tr>
<td>38</td>
<td>Amino Overview</td>
<td>42</td>
</tr>
<tr>
<td>39</td>
<td>Violacein production in E.Coli</td>
<td>44</td>
</tr>
<tr>
<td>40</td>
<td>Violacein production in E.Coli in liquid culture</td>
<td>44</td>
</tr>
<tr>
<td>41</td>
<td>Violacein production pathway</td>
<td>45</td>
</tr>
<tr>
<td>42</td>
<td>Amino’s Transformation interface</td>
<td>45</td>
</tr>
<tr>
<td>43 to 48</td>
<td>Transformation Protocol as done in Amino</td>
<td>47</td>
</tr>
<tr>
<td>49</td>
<td>Centrifuge Schematic</td>
<td>49</td>
</tr>
<tr>
<td>50</td>
<td>Centrifuge Prototype</td>
<td>49</td>
</tr>
<tr>
<td>51</td>
<td>Heating/ Cooling Schematic</td>
<td>49</td>
</tr>
<tr>
<td>52</td>
<td>Heating/ Cooling Prototype</td>
<td>49</td>
</tr>
<tr>
<td>53</td>
<td>Pump Schematic</td>
<td>50</td>
</tr>
<tr>
<td>54</td>
<td>Pump Prototype</td>
<td>50</td>
</tr>
<tr>
<td>55</td>
<td>Sample Chemostat System</td>
<td>50</td>
</tr>
<tr>
<td>56</td>
<td>Sample Culturing System</td>
<td>50</td>
</tr>
<tr>
<td>57</td>
<td>Culturing Interface Amino</td>
<td>51</td>
</tr>
<tr>
<td>58</td>
<td>Continuous Culturing System Amino</td>
<td>51</td>
</tr>
<tr>
<td>59</td>
<td>First Prototype Amino</td>
<td>54</td>
</tr>
<tr>
<td>60</td>
<td>Rendering Amino</td>
<td>54</td>
</tr>
<tr>
<td>61</td>
<td>First Major Interface Prototype Amino</td>
<td>55</td>
</tr>
<tr>
<td>62</td>
<td>Second Major Interface Prototype Amino</td>
<td>55</td>
</tr>
<tr>
<td>63</td>
<td>Third Major Interface Prototype Amino</td>
<td>56</td>
</tr>
<tr>
<td>64</td>
<td>Fourth Major Interface Prototype Amino</td>
<td>56</td>
</tr>
<tr>
<td>65</td>
<td>Wood Samples</td>
<td>57</td>
</tr>
<tr>
<td>66</td>
<td>Black Acrylic Prototype</td>
<td>58</td>
</tr>
<tr>
<td>67</td>
<td>White Acrylic Prototype</td>
<td>58</td>
</tr>
<tr>
<td>68</td>
<td>Aluminium Prototype</td>
<td>59</td>
</tr>
<tr>
<td>-----</td>
<td>----------------------</td>
<td>----</td>
</tr>
<tr>
<td>69</td>
<td>Aluminium and Rosewood Prototype</td>
<td>59</td>
</tr>
<tr>
<td>70</td>
<td>BentoLab</td>
<td>60</td>
</tr>
<tr>
<td>71</td>
<td>OpenPCR</td>
<td>60</td>
</tr>
</tbody>
</table>
Section 1 **Introduction**

*The future is uncertain: life is part biology, part machine. Technology and play can transform the banality of the commonplace into fantasy.* –Takashi Murakami
1.1. Overview

With the ability to transfer a trait from one creature to another purposefully, synthetic biology is advancing across unforeseen domains. From algae cells that convert carbon dioxide to fuel (Beer, 2009), bio-cementation bacteria to terraform mars (Hsu, 2014), and lab-grown meat (Bhat, 2011), synthetic biology offers new materials for designers, technologists, and artists to explore. and yet, public opinion lags behind these scientific advancements.

From the initial sequencing of the human genome in 2000, whole sets of technologies came to fruition. Not only are we able to read and write DNA, but the cost at which we do keeps dropping as the speed increases. This accessibility enables what were once large efforts conducted in research labs to now be happening on kitchen tables (Wohlsen, 2012).

With no signs of slowing down, the new practice of bioengineering in labs and biohacking at home is running into ethical and social issues. The advances in technology are happening at a greater rate than law can keep up, and our societal view is tinged from our complex social and medical history with microorganisms. This can create a negative cultural view, which has the potential to threaten whole worlds of innovation, and creates crucial importance for the public to have a comprehensive understanding of these new technologies.

In part due to a lack of exposure, the acceptance of synthetic biology and modified organisms has been limited. Public engagement and education could provide the opportunity for an informed society to welcome a transition from a century of chemistry, physics and information sciences into a century of molecular and synthetic biology.

A growing number of biologically-based consumer products are hitting the market and many innovations are in the pipeline. However, a consumer desire for synthetic biology has yet to happen as people at large remain unaware of the possibilities offered by Synthetic Biology to answer our needs and desires; the benefits and opportunities of synthetic biology remain opaque as the breath and altitude of the field makes building a cultural imagination around it difficult. In order to explore current public attitudes towards this emerging market, this thesis will survey the current product landscape.

From this foundational work, Amino, an object that allows direct interaction with microorganisms in everyday life is produced. Design’s fundamental task is to help people metabolize change, interpreting science and technologies into objects and experiences that can be assimilated into life, art, and culture.
Section 1 Introduction

*Amino* has the potential to help shift the public perception of Synthetic Biology by helping non-traditional audiences understand the opportunities of the field as it plays a role in building the imagination around it and explores the promise of synthetic biology occurring outside the lab. Biotechnology is going through a transition from being centralized to being distributed, and *Amino* will facilitate this transition. Amino is at the forefront of this transition and slots into the emerging ecosystem as it enables anyone to run DNA programs and watch them grow.

The cultural future of Synthetic Biology is twofolds in its mandates; it must diminish the anxiety surrounding it, and build wonder and desire for it. *Amino* sets out to do both by placing the real processes and materials of synthetic biology in the users hands and to begin to make a user to dream of what could come next.

1.2. Aims

This thesis proposes that cultural products that educate and enchant users could play the role of instigator and create public engagement around difficult topics, namely synthetic biology. The thesis aims to establish a link between desirable design and opinion shifts through the creation of a consumer product prototype that enables cell transformation and continuous culturing on a personal scale outside the lab.

1.3. Contribution

This thesis offers the following contributions:

1. An overview of the design space around Synthetic Biology
2. The creation of a worldview of biology, synthetic and natural, as a living system we can experience and interact with.
3. A fully-functional DNA transformation station that can be used in the home
4. A small scale personal bioreactor that allows for user interaction with the culture
5. Application prototypes that show how low-cost alternatives to lab equipments can be made and used.
1.4. **Outline**

The following sections describe the evolution of ideas in this thesis:

**Background:** introduces a context for the field of Synthetic Biology and the state of its public perception, as well as outlines the role of Design for culture and some of the theories and tools available to create products with the potential to spur change. This section also contains example of relevant work.

**Motivation:** explains the importance of public participation in the field of Synthetic Biology based on its predicted and current impact on personal and public life. This section includes relevant work in the space of biology and art.

**Design:** describes the purpose, audience and materials and methods of Amino.

**Evaluations:** surveys the design development of the interface and materials for Amino, as well as evaluates the system performance for the transformation and culture of cells.

**Conclusion:** establish the commercial application of *Amino* and its other potential uses and summarizes the thesis.
Section 2 Background
Section 2 Background

2.1. Synthetic Biology

2.1.1. Brief History of Emergence as a Field

Synthetic biology is a branch of biology that draws on biotechnology, evolutionary biology, molecular biology, systems biology, and electrical engineering. It is a further iteration of genetic engineering and, as a rapidly growing field, many definitions currently exist. Common to all these is the idea of applying engineering principles to fundamental components of biology. (Endy)

Bioengineering has enabled us to read and manipulate DNA—the instruction set all living organisms possess in their cells—and this fundamental work has allowed genetic engineer to go one step further by selecting genetic code from one organism and adding it to another. Synthetic Biology goes further still, with the design and construction of new biological parts not found in nature. Scientists use computers and chemicals under the guiding principles of modern engineering in order to create these new parts from scratch.
Section 2 Background

The above examples, taken from the BioBuilder curriculum, explains the essence of bioengineering: In order to keep an indoor plant alive, an electrical engineer could propose a sensor and actuator system like in figure 2, a mechanical engineer a tipping pot solution like in figure 3 and a bio engineer could propose to transfer camel genes into the plants DNA.

The element that distinguishes Synthetic Biology from other biology and engineering is this specific focus on imagining and producing novel core components that can be assembled into larger systems. These new organisms and system play a role in changing many areas of life including medicine, fuel, cosmetics, food, and materials. A recent synthetic biology result was launch, the anti-malaria drug artemisin. Over 7% of the world’s population die or become infected from malaria each year. The low-cost and ease of production of this drug is just one example of the ways synthetic biology will affect our future. (Keasling, 2013)

The emerging boom in Synthetic Biology is driven, in part, by various capital agendas as well as by some advanced in foundational technologies. Synthetic biology came to fruition because of four major agendas, the first three centering on how to test, further and implement our understanding of biology while the fourth comes from a desire to use biology as a technology to process information, produce energy, manufacture chemicals and create materials. (Endy, Synberc) The progress itself is driven by advances in two foundational technologies: the sequencing and synthesizing of DNA [Fig. 4 & 5]. While one allows for a greater understanding of the matter, the second allows the ability to test out novel designs of DNA. As the price dramatically lowers and the capability and speed at which they can be carried out rises, the impact of Synthetic Biology in our daily lives increases.
2.1.2. **Public Perception of Synthetic Biology**

Synthetic Biology is often regarded with suspicions and doubt, especially as it starts to leave the labs and corporations. This is common to all processes of democratization in media and even dates all the way back to the advent of the printing press.

In the 15th century, the arrival of the Gutenberg’s printing press was met with reserved feelings. Hieronimo Squarciafico, the Italian humanist, worried that the “easy availability of books would lead to intellectual laziness, making men ‘less studious’ and weakening their minds. Others argued that cheaply printed books and broadsheets would undermine religious authority, demean the work of scholars and scribes, and spread sedition and debauchery. As New York University professor Clay Shirky notes, ‘Most of the arguments made against the printing press were correct, even prescient. But, again, the doomsayers were unable to imagine the myriad blessings that the printed word would deliver.”

Just as with the advent of the written word, widespread reading and the printing of books, new technologies often hit reluctance before becoming a source to spread information and expand human knowledge. (Krug, 2006)

Concerned with the relationship between medicine, biology, philosophy, politics, and laws, bioethicists and society face an era of unprecedented biological change. Scientists continue to develop the ability to clone mammals while regenerative medicine seeks to unlock the power to heal ourselves with our cells. Synthetic biology may allow us to create new species along with genetic modification which offers the potential to radically alter our DNA.
Section 2 Background

The public acceptance of synthetic biology has been surveyed through questionnaires (Koeppe, 2010) and studies (Pauwels, 2013, Torgersen, 2009), and stimulated through art, speculative design, and consumer products. The field of medicine and energy had the highest degrees of public acceptance (83% and 80% respectively) in opposition to food (30%) and computer / electronics (25%) (Koeppe, 2010). This is, in all likelihood, because the problems presented in medicine and energy are more easily apprehended than in food security and entertainment. This is possible because it is easy and reasonable to speculate that most people would be comforted by advances like the new bacterial litmus paper to detect Ebola [Fig. 8]. This strip of paper is coated with a modified organism that reacts visually to the presence of Ebola, thus making a cheap, reliable sensor for a present day crisis.

In the same way that the Litmus paper represents an actual implementation of a life-affirming way that scientist can use Synthetic Biology, the work being done by artist with biology represents the beginning of the articulation of the questions surrounding it. Pushing at the edges, these artworks, like the early transgenic GFP Bunny of Eduardo Kac [Fig.10], represents the fears and awe for the biological. The 2012 MoMA Victimless Leather piece [Fig. 11] by Oron Catts succeeded in sparking debates and entering the cultural imagination when the cells used to grow a leather jacket grew too quickly and blocked the bioreactor in which they were housed. The museum and artist decided to unplug the system, thereby “killing” it.

In an effort to bring the Synthetic Biology debates to the public, artists and designers create a dialogue between different disciplines and the public. They play two roles, one that is to deploy technologies that affect lives and a second that is to design for the imagination of the future. Like most technologies, one of its greatest value may well be when it is embedded most deeply in the background; where many peoples lives may be saved by the Litmus Paper sensor but never know it. Therefore designing for consciousness is a different take all together.
Section 2 Background

2.2. Design for Public Acceptance

To design artifacts is to design people’s lives. – Jonas Lowgren

2.2.1. The Role of Design

Design’s primary focus is to render complicated technologies, sciences and ideas into digestible objects, experiences and services for the mainstream. (Antonelli, 2008) Objects can do this because of our emotional connection to them. We define ourselves through them and they play an important role in forming our world view, they help us make our minds, reaching out to us to form active partnerships. (Turkle, 2011) Objects link our emotional and intellectual selves. They become companions in our lives, evocative objects.

Most objects hold a power based on the moment in which they entered their users lives - mementos. Some objects, however, possessing an uncanny quality, seem to be intrinsically evocative. The uncanny —that feeling of familiar yet unfamiliar— can be cultivated through design decisions.

2.2.2. Design Strategies

Designers rely on strategies and theories to emotionally affect users in shifting or grounding their world view. Experiencing products starts with sensory motor skills, and evolves into a deep maze of factors, strategies, emotional and experiential dynamics. As an object of play which engages both mind and heart, Amino needs to engage the user in both spontaneous play – Paida– and controlled play –Ludus. By achieving the right balance between use and discovery, we will be provided with and object that sits at the center of Ludus and Paida.

This section provides an overview of emotional design, and the creation of product attachment and desirability through ease of use and discovery. This includes how to Design for Complexity (modularity, automation, taskonomy), for Pleasure (control, accomplishment, enchantment), for Growth (bricolage, scaffolding, symbiosis).
2.2.2.1. Designing for complexity

Complexity is inevitable when designing desirable consumer products. As features on a product increase, so does its desirability [Fig.11] (Norman, 2008). The resulting complexity is not a problem, it is the possible confusion and frustration of multiple features that can detract from user experience. Complexity can be managed using simple design rules; modularity, automation, activity-centered design and understandability.

Modularity, when designing for complexity, can allow for ease of use and approachability. By diving the activity into small, manageable modules, the user can relax and attract the problem one section at a time. Printers, Scanners and Copiers do this well, grouping each action in sections so that each becomes simple and isolated from the others.

In Synthetic Biology, this means separating each activity by step to be performed. For example, in a DNA transformation, there are 4 main steps, including centrifuging, heat-shocking and recovery. Labs already provide modularity in that most lab equipment performs only one task, a centrifuge for centrifuging, a heat block for heat-shocking and ice buckets for recovery. In a way, a lab provides modularity by demanding that many individual machine be bought and used.

Another way to solve complexity is automation. By adding more technology, the designer can solve certain user-problems where human error or sequence of action can be problematic. The
caveat is that this can create more problems when badly structured. Automation can reduce stress, workload and decrease errors. In order for automation to be successful, it needs to be understandable, rely on signifiers and give visual cues as to the process underway. Good mapping is necessary to ensure that the relationship between actions and results is apparent. (Norman, 2006) In a lab environment, this can look like liquid-handling robots, that, once programmed, will perform the tedious tasks of dispensing specific amounts of liquids in vials or dishes. This replaces manual pipetting, a task that demands skills and concentration where user error can be harmful and costly.

Taskonomy is another way for designer to deal with complexity. Also known as Activity-Centered Design (ACD), Taskonomy-focused devices are successful because they are developed with an understanding of the activities to be performed by the user (Norman). They support real behaviors from the standpoint of people, not engineers. These behaviors are dictated by the task and activity to be done, the environment, the context and the goals, and not by taxonomy. Anthropologist Janet Dougherty and Charles Keller found that, when studying blacksmiths and carpenters, they would store their tools by activities and not by class - the hammer next to the anvil, next to the tongs, so that they are ready for use. Taxonomy is appropriate when there is no context for the information or activity. Once an activity has begun, taskonomy should take
Section 2 Background

over, placing things that need to be used together. “In other words, good behavioral organization reflects human activity structure, not dictionary classification.” (Norman, 2006)

For a bioengineer, taskonomy means pipets next to tips, next to discardd container, next to tube and tube holders, next to sharpie for labelling and always with a spray bottle of ethanol close on hand [Fig.12]

Product experiences and interactivity are not designed, they are suggested -- frameworks are created to support interactions. The better the designer, the less chances that this framework will be misused or misunderstood. A course of acceptable actions to be performed on and with the objects are suggested. In a successful product, these affordances are easy to understand and knowledge that things can go wrong - that the key is to design to ensure that people will know how to react.

By focusing on the individual user and his or her goal(s), the designer can support the opportunity of a satisfying experience. In fact, the more successful these intended interactivity frameworks are, the more pleasing the product experience will be.

“Even amidst the growing complexity that surrounds them, products maintain their power to imbue our lives with a sense of fulfillment. The best products are tools that enhance our lives, allow us to do things that would otherwise be impossible and give us great pleasure.” (Bennet, 2001)

2.2.2.2. Designing for pleasure

Emotional design is a critical part of the enjoyment of a product. From the enjoyment stems product attachment and sustained interaction. Necessary to enjoyment are the need to feel in control and the pleasure of accomplishment (Norman, 2004).

During the product interaction, the user needs to maintain a sense of control for the processes underway. This requires a delicate balance between automation, mapping and user input. By having an interface that is visually explicit as to the steps that need to happen, gives an overview of all the options and informs how to attain goals, the object can instill a sense of control in the users. The predictability of the device creates a sense of comfort. If the user can explain how he
Section 2 Background

got there, what can happen here, and where he will go next, his need for control will be rewarded and he will be able to feel a sense of accomplishment. (Krug, 2006)

The pleasure aspect of attachment does relate to the actual usage of the object as seen above, but also emerges out of pleasure from surprise, an unexpected functionality or interaction.

This sense of surprise, of enchantment comes from the act of being shown the extraordinary amongst the familiar, revealing a world that is neither inert nor devoid of mystery. The feeling of being charmed by an unprocessed encounter and the uncanny feeling of being torn out of a default intellectual-sensory state creates a return to a childlike excitement about life, a sense of fulness, liveliness and excitement. (Bennet, 2001) This enchantment can derive from product use and create successful desirability; it is manufactured by a greater sense of play, a return to familiar aesthetics and a slight strangeness that is neither dismissive of nor absorbed by the everyday. (Dunne & Raby, 2001). In Synthetic Biology, this sense of enchantment appears quite easily. The simple act of modifying a living being, or seeing it produce a tangible product is instantly awe-inspiring.

Pleasurable interactions, surprise and enchantment can similarly be brought on by the impression of magic provided by technology. Smart objects often offer wonder through automagical processes and interactions. Intriguing, captivating, surprising, the automagical — automatic and magical— is an approach that combines the willingness to hide the mechanisms and circuitry with the will to foster trust and wonder. Automatas, for example, can be a magical experience because the simple act of turning a handle brings an entire system to life. (Park, 2009) Electronics allow for this added depth of interaction, offering responsiveness to the user; it holds the innate ability to infuse magical qualities in the ordinary. (Dunne & Raby, 2001)

2.2.2.3. Designing for Growth

The conditions that are found most comfortable by humans are the ones that are design to allow for expansion of the self. (Antonelli, 2008) These objects that transcend physical boundaries are created through different design tools, 3 of which are the idea of Bricolage — the growth of self —, Scaffolding — the growth of knowledge — and Symbiosis — the growth of relationships.

Expressed by Levis-Strauss in the 1960s, the idea of Bricolage / Bricoleur is about a style of working in which materials are manipulated to develop new thoughts. (Turkle, 2011) A way of tackling new problems but also a way of exploring new ways of thinking and viewing the world
and the self, bricolage relies on giving a finite set of materials to be explored tactically, physically. It is a flexible way of thinking that appeals through play and experimentation. By reconstructing with the same materials over and over, the Bricoleur expands his mind and universe. Biology offers this re-mixing of material to scientist and amateurs quite by accident, as most living organism require the same few materials and environment to prosper with quite different results. Glucose, water, heat, oxygen or CO2 are the basic needs for most cells with strikingly different results, from the production of ethanol to the taste of vanilla.

Using the same approach of a finite set of materials as starting point, the idea behind using scaffolding in user interaction and learning is to promote the growth of knowledge over time. This allows the user to start with a very linear and simple interaction, and as he gets more comfortable and knowledgable about the system and subject, the product allows him to go deeper. While an activity may be very guided at the beginning, that structure can fall away to allow the user to freely explore the product. By using pre-existing knowledge, the user can move from focused to guided instruction into collaborative and independent learning [Fig.12] This type of learning is often found in classrooms, including for the life sciences. Biology always builds on existing knowledge which allows you to probe deeper and deeper. The birth of Synthetic biology stems from the knowledge amassed in Genetic Engineering, which in itself was born from bioengineering, the act of breeding of two species together.

Furthering intellectual learning is to be supplemented by emotional growth in order to achieve lasting product attachment. The use of techniques to promote a sense of symbiosis with the product helps foster the sustainability of the user-object relationship. Symbiosis, a concept derived from biology and applied here to designed interactions as an intimate relationship

Fig. 13 Instructional Scaffolding – Reprinted from ASCD.org, 2015
between technology and the body can be created between two different organisms living in close physical association. A mutually beneficial relationship can create a stronger, natural bond with the user, easing him into adoption of a technology or object that may seem alien at first. (Andraos & Sridhar, 2006)

The Symbiotic feeling can be promoted by the adding a need for sustained touch during product interaction. Touching becomes interactive, as it is a reciprocal sense; touching implies being touched simultaneously, whereas neither seeing, tasting nor hearing imply being seen, tasted or heard. As touch implies physical contact, and the feeling of being in contact, it also implies intimacy. Touch is a strong foundation for affection and emotions and can blur and distort the boundaries between the experienced self and the world, creating a richer immersive experience. Electronic products offers this blur by simulating the user as the environment or ‘real’ entity would. This increasing of sensory output and input increases the user’s sense of presence, thereby increasing emotional responses and product attachment.

Using materials that demand touch can enhance the success of this approach. For examples, skins of natural origin radiate comfort, security, durability and sensuality. Natural materials demand to be touched and interacted with, glowing with the warmth of a user’s touch, slowly eroded into a familiar shape, and reminding humans of the mothering aspect of nature.

2.2.2.4. Attachment and Desire

By designing for complexity, pleasure and growth, designers can succeed in creating lasting product attachment in their users. The ability to use the product efficiently while still being able to be surprised takes the product beyond object to experience; it stops being a mere object and becomes extraordinary, embodied knowledge (Schifferstien & Hekkert, 2007). This is what Amino set out to achieve.
Section 3  

**Motivation**

*The feeling of awed wonder that science gives us is one of the highest experiences of which the human psyche is capable. It is truly one of the things that make life worth living*

- Richard Dawkins
Section 3 Motivation

3.1 Impact of Synthetic Biology

3.1.1. Distributed bioengineering

For many, increasingly, the first experience with Synthetic Biology will take place not in visit a lab but in a DIY hack space, a garage or even a kitchen, surrounded by coffee, pastries, latex gloves and ice buckets. Synbiota, is a Canadian start-up that is taking biotech beyond the walls of institutions and large corporations and into the public realm with an integrated software and wetware platform to transform DNA. Their kit of standardized DNA parts [Fig. 16] can be used alongside the web-based DNA design software to create and conceptualize genetic circuits before they are assembled on site.

This type of distributed biohacking is happening in part because of the ease with which events and experiments can happen in domestic spaces. Academic policies and red tape can keep institutional labs from being a viable option; the delay from organizing to holding the event or getting the supply spanning months, not weeks. As such, many decide to explore off-campus, and, in the tradition of DIYbio hackers, promoted their work or event as part of the movement.

Started by DIY enthusiast like MIT graduate Kay Aull, who set up eBay-bought lab equipment in a closet to test her DNA for a faulty hereditary gene when medical would not do it, DIY biohacking has been going on for years. With the price of technology going down and the speed at which sequencing and synthesizing occurs speeding, formally recognize in 2008 with the launch of DIYbio.org, the movement is dedicated to provide cheap, accessible, transparent biohacking resources and a safe community to explore and expand knowledge. This led to an exploding of Biohacking spaces opening around the globe, with New York’s pioneer Genspace leading the way.
Hosting events, workshops and outreach to a growing community since 2009, Genspace is the model for DIYBio spaces. Currently found in over 60 cities worldwide, DIYbio spaces not only offer equipment and infrastructure for DIYBio enthusiast but also safety, community and inspiration for the movement.

**Biobuilder**, a startup from Natalie Kuldell, professor of Bioengineering at MIT, puts current synthetic biology research into the hands of K-12 teachers and students. By converting the science into teachable modules, **Biobuilder** fosters engagement and interest in the field. Providing access to different lab activities including the opportunity to create the smell of...
Section 3 Motivation

bananas in an E.Coli cell, or the chance to take a bacterial photography by modifying E.Coli cells to produce pigment when exposed to red light, all the protocols include both materials for teachers and for the students to experiment in class.

IGEM, the international competition to create genetically engineered parts, is another one of the companies creating a catalog of parts, based on a plug-and-play system for experimentation with biology. This catalog contains over 18,000 components and are available to the hundreds of students who partake in the competition each year.

Similarly, Biobricks, lego-like snippets of DNA used to assemble and design biological circuits, are to synthetic biology what the standardization of electronics parts like diodes were for personal electronics and computing. Through Biobricks, the Biobricks Foundation strives towards an open and ethical science that brings together engineers, scientists, attorneys, innovators, teachers, students, policymakers, and ordinary citizens to create safe, effective, ethical and publicly available solutions to architecture, medicine, environmental, agricultural problems.

Freeman Dyson, FRS, a prominent theoretical physicist and mathematician known for his work in quantum electrodynamics, solid-state physics, astronomy and nuclear engineering, paints a commonly accepted picture of bioengineering’s future, at least amongst synthio enthusiasts.

"I see a bright future for the biotechnology industry when it follows the path of the computer industry, the path that von Neumann failed to foresee, becoming small and domesticated rather than big and centralized. The first step in this direction was already taken recently, when genetically modified tropical fish with new and brilliant colors appeared in pet stores. For biotechnology to become domesticated, the next step is to become user-friendly."
Few of the new creations will be masterpieces, but a great many will bring joy to their creators and variety to our fauna and flora. The final step in the domestication of biotechnology will be biotech games, designed like computer games for children down to kindergarten age but played with real eggs and seeds rather than with images on a screen. Playing such games, kids will acquire an intimate feeling for the organisms that they are growing.” (2007)

Followed by a the need to establish rules and regulations around these potentially dangerous games, this future of Freeman Dyson is definitely one Amino strives towards.

3.1.2. Bioengineering in the home

Gene swapping is similar in its complexity to a cultural evolution rather than a biological evolution and, although part of our daily life since the days of selective breeding of plants and animal, the scale with which synthetic biology can impact our lives is new (Searle, 2013). In fact, bioengineering is going to have a big impact in personal lives relatively soon. From personalized medicine to cosmetics, materials and food, the average consumer will soon have to navigate a plethora of choices related to synthetic biology and biology.

Already, a visit to the supermarket finds the consumer faced with numberless pro-/pre-biotics, kefir, kombuchas, genetically modified fruits and vegetables like the upcoming apple that doesn’t brown [Fig. 20], certified non-genetically modified produce, synthetically engineered ingredients like Vanilla, etc. It doesn’t stop at the things we eat, however; a trip to the cosmetic
Section 3 **Motivation**

aisle will find as many biologically engineered creams and perfumes. Some of these will even be packaged in bioengineered and manufactured materials [fig. 21].

Companies are currently creating victimless leather grown in vats, fabrics dyed with biological pigments [fig. 22] and lab-grown meats [fig.23] Given a few years, everyone will be able to dress, eat and consume synthetically biological products, and will need to be educated in the subject to make informed decisions.

“Designing genomes will be a personal thing, a new art form as creative as painting or sculpture.” – Freeman Dyson, 2007
Section 4 Related Works

while my project sheds light on the subject, it is not a lamp.

– Basheer Tome, 2015
4.1 Overview

The true pioneers of Bioart have been working to bring the science and its philosophy to light for the last twenty years. Working with living matter, Eduard Kac, Joe Davis, Paola Antonelli have all made or curated artworks that speaks to the future of Synthetic Biology in our daily lives.

For example, Joe Davis, a research affiliate at MIT and Harvard, used E.Coli cells modified to polymerize silica in order to replicate the electrical characteristics necessary to power a radio, thereby creating the first GMO Bacterial Radio [Fig.24]. Antonelli’s curation of Design and the Elastic Mind brought the first living synthetic organism in the white walls of the gallery with the work of Oron Catts at Synbiotica (including Victimless Leather, section 1 [Fig.10]).

Despite the efforts, the cultural view around synthetic biology has yet to catch up with the promises the science offers in tangible forms. Unknown and alien for most, our cultural imagination is tainted with our complex social and medical history with the microbial and this fear is materialized in the stories we tell, and the policies we make.
Section 4 Related Work

Jurassic Park, Gattaca, The Island of Dr. Moreau, The Twilight Zone, Blood Music, Resident Evil, these dystopian, bioengineered zombie/apocalypse fictions are just a few of what our culture has grown up with. Subsequently its no surprise 23andme, a pioneer in getting genetic science into the public sphere, is being policed and restricted.

4.2. Life Sciences

Unphased, designers, artists and engineered have followed in the footsteps of Davis and Kac, while new fiction is friendlier to microorganisms (Fig.28 microorganisms as depicted in anime Moyasimon) Notable and relevant work include Ambio, BentoLab, OpenPCR, Tardigotchi.

Fig. 28 Moyasimon, Anime – Reprinted from Wikipedia, 2015

Fig. 29 Ambio bacterial lamp by Teresa Van Dongen – Reprinted from teresavandongen.com, 2015
Section 4 Related Work

The speculative bacterial product, *Ambio* [Fig. 29], balances two weights and a glass tube of Photobacterium in a saltwater medium. Inspired by bioluminescence found on beaches, this lamp is a “visualization of a research on how to use nature as a source of energy.” (Van Dogen) The bioluminescence takes place when the organism are disturbed, in this case by a gentle push on the tube. The artist, Teresa Van Dogen worked in collaboration with two life science students, B.M. Joosse and R.M.P. Groen of TU Delft. The lamp does not work in a commercial setting and does not contain synthetic organism, but does show a successful creation of desire for products containing bacteria using the design strategies in section 2.

In contrast to *Ambio*, the *BentoLab* [Fig.30] and *OpenPCR* machine [Fig.31] are fully functional consumer products that allows scientist, DIYbio enthusiast, and others to use a portable, personal laboratory. Designed for ease of use and efficiency, the *BentoLab* appeals to scientist and enthusiast who are already acquainted with the lab methods its offers: centrifuging, PCR, and electrophoresis. The *OpenPCR* allows low-cost (650$) thermocycler capacity to control PCR reaction for DNA detection and sequencing. Sold in parts, it is a DIY solution to expensive and restricted lab equipment. *Amino* aspires to the laboratory efficiency of BentoLab and OpenPCR while looking to objects like the *Tamagotchi* [Fig.34] and the *Furby* [Fig.33] in terms of interaction and worldview.
Section 4 Related Work

A recent art piece, Tardigotchi [Fig. 32], houses a living micro-animal, the tardigrade inside a shell. A tardigrade avatar lives onscreen within the object and on a web app. By feeding this digital avatar the real microorganism living inside the shell is also fed. This can be done through a button on the object. An email interface activates a heating lamp, which provides the micro animal with a moment of warmth. The Tardigotchi asks if affection can blossom from a persistent pattern, and from the knowledge that an unseen biological life is the beneficiary of the same attention of the virtual creature.
4.3. Cultural Significance

Inspiration to the Tardigotchi, the Furby [Fig.33] and Tamagotchi [Fig.34] toys of the 1990s are key components in the landscape from which Amino draws and open up a new section of related works, that which inspire form, interaction and cultural significance. Alongside Duchamp’s Boîte-en-Valise, LittleBits and 150-in-One, the anthropomorphic toys helped metabolize culture change.

Tamagotchis, handheld digital pets from the 1990s, are programmed creature housed in a plastic eggs with limited controls. This creature must be kept alive and well through feeding, cleaning and play delivered through the digital interface. The interaction cannot be paused and the level of caring influences its personality, similarly to its robotic cousin, the Furby. The Furby—a robotic toy whose’s personality evolves based on usage—starts with its own “language” and learns english through repeated interactions. With a dozen personality profiles, it reacts to different stimuli, (petting, tail pulling, voice, …) in order to set its reactions. In both cases, this type of interaction and perceived need from the object stimulates desire. In a similar manner to the cultural work Tamagotchies and Furbies did for artificial intelligence and personal robotics, Amino will bring a simplified and resonant experience of synthetic biology to the broad public with its unfailing biological ecosystem.
Duchamp’s *Boîte-en-Valise* [Fig. 35] is a miniature, portable monograph that include limited edition prints of his work. *Boîte-en-Valise* looked at the idea of the precious vs the replicable and served to become a world within a world, a placeholder for the imagined world of surrounding Duchamp’s art. These portable museums confound the boundaries between content and context, container and contained. They serve as both display and subject. Amino inscribes itself in this idea of portable worlds-within-world, of living systems that are at the same time unique and replicable.

*LittleBits* [Fig. 36] is a set of parts that “puts the power of electronics in the hands of everyone.” [littlebits.com](http://www.littlebits.com) It allows people to make electronic circuits and smart objects without the need for soldering, wiring or programming. The system is based on a series of actuator, sensor and power modules that snap together with magnets. Their appealing design and ease of use serves to create desirability and demand for electronics in a non-traditional market, in a similar manner their predecessor, RadioShack’s electronic playground *150-in-One* [Fig. 37] did for the earlier generation.
These works all served to inspire or inform the space in which Amino lives; some are applied pedagogic design, while some are art. Amino is intended to straddle between the two as an object for use and speculation.
Section 5 Design
5.1. Purpose And System

*Amino* is a design driven mini-lab that allows users to carry out a bacterial transformation and enables the subsequent care and feeding of the cells that are grown. Inspired by Tamagotchis, the genetic transformation of an organism’s DNA is performed by the user through guided interactions, resulting in their synthetic organism for which they can care like you would a pet. Amino is developed using low cost ways of carrying out lab-like procedures in the home and is packaged in a suitcase-sized continuous bioreactor for cells.

Design’s fundamental task is to help people deal with change, interpreting science and technologies into objects and experiences that can be assimilated into life, art, and culture. Amino has the potential to help shift public perception of Synthetic Biology and get non-traditional audiences excited about taking part in this field.

Biotechnology is going through a transition from being centralized to being distributed, and *Amino* will facilitate this transition. Amino is at the forefront of this transition and slots into the emerging ecosystem as it enables anyone to run DNA programs that are created by other DNA creation companies. *Amino* could be the Apple II for synthetic biology, with the exception that you can’t create DNA programs with it, you can execute them, control the outcomes, and in the long term, perhaps extract end-products from it.

5.2. User

The projected user for version 1 of *Amino* is being looked at as middle-school and above, with an interest in new consumer design and technologies, consumer of gadgets and collectible kickstarter inventions, and the DIY (i.e. Arduino, Scratch).
Section 5 Design

5.3. Materials and Methods

5.3.1. Overview

Fig. 38 Amino’s user-facing components
5.3.2. Aesthetics / User Experience

*Forms and textures can be manipulated into distorting the limits between the hyper-reality and everyday life, evoking a world of fantasy and fiction.* - Dunne & Raby

Through the different design theories explored in the background section, *Amino* will engender desirability and attachment, encouraging the user to interact often and overcome preconceptions.

The design of *Amino* focuses on intimacy and curiosity. By creating a moment of ambiguity and anticipation, the user is invited into a relationship with the object that allows for the inclusion of the user psyche and narrative. By growing your own colony(ies) through decisions and happenstance, each journey will be different and unscripted, and these types of interactions coupled with anticipation of events, will heighten the sense of intimacy thereby facilitating subject-object empathy and an emotionally durable relationship. (Chapman, 2005)

The human brain engages with objects emotionally through a three level structure: visceral, behavioral, reflective. As an object and experience, *Amino* will interact on the visceral level through its material and formal qualities, and will connect with the user on a behavioral level through playful, unscripted interactions and narrative. It will create enchantment through the initial sense of curiosity, wonder and possibility, capitalizing on the idea that the less humans understand the phenomenon that yields an action, the more likely they are to impart on it the sense of wonder.

In order to fulfill the reflective criteria for emotional engagement, *Amino* will serve as symbolic of concerns and exploration in synthetic biology, allowing the user a sense of participation in a current debate; as extension of our bodies, objects are associated with social identity. Over the past two centuries, people increasingly have defined themselves through the products they buy and use. The American ‘standard of living’ is embodied in an endless inventory of objects; these define the owner through their symbolic nature.

With this structure, *Amino* will engender emotional sustainability and desire. This connection, and the learning experienced throughout the interaction with Amino, will allow users to better understand the possibilities and risks associated with engineered biological systems, and assist in the creation of a space for microbial consumer products, moving past our complex history.
5.3.3. Organism

Fig. 39 Violacein production in E.Coli cells

Fig. 40 Violacein production in E.Coli cells in a liquid culture (Left). RFP production in E. Coli cells in a liquid culture (Right)
Section 5 Design

Fig. 41 Violacein production pathway in E.Coli cells

Fig. 42 Amino's transformation interface
Section 5 Design

The organism used for the prototype trials of Amino is competent E.Coli cells that are transformed to produce violacein, which results in a visible purple colour in the bacterial colonies. This purple colour is proportional to the amount of tryptophan present in the media and can be modified by the user.

The organism is provided by Synbiota, as part of their Rainbow Factory kit. In the case of Amino, the organism is grown in a liquid culture of LB Broth and not on an agar plate.

5.3.4. Transformation

A transformation is the process of putting DNA plasmids into bacteria. A salt solution, the transformation buffer, allows the DNA to enter the cell membrane and, by heat shocking the bacteria, this will allow the DNA to be taking up by the cell. The growth media will then allow these cells to recover and multiply. The following protocol describes the step by step instructions to add the Violacein producing plasmid into the competent E. Coli cells. Figures [43 to 48 illustrate the process in Amino. Larger images can be found in the Appendix.]

5.3.4.1. Transformation Protocol using Amino

Prepare cells
1. Pump the cells growing in the filter chamber inside the device into the micro-centrifuge tube by pressing the button.
2. Take the tube and secure it onto the centrifuge. start the centrifuge by pressing the button. The timer is set for 1 min.
3. Remove the tube from the centrifuge and, using the first pipet (100 μl), discard the liquid from the pelleted cells.

Add DNA
4. Add the plasmid DNA using the second pipet (100 μl) into the transformation buffer tube. Wait for 10 seconds
5. Add the plasmid DNA and buffer solution to the micro-centrifuge tube containing your pelleted E. Coli using the second pipet (100 μl).
6. Incubate at 4°C (“on ice”) for 30 minutes. The timer will start automatically when the tube is inserted.

Heat Shock
7. Place the E. Coli tube in the 42°C holder for 90 seconds. The timer will start automatically when the tube is inserted.
Section 5 Design

8. Immediately put on 4°C ("on ice") for 5 minutes. The timer will start automatically when the tube is inserted.

Recovery

9. Add the transformed bacteria to the recovery tube containing 250 μl of LB using the third pipet (100 μl).

10. Pump back into the filter chamber inside the device to incubate at 37°C for 40 minutes by pressing the button.

Grow overnight

11. Wait for 12 to 24 hours while the cells incubate. Once ready they will be pumped through the culture chamber in the bio-reactor for continuous culturing.

Fig. 43 Amino’s transformation Step 1

Fig. 44 Amino’s transformation Step 2

Fig. 45 Amino’s transformation Step 3
5.3.4.2. Built Parts

The transformation in Amino relies on several parts build specifically for the system. The centrifuge, heating, cooling, incubating and in/out pumping of the cells are custom built using DIY Electronic techniques.

The centrifuge is build using a fan blade attached to a 1200rpm DC motor. This spins at a rate high enough to pellet the cells. [Fig. 49 & 50]
Section 5 Design

The heating and cooling modules are based off Thermoelectric systems. By using a peltier controlled by Arduino, the necessary temperatures of 4°C, 42°C and 37°C can be achieved. For heat shocking, the peltier is layered on top of a fan and heatsink module while a machined aluminum sheet is affixed to the top of the peltier to hold the microcentrifuge tube. The cooling module also contained a vibrating coin motor to keep the cells in suspension during the “on ice” time. [Fig. 51 & 52]

In order to pump the cells in and out of the continuous culture system for transformation, Amino uses Arduino controlled micropumps to move the cells suspended in media. [Fig. 53 & 54]
Section 5 Design

5.3.5. Continuous Culturing

The bacteria, once transformed and incubated overnight, will be pumped into a chemostat system that allows for continuous culturing. Based on existing system principles [Fig. 55 & 56], Amino’s bioreactor system includes pH and temperature sensors connected to gauges for the user to monitor as well as the to the controller for the autonomous monitoring of media flow. The system has buffer, tryptophan and glucose inputs controlled via push-button by the user and autonomous waster removal. The diagram in figure 57 reviews all the user inputs on the desktop interface. Figure 58 reviews the overall system connections.
Section 5 Design

Fig. 57 Culturing Care Interface Amino

Fig. 58 Continuous Culturing System Amino
Section 6 Evaluations
Section 6 Evaluations

6.1. Design

6.1.1. Interface

With the need for a perfect balance between Ludus and Paida, between didactic and inspiring, Amino’s interface is designed in response to multiple constraints. The interface requires safety (minimal liquid handling, sturdy containers), simplicity (easy to follow, easy to perform) and attractiveness (fetching layout, desirable materials, engaging for the imagination).

As the organisms and chemicals are rated biosafety level 1, attention is payed to the housing, discard and handling of liquids, sharps—pipet tips— and cells. Glass sealed vials accessed through pumps and micro controllers have been selected for most liquids. In the case of liquids that need direct handling, this is kept to a minimum, and pipets and gloves are provided, along with a discard container. This ensures that Amino will be a safe environment to perform DNA transformation and grow cultures by beginner and more advanced users.

Simplicity was directly impacted by the science behind the transformation and growth of organisms as well as the necessary safety requirements for use in the home by beginners. This was achieved by separating the Transformation section and the Care / Continuous culturing section of the bioreactor. This can be seen in the last two major iteration of Amino, [Fig. 62&63] after user feedback (Human-Centered Designer A. Hope, Hardware Interface Designer B. Tome, BioTechnologist Dr. J. Pahara). The final linear layout of the transformation section of Amino speaks to ease of use and the desire for a self contained system with minimal literature. Often heard in biohacking workshop are the classic “I lost my DNA tube”, “Where’s the pipet?”, etc. which speaks to the need for self contained units when in a out-of-lab setting. In Amino, the moving parts are limited to three pipets that are positioned in holders next to the step in which they need to be used. The linearity, from left to right, is supported by a step identification system which lights up the area / vessels and button that are needed for the step. Once the step is completed, the next section lights up to use.

In terms of attractiveness, there was a definite trade off and balance to be achieve with ease of use. The size was a big factor, where a smaller device would have a better desirability and “enclosed world” feeling, but the ease of use was majorly compromised. The final size uses all the real estate provided while finding the similar, tried and tested format of a laptop / suitcase/ record player. The layout of vessels and components are related to the need for simplicity as well, but are arranged to give off a playground / fairground feel, which is augmented by the use of colourful buttons in the last prototype , figure 63.

Following are a series of the major iterations of the interface design. Laser cut files can be found in the Appendix.
Section 6 Evaluations

Fig. 59 First Prototype Amino

Fig. 60 Rendering with Electronics Amino
Section 6 Evaluations

Fig. 61 First Major Interface Prototype Amino

Fig. 62 Second Major Interface Prototype Amino
Section 6 Evaluations

Fig. 63 Third Major Interface Prototype Amino

Fig. 64 Fourth and Final Major Interface Prototype Amino
Section 6 Evaluations

6.1.2. Materials

In order to respond to the criteria above and maintain the balance between effective and playful, materials were considered and evaluated. The final prototype designed in terms of this thesis is made up of glass vessels to house the culture and chemicals, plastic buttons and cover, aluminum centrifuge blade and detailing, rubber pipet tips and a birch wood base (further iterations of molded plastic and rubber are considered for a commercially-viable version of Amino, as will be discussed in Section 7).

Throughout the design of Amino, several materials and layouts were considered, prototyped and tested against durability and desirability. Wood, plastic, aluminum were all made into physical prototypes and tested with users for desirability. Each material was tested for liquid resistance and durability independently of users. The chosen prototype of a sealed wooden base and glass vessels fulfill both criteria. The following figures reflect major material explorations of Amino.

Fig. 64 Wood samples (Left: Stained Maple, Middle: Rosewood, Right: Mahogany.)
Fig. 67 Aluminium

Fig. 68 Rosewood and Aluminum
Fig. 69 Maple ply and White Acrylic

Fig. 70 Birch
Section 7 **Conclusion**
Section 7 Conclusion

7.1. Future Work

7.1.1. Development of the System
In terms of prototype development, Amino includes an initial sensor network, miniature pumps as well as a refined version of the user interaction for both the transformation and the bioreactor components of the system. The instruction manual is still in development. Following user testing, the system will be refined and the Arduino boards replaced by custom electronics. Optical Density and other sensing will also be added. Further user studies will be required in order to take the system into the commercial product realm.

7.1.2. Commercial & Other Applications
Currently Amino is designed and developed as a stand-alone product for deployment/sales in educational markets (STEM, high school, university, DIYbio, cyber-learning). While synthetic biology, life science, and biology are a fraction of total STEM funding, in 2011, STEM funding in the US alone reached $3.4B. Education can be an initial market focus to both validate Amino and earn short term revenues. Because Amino is a stand alone “mini” bioreactor, it could be extended to other niches like counter-top bio-reacting.

7.2. Concluding remarks
To disseminate new technologies and sciences to mainstream audience in order to facilitate conversation and transparency is the fundamental role of design. These new technologies and sciences are often poised to create change in people’s daily lives and, as such, require public acceptance and understanding. Synthetic biology, a new field in the life sciences that allows for the creation of new organisms and biological systems is particularly impactful, and has been compared to the industrial revolution in terms of predicted impact. (Wohlson, 2012) In looking at how can synthetic biology find a place in the home and explore public acceptance of synthetic biology, Amino has been created to allow direct interaction with microorganisms. By introducing the idea of a fully functional mini-lab for synthetic biology to a non-traditional audience and framing it in a playful, desirable way in both aesthetics and interaction, this thesis shows the potential for transformative design in the field of synthetic biology.

The contribution of this thesis are:
1. An overview of the design space around Synthetic Biology
2. Establishing a worldview for biology, synthetic and natural, as a living system we can experience and interact with.
3. A fully-functional DNA transformation station that can be used in the home
4. A small scale personal bioreactor that allows for user interaction with the culture
Section 8 **References**
References


Section 9 Appendix
Violacein Datasheet

Product Information

Violacein
from Janthinobacterium lividum

Catalog Number V9389
Storage Temperature 2–8 °C

CAS RN 548-54-9

Product Description
Molecular Weight: 343.33
Molecular formula: C_{29}H_{33}N_{2}O_{3}

Violacein, a violet pigment, is an indole derivative produced by different bacterial strains such as Chromobacterium violaceum, Janthinobacterium lividum, Chromobacterium lividum, and Pseudalteromonas luteoviolacea. This pigment possesses antitumoral, antibacterial, antiproliferogenic, antineoplastic, and antiviral activities. The antiprotozoal activity of violacein is also detected for its derivative deoxyviolacein. Violacein and its \( \beta \)-cyclodextrin complexes are found to trigger apoptosis and differentiation in HL60 leukemic cells. Violacein cytotoxicity in HL60 cells is preceded by activation of caspase 8, transcription of NF-κB target genes, and p38-MAPK activation, which resembles TNF-α signal transduction in these cells. These properties make violacein a member of a novel class of cytotoxic drugs mediating apoptosis of HL60 cells by way of specific activation of TNF receptor 1.

Purity (HPLC):
violacein and deoxyviolacein >98%
violacein >95%

Precautions and Disclaimer
This product is for R&D use only, not for drug, household, or other uses. Please consult the Material Safety Data Sheet for information regarding hazards and safe handling practices.

Preparation Instructions
Violacein is insoluble in water. It is soluble in alcohols such as methanol and ethanol, and soluble in acetone.

Storage/Stability
Store the product at 2–8 °C. Under these conditions, the product is stable for two years.

References

KAA,DWF,MAM 10/08-1
Transformation Steps in *Amino*
Lasercut file, Final Prototype - 12x10x5.25 in

Bottom - Wood
Base

Sides - Wood

Top - Acrylic
Cover

Sides - Acrylic

Interface - Wood
Top