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Load-a-Dose: An Automated Insulin Loading Device

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Executive summary

Diabetes is a disease that affects absorption of insulin, a hormone in the human body that regulates glucose. A lifestyle-changing complication of diabetes is impaired vision, which may be a result of degenerative eye diseases like diabetic retinopathy. For the elderly, impaired vision combined with limited dexterity can make current self-dosing methods challenging, thus increasing the risk for dosing errors. Resulting improper insulin management can have serious consequences including disorientation, light-headedness, coma, and even death. Current methods for regulating insulin, including insulin pumps, pens, and syringes with vials, generally do not cater towards patients with sensory impairments. Even the device accessory, Count-A-Dose, which is marketed to the blind requires significant audio and tactile feedback to manually count insulin units, making it quite unpopular within the blind community.

To address the unmet need to accurately dose insulin for diabetic patients with low visual acuity and dexterity, this report focuses on the design of an accessory device for drawing insulin into syringes. By creating a repeatable, automated insulin drawing process, individuals with visual and dexterity-related impairments will have a lower risk of health complications and have an overall improved method for diabetes management.

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The Need

Introduction

Diabetes is a chronic disease characterized by the insufficient production of the hormone, insulin, which affects an estimated 422 million adults worldwide [1]. Insulin is important for normal bodily function because it regulates the amount of glucose, or sugar, present in the blood stream. Between 2014 and 1980, the global percentage of diabetics nearly doubled, presumably because of the increase in obesity rates [1]. Obesity is a risk factor of type 2 diabetes, the most common form of diabetes, where the body develops resistance to insulin, outstripping the body's ability to absorb insulin. In comparison, type 1 diabetics have autoimmune destruction of insulin producing cells in the pancreas which halts insulin production.

Without proper management, diabetes can cause sugar imbalances in the body which have a range of serious side effects. Hyperglycemia, the state of having an excess amount of blood sugar in the body usually without symptoms. Exposure to high blood glucose overtime causes fatigue and both weight loss and dehydration as excess sugar is released in urine. In comparison, hypoglycemia is when blood sugar is too low. This can lead to dizziness, headache, muscle weakness, and unconsciousness [2]. Ultimately, the danger associated with these sugar imbalances contribute to complications and death. Diabetes the 7th leading cause of mortality in the United States in 2015 [3].

Figure 1: A scene as viewed by someone with normal vision (top) and by someone with diabetic retinopathy (bottom) [4]

A prominent consequence of diabetes is the deterioration of vision over time due to diabetic retinopathy (DR) [4]. The altered vision caused by these diseases (figure 1) increases risk for insulin dosing-related errors. For older adults specifically, vision loss is twice as likely to be reported than in younger populations [5], and there is an increased susceptibility to dexterity challenges [6]. These impairments in combination increase likelihood for emergency diabetic medical intervention; Adults aged over 75 have double the rate of emergency visits due to hypoglycemia when compared to the general population [7], and adults aged over 65 make up 40% of insulin-related hypoglycemia and errors [8]. These hospital visits not only negatively affect the aging population but also represent 43% of the medical cost of diabetes for the US , a total of $76 billion [9].

The remainder of this report will be focusing on the diabetic population over 65 (hereby after noted as geriatric) with visual and tactile impairments.

Need Statement

Although insulin has been commercially produced since 1923, there has been little innovation on insulin delivery methods designed for individuals with limited dexterity or vision [10]. For diabetics who have such impairments, including the dark spots associated with diabetic retinopathy, common insulin delivery methods can be quite challenging. Both insulin pens and insulin vials with syringes require visual confirmation for dosing. Thus, it is our aim to develop **a**

way to prevent the mis-dosing of insulin for geriatric individuals with visual or dexterity impairments to improve diabetes management.

This aim has been developed based on three critical assumptions: the target population is not highly active and will subsequently load insulin at home, insurance consistently covers insulin vials (described in detail in a later section), and that visual and tactile impairments are addressed similarly. At-home insulin loading is a part of personal diabetes management, the largest and fastest growing market for insulin delivery devices [11]. Even though doctors and other healthcare professionals are vital resources for proper management of diabetes, interactions with this healthcare team are limited to scheduled visits and/or emergencies. On this basis, developing a tool for independent insulin administration will help improve daily care and hopefully limit the need for medical emergencies associated with improper dosing.

Current Solutions

There are a variety of insulin delivery devices currently on the market including insulin vials and syringes, insulin pens, and insulin pumps. Device selection between these popular options is highly dependent on insurance coverage, individual needs, and physical capabilities.

Insulin vials and syringes are the most common and most traditional insulin delivery method. The first-ever human insulin shot was delivered by syringe in 1922 [12]. Today in the United States, more than half of all insulin is still delivered via syringe by both physicians at hospital setting and diabetic patients [12]. Syringes are disposable, intended for one time use, and are commonly preferred by users due to its affordability.

Figure 2: example of insulin pen [12]

While syringes still dominate the insulin market in the United States, insulin pens are growing increasingly popular [13]. Pens come in two varieties: disposable prefilled pens, and reusable pens that take a prefilled cartridge of insulin. The dial at the base of the pen is rotated to select dosing amount (figure 2). For much of the world, insulin pens have been the most popular insulin delivery method [12]. However, they are difficult to obtain, often requiring preauthorization from a clinician, and are highly dependent on year-to-year insurance coverage changes.

Figure 3: example of insulin pump [11]

Figure 4: Count-a-Dose device [15]

The most expensive of the standard delivery methods is the continuous subcutaneous insulin infusion method, commonly known as an insulin pump (figure 3). The pump mimics how a normal pancreas functions by releasing insulin slowly and as needed into the body. Rapid-acting insulin enters the user’s body through a small, flexible tube (catheter), which goes into the user’s abdominal subcutaneous fat and is taped in place. The device is programmed with a clinician’s guidance. Over the course of the device’s life, expenses can add up to $6000, with monthly supply costs up to $300 [14].

To target diabetic patients with low visual acuity, the Count-a-Dose syringe accessory device was created (figure 4). The device assists with filling 50-unit syringes by providing tactile and audio feedback to count drawn units of insulin. It holds two insulin vials so that different types of insulin can be mixed (if necessary), and makes a distinct click that can be both heard and felt with each unit of insulin drawn into the syringe [15]. However, according to the Department Services for the Blind, the Count-a-Dose device is difficult to use and is not popular in the blind community.

In general, the biggest shortfall of current insulin delivery solutions is accessibility, both in usability and financially. Insulin delivery methods generally cater to a narrow, ideally developed ability spectrum reliant on acute vision and finite motor control or dexterity. Considering that over 25% of the US population 65 and older are diabetic, there is significant room for technological advancements that accommodate common conditions including arthritis, vision loss, and reduced strength [16]. Additionally, many insurance companies require lengthy, demanding approval processes before they will cover prescriptions of an insulin pump or pen. This places financial burden on the individual which may prevent access to either delivery methods entirely.

In comparison to insulin pumps and pens, insulin vials and syringes are inexpensive and simple in design. Because all insurances cover insulin syringes and vials for diabetics, this proves to be the most inexpensive and easiest to obtain delivery method. Additionally, due to the simple nature of syringes, there is room for innovation with regards to device accessories like the previously mentioned Count-A-Dose. Thus, we have chosen to pursue a solution specific to syringe and vial insulin delivery.

Engineering Design Constraints

To design a solution for geriatric individuals with visual and dexterity-related impairments, we scoped five core functions not holistically addressed with commercially available insulin delivery products. These core functions were developed in conjunction with clinical mentor feedback to articulate key user requirements. The following table summarizes the selected four functions and includes relevant standards and measurables to meet each function (table 1):

Core Function	Measurable	Relevant Standard
Accepts all insulin types	Number of compatible insulin types and brands	
Accurate dosing	Accuracy of insulin draw vs. input quantity (linearity test)	ISO 14971- Application of risk management to medical devices
Automatically draws insulin consistently	Variability of repeated doses	IEC 60601- Medical electrical equipment
Accessible for impaired vision	Decibel level of audio output	IEC 62366-1- Application of usability engineering

Table 1: Summary of core functions and methods for evaluating device compliance [17]

Accepts All Insulin Types

Insulin prices and brand accessibility are highly variable year to year, which places a burden on diabetic patients during times of change in the general market or in individual coverage. To accommodate for brand and insulin type variability, we needed to design an insulin delivery solution adaptable to a wide variety of insulin vials. This is the primary motivation for evaluating the breadth of compatible insulin types and brands; by creating an interface that universally accepts insulin vials, the user does not need to be restricted to specific insulin types or brands.

Accurate Dosing

Some common insulin delivery solutions, including the insulin pen, have history-proven success records which support their popularity. To compete with such current devices, we needed to make a device that falls within a predetermined accuracy range, as well as one that is comparable to the gold standards of today's technologies. Listed in ISO 14971 are processes for risk management related to medical devices, which serves as a formal outline for overall safety precautions. However, since there is not a standardized required insulin delivery tolerance, we chose a metric of ±1 unit, as advised by our project mentors. This ensures that our device would produce safe dosing without requiring visual confirmation by the user. We evaluated this metric by performing a linearity test to map programmed unit inputs to visually inspected outputs, as read along the syringe tick marks.

Automatically Draws Insulin Consistently

Accuracy and repeatability are two dependent but equally important design considerations to ensure user safety. Because the proposed solution would ideally replace current insulin dosing methods, or fill a critically missing aspect of an individual's diabetes management program, the proposed device had to withstand cyclical use without affected performance. IEC 60601 includes standards for device use "in the home healthcare environment" which requires implementation of precautionary safety measures to ensure repeatable results, and inclusion of failure modes to prevent dosing inaccuracies during predicted device shortfalls. For Load-A-Dose, we wanted our prototype to have less than 10% error with repeated trials.

Accessible for Impaired Vision

Current insulin dosing solutions are not holistically accessible to diabetics with visual and dexterity-related impairments. To meet the needs of individuals with these physical limitations, we needed to co-design a solution with experts who understand the needs of our intended audience. This inspired the design specification for audio feedback and instructions to meet or exceed 60 dB, the average noise level of a restaurant, office, or environment with background music decibel [18]. Traditional insulin delivery methods rely on visual confirmation during the dosing procedure, so this design specification addresses an alternative source of user feedback perceivable by individuals with impaired vision.

Design and Prototyping

Initially, we had several proposed design concepts within the realm of insulin syringe and vial accessories. Using a Quality Function Deployment (QFD), we ranked 6 designs against design specifications and customer needs (Appendices A, C). The second place solution, noted as the "Count-A-Dose Adapter", was an accessory for the already developed accessory device, Count-A-Dose. This solution would eliminate the need to keep a mental count of dial rotations, thus reducing susceptibility to miscount and ultimately misdoes by automating the dial turn count. Through voice recognition, a dose amount would be spoken to the device, and an appropriately timed hard stop would allow the user to dial to their intended amount. However, guest speaker and current patent attorney, Andrew Laughlin, said this concept would have significant intellectual property barriers and would require licensing from the device maker, Prodigy, thus rendering it not appropriately novel.

The third highest ranked concept were a series of flow regulators which would monitor insulin input and output of both a vial and syringe. This concept would have been relatively simple and placed high emphasis on accuracy, therefore highly enabling those with visual impairments. However, there was little consideration for mechanical assistance for the act of drawing the syringe plunger, which does not address the previously stated needs of individuals with limited dexterity. For this reason, we decided there was not a viable solution.

Current Design: Load-A-Dose

Our top ranked design concept, an automated insulin loader, known as Load-A-Dose, was chosen because it incorporates a two-fold approach to meet the needs of our chosen population- the device prioritizes both accuracy and usability. Load-A-Dose was designed in conjunction with need experts from Department Services for the Blind (DSB) and the Washington Braille. Their feedback focused on creating a simple user interface (UI); this included to minimize the number of buttons, increase button spacing, emboss buttons, have an accessible instruction (like audio feedback), have high color contrast, and to have device markers that can indicate directionality (i.e. to differentiate top versus bottom). Collectively, these suggestions mimic the design of the Talking Book, a device designed for the blind to access books without braille (figure 5).

Figure 5: a standard (left) and advanced (right) Talking Book [19]

The Talking Book motivated many aspects of our prototype, most of which were implemented to simplify the device layout. First, we discarded our initial idea of a full number pad for dose inputs to instead integrate a two-button up or down method. We also set a preprogrammed dosage of 10 units upon the startup of Load-A-Dose, which can then be modified by increments of 1 unit. This will prevent prolonged button pressing for repeated doses. Future iterations will have a memory storage to quickly recall previous entries.

Using feedback from various stakeholders, the current prototype of Load-A-Dose has been designed with several key features. The exterior casing of the device was 3D printed to house four differently shaped and embossed silicone buttons, an LCD readout screen, a speaker, and a compartment for an automated vial holder (figure 6). The entire unit sits vertically in a 3D printed table stand to promote proper vertical alignment of the syringe relative to the vial. A magazine loading device attaches to the main unit to assist with syringe loading (figure 7). A separate device, known as VerifEYE, is a radiofrequency identification (RF ID) reader that audibly and visually verifies insulin vial contents when labeled with an RF ID tag (see Appendix D).

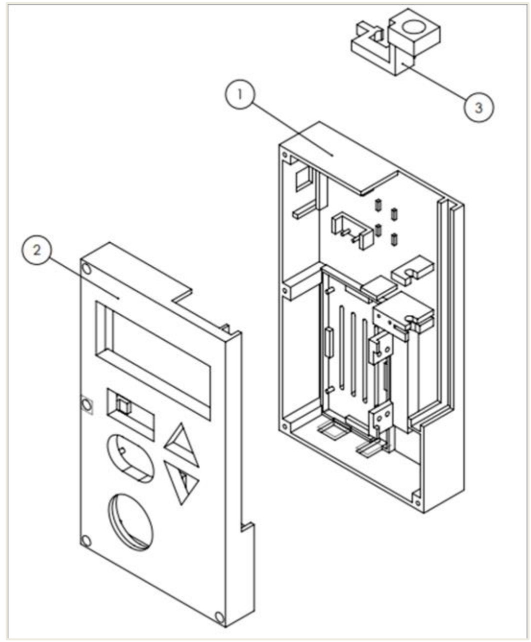


Figure 6: the front face (2), back face (1), and vial holder (3) of the Load-A-Dose housing unit

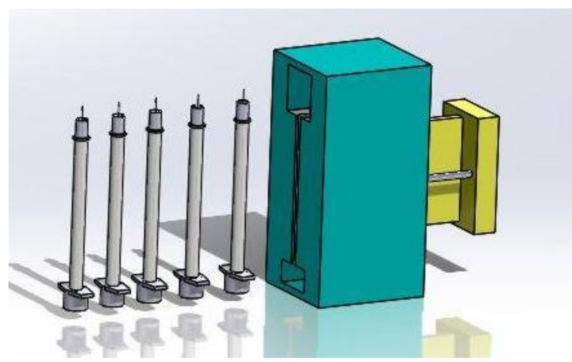


Figure 7: a magazine-style loading device to assist syringe placement

The current prototype is powered using an Arduino Mega to control all automated components (see wiring schematic in Appendix D). The primary function of drawing insulin is conducted using a linear actuator, or threaded rod slider and stepper motor, to move a syringe plunger relative to a fixed shaft. Air must be dispensed into the insulin vial prior to dosing to prevent formation of a vacuum. Thus, the vial holder of Load-A-Dose has also been automated using limit switches so that the vial will be lowered onto the syringe needle to allow for initial air drawing and dispensing. The insulin vial is lowered onto the needle, an initial 2 unit priming is administered to remove all air, and then the input insulin dose is drawn. The properly dosed syringe is then removed manually. Presently, the syringe comes out uncapped, however future iterations will automate placement of the original protective cap back onto the needle tip. A visual description of the Load-A-Dose process can be found in Appendix D.

Next Steps

Future prototype iterations will be driven by stakeholder feedback and user testing. The following table includes several design additions listed by intended chronological order (table 2):

Design Component	Motivation
Magazine of syringes	Integrate device to ease syringe loading into the device with a handheld assistive tool
Vial level detection sensor	To prevent insulin drawing unless the vial is vertical (i.e. the insulin level is parallel to the top face of the device) and to ensure that there is sufficient insulin

Weight verification of dose	Ensures that sufficient insulin has been drawn; acts as a second check to prevent drawn air
Vial sterilization step	Required safety precaution

Table 2: Summary of future Load-A-Dose modifications

Engineering Analyses & Testing

The primary evaluations of Load-A-Dose have targeted user safety and usability. This has been achieved using the previously described four design specifications: accuracy of insulin inputs compared to actual dose drawn, dose repeatability, audio output decibel level, and the number of compatible insulin configurations. Since insulin vial sizes are relatively standardized to our knowledge, we have omitted this measurable in the following section based on the assumption that our vial holder and gasket combination will appropriately hold all insulin types. Collectively, these measurables convey the general efficacy of our prototyped device and have been used to inform future iterations.

Insulin Input Accuracy

To quantify device accuracy, we repeated a randomized trial of six inputs (5, 10, 20, 30, 40, and 50 units) five times (figure 8). A single user entered each quantity using the automated process, then visually assessed the output using increment lines along the syringe. Data was recorded to 0.5 of a unit, the assumed minimum feasible accuracy given the experimental setup. These results produced an R^2 value of 0.996 for a linearity test, indicating that our device produces outputs matching inputs almost perfectly linearly.

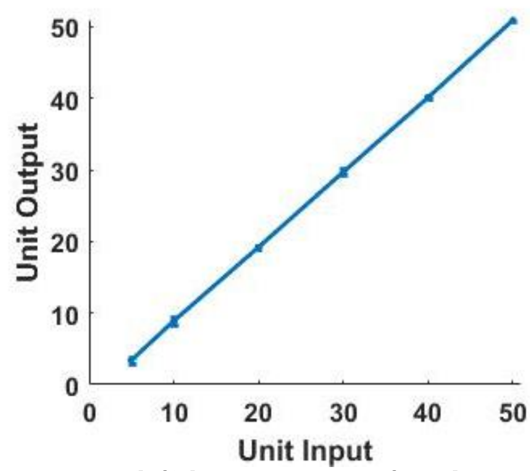


Figure 8: (left) linearity testing of Load-A-Dose for 5, 10, 20, 30, 40, and 50 unit inputs with error bars

Throughout the duration of this test, Load-A-Dose met our prescribed ±1 unit tolerance for all inputs except 5 units. For 3 out of 5 trials for the 5 unit input, Load-A-Dose produced a syringe output of 3 units. This thrice deviation of -2 units implies that our mechanical system could be accurate to the given specification only above 5 units. To address this limitation, we will refine the accuracy of our linear actuator and mechanical system. We additionally will research what the minimum necessary dose value should be for our given population of geriatric individuals with diabetes.

Dose Repeatability

In conjunction with accurate dosing, Load-A-Dose must be consistent in its delivery. Using the same experimental setup as described above, we analyzed the percent difference (or percent error) of our data to evaluate the variability associated with each tested input. Figure 9 depicts these results using the following equation:

$$\% \; Error = \left| \frac{Output - Input}{Input} \right| * 100$$

As seen in the accuracy plot above, we had the greatest variability in percent error for the 5 unit input; this ranged from -40% to -20%. The second largest variability range was associated with the 10 unit input, having ranged from -20% to -5%. Although the magnitude of these differences is relatively large, insulin delivery is safer to err on under dosing rather than overdosing. This is because the body will have hyperglycemic side effects that are much more difficult to manage than those associated with slight under dosing, or hypoglycemia.

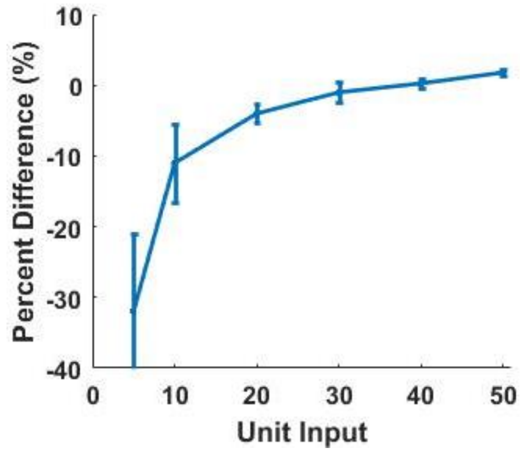


Figure 9: Evaluation of percent errors with respect to unit inputs

These results depict that we failed to meet the criterion of having less than 10% error per unit input. However, above the input of 10 units, the percent error converges about zero, which shows promising preliminary results for our current actuation strategy. Future device iterations will target the accuracy of inputs for 10 units and below.

Audio Output

To allow for use in environments with background noise, we created audio files that had a minimum decibel level of 60 dB, as seen in figure 10. These audio recordings provide audible feedback to the user during device interaction, and thus are critical for confirming proper device use. Future device iterations will allow for adjustable audio feedback to accommodate for louder or quieter environments, as well as the option for a headphone jack plug in.

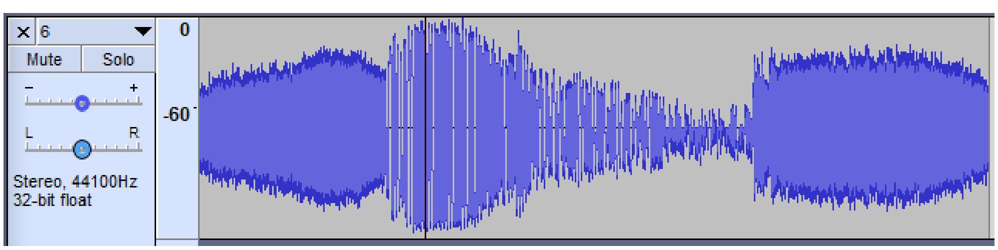


Figure 10: Sample audio file of Load-A-Dose audible feedback

Intellectual Property (IP)

Because diabetes management has been a heavily researched area of medical care and device development, there is significant limitation for novel innovation. With that said, we received help from experts at the Washington Research Foundation (WRF) to help put together a family landscape to better understand potential IP hurdles. Load-A-Dose's primary source of inspiration, Count-A-Dose, is no longer actively patented and therefore does not restrict design creativity within the device accessory platform. To inform potential avenues for novelty relating to Load-A-Dose, the following analysis depicts present patents and prior art, evidence that similar technology has already been disclosed [20].

Traditional Syringes and the Syringe Pump

In 1988, a surge of patents were filed on all aspects and types of single-use syringes [21]. However, since over 20 years has passed since then, these patents are no longer active. This is promising for the business opportunity relating to Load-A-Dose because there will be less IP restrictions on developing proprietary syringes for the proposed syringe magazine. For this loading mechanism to be successful, it would require prepackaged, sterile syringes, rather than a typical purchase of single syringes.

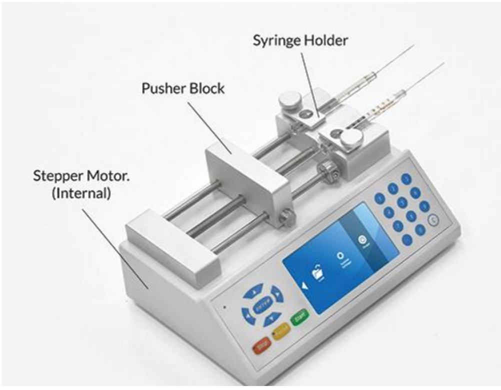


Figure 11: schematic of the components of a syringe pump [22]

From a system standpoint, syringe pumps are mechanically very similar to the Load-A-Dose design (figure 11). The pump uses a linear actuator to control various parameters, including fluid input or output rates and pressures, with high accuracy. The drawing or dispensing of fluid from syringes is preprogrammed to power a stepper motor nearly identical to the Load-A-Dose prototype. However, syringe pumps are predominantly used in research settings, and lack an accessibly designed user interface like that of Load-A-Dose for users with functional limitations. Our design's mechanism is not novel, but the combination of audio and visual instructions and feedback, simplified buttons, and streamlined UI could be.

Keys as a Device Accessory

Defined as an "accessory device to a piston hypodermic syringe", the XTRACT Solutions Syringe Keys (Keys) have been a source of inspiration to develop the Load-A-Dose design [23]. The Keys themselves are a series of plastic clips calibrated to act as hard stops for XTRAXT syringes (figure 12). Although this is a simplistic mechanism for dosing accurately, the patent literature for the Keys well defines processes for validation testing that is relevant for future commercialization. Additionally, the Keys FDA application references Count-A-Dose as a predecessor, which correlates its design back to our initial project motivation [23].

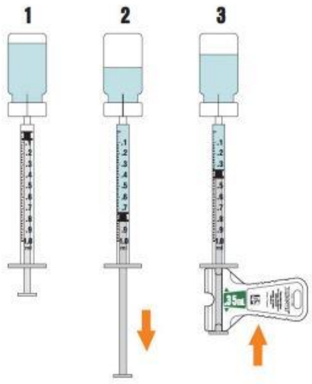


Figure 12: Process of using the Keys [23]

Injection Device with Audio Output

A device designed for the visually impaired to inject medication was filed in 2014. This solution provides audio and visual feedback to inform the user of contents drawn, as well as the amount of medication left inside. A needle is connected to the device housing, and a pharmaceutical cartridge is stored within.

This device presents strong IP hurdles due to the similar input and output methods but does not automate the act of drawing medication. Furthermore, this device is used for accurate injections, and does not load an internal syringe. These differences could be crucial when moving forward with Load-A-Dose patentable claims.

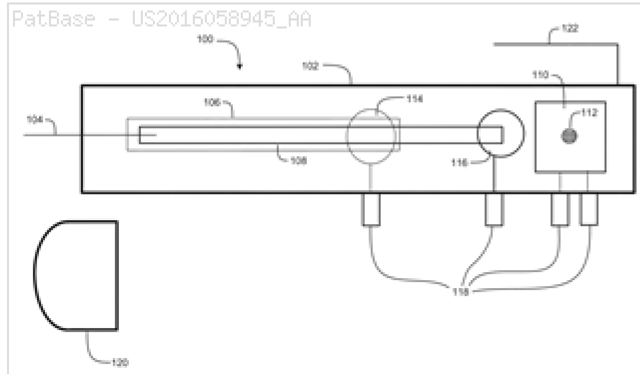


Figure 13: schematic of the device for the visually impaired which provides audio outputs [24]

Kit for Loading and Disposing of Syringes

Approved since 2002, a patent out of New York covers a method and device for dosing a syringe using a calibrated external housing. This housing assists in protecting the user from the sterile needle and magnifies the unit lines along the syringe shaft to aid with accurate dosing. A safety step then moves the needle after contamination into a protected sharps housing.

Some of the main differences between this device and Load-A-Dose is the lack of user feedback and the limited number of safety mechanisms for ensuring accurate medication draws from the vial. This device still relies on visual user confirmation for proper use.

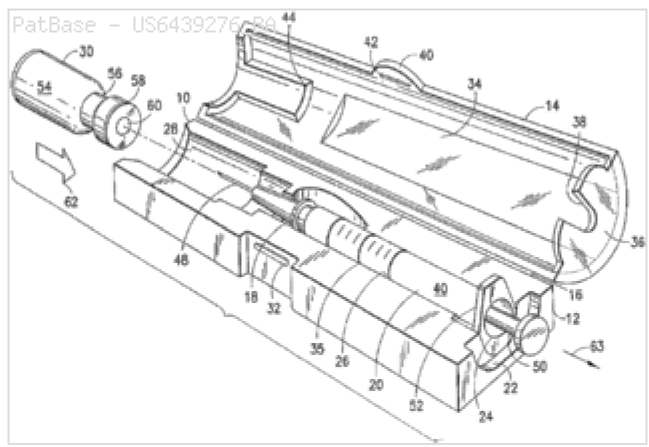


Figure 14: schematic of the pivoting housing to help contain load then dispose of contaminated needles [25]

Load-A-Dose Novelty

Through our research, we have confirmed to the best of our ability that we do not infringe on the rights of any currently active patents. With this assumption, we have developed Load-A-Dose to be a novel product because of its overall feature integration, in combination with dual platforms for user feedback and the intent for dual platforms for user input. This includes the semi-autonomous actuation methods, audio and visual outputs, high contrast button system, magazine-style syringe loading device, and proposed output verification steps. Although insulin delivery methods have been around for decades, this combination of features designed for visual and dexterity impairments is new. Additionally, Load-A-Dose mechanisms are not obvious to integrate together because they have been guided by medical professionals with field expertise, and thus rely on observations for design motivation not accessible to the general public.

Market Analysis and Business Opportunity

Load-A-Dose has an overall promising market outlook due to the high value associated with diabetes management. The insulin delivery market in 2016 had an estimated value of $12 billion. Furthermore, the projections for this market expect the net value to increase to $18 billion by 2021. The target population of Load-A-Dose, specifically those who self-administer insulin, have a tremendous projected growth rate over the next few years (figure 15); the at-home market segment is projected to increase from $6 billion in 2016 to $15 billion in 2025 [26].

At this point in time, the insulin pen is the only solution that moderately addresses the needs of diabetic individuals with low visual acuity. However, this device is not appropriate for individuals with poor dexterity or with little to no healthcare coverage due to the additional preauthorization steps required for a physician's prescription. By accurately and consistently addressing these needs, Load-A-Dose will be an accessible and affordable option, in comparison to pens and insulin pumps which are more expensive and may have higher patient costs even with insurance coverage. With the associated market opportunity for insulin delivery, Load-a-dose finds itself filling a space that few to no others have challenged. If we can capture just a fraction of a percent of this market, Load-A-Dose could be a multi-million-dollar company and have an edge in one of the most fastest growing market populations.

End User Segment in the Insulin Delivery Device (in USD Millions)

Figure 15: Chart of user segment in insulin delivery device market [26]

Marketing and Financial Strategies

To advertise our device to our target population, we plan to use both Business to Business (B2B) and Key Opinion Leaders strategies and engagement. We are simply advertising our product by having physicians speak about and on behalf of our product. To connect with physicians, we plan to partner with hospitals and clinics by hosting Lunch 'n Learns and attend medical device trade shows. Through these platforms, we will demonstrate our product and educate physicians on the ease and importance of our device to their patients, especially diabetic patients with low visual acuity. In addition, we plan to advertise through digital and print marketing literature showing studies of how our devices is easy to use among visually impaired individuals and the accuracy of our device [27]. As our company grows, we plan to hire experienced and trained medical sales representatives.

We plan to sell our device, Load-A-Dose, for $270 to our customers. This would be one purchase for the user. However, to create a recurring revenue stream, we plan to sell disposable syringe magazine loaders. Each syringe magazine loader would cost $15 and include 5 preloaded syringes.

Unit	Production Cost	Revenue	Net Income/Profit
Load-A-Dose	$90.00	$270.00	$180.00
Syringe Magazine Loader	$5.00	$15.00	$10.00

Table 3: Summary of finances relating to the syringe magazine loader and Load-A-Dose device

As seen in table 3, the production cost for the Load-A-Dose device covers the LCD display, insulin syringes, a basic processing board, a microcontroller, circuitry, and the mold injection for manufacturing of the product's plastic shell enclosure. The production cost of the syringe magazine loader will cover the mold injection of the loader and insulin syringes.

Table 4 (below) shows our financials of production cost, revenue, and profit projected in the next four years for the sale of both the syringe magazine loader and Load-A-Dose device. We assume we would sell 500,000 units in the initial year and each user would need an average of 3 syringe magazine loaders per month. This may sound optimistic at first, however, this considered reasonable project sell. The value of our projected sells only accounts for less than 5% of the market of diabetic patients with DR (approximately 10 million people). Our product appeals to this market segment because there is no competition filling the same niche as our product does. Net income each year is far more than enough to fund all production for the next year, meaning that no additional funding will be needed past year one of operations. Leftover income from the previous year will amount to roughly $1 billion even after production costs for the next year, which will be more than enough to pay for facilities, R&D, and human resources.

Year	2018	2019	2020	2021
Production Cost	$105 million	$123 million	$117 million	$118.5 million
Annual Revenues	$315 million	$369 million	$351 million	$355 million
Net Income	$210 million	$246 million	$234 million	$237 million

Table 4: Table of the financials of production cost, revenue, and profit projected in the next four years, assuming our product has been patented and FDA approved ready to sell on the market.

Reimbursements & Regulatory

In the United States, 92% of adults with diabetes cover their medical expense through some form of health insurance, which includes Medicare, Medicaid, private insurance, and military benefits [27]. In our target population of users 65 years and older, the predominant health care coverage is Medicare, a federal health insurance program for U.S. citizens in this age range. Nearly 99% of diabetic patients who are 65 years and older are covered by Medicare.

Load-A-Dose is an assisting device that would be eligible for coverage under Medicare Part B. Medicare Part B covers medical expense that are deemed medically necessary, such as doctors' services, preventive care, and durable medical equipment. By marketing our device as a necessity for patients who have low visual acuity and/ or limited dexterity, doctors can prescribe our device with insurance coverage.

To appropriately charge Load-A-Dose to patient insurance, there are several important codes for reimbursement. In general, the International Classification of Diseases (ICD) is a system of codes used to identify diagnoses [28]. These codes help to convey the status and severity of an individual's condition. Current Procedural Terminology (CPT) is an additional medical code that reports medical and surgical services to regulated entities [28]. These two sets of codes are used in conjunction for electronic medical billing (table 5).

ICD-10-CM Code	**Description**
E08-E13	Diabetes mellitus (includes diabetes mellitus related eye conditions)
F01-F80	Specific developmental disorder of motor function

CPT Code	**Description**
99500-99602	Home health procedures and services
99381-99429	Preventative Medicine Services
95250-95251	Endocrinology Services

Table 5: Summary of potential ICD and CPT codes for prescribing Load-A-Dose [29,30].

FDA Regulation

As confirmed by discussions with guest FDA experts, Load-A-Dose will be classified as a class II medical device under code 880, general hospital and personal use devices. Load-A-Dose is classified as class II because it has moderate risk associated with medication dosing but is not complex enough nor risky enough to fall under class III. During the design phase of this prototype, we intentionally tried to avoid creating a class III device by omitting a feature to inject insulin automatically. Avoidance of this high-risk automation procedure limits susceptibility to more strenuous regulation for a higher FDA classification. Load-A-Dose will additionally require adherence to the 510(k) process for premarket notification prior to device sales.

To begin the application for FDA approval for Load-A-Dose, we selected a possible predicate device appropriate for the next generation Load-A-Dose prototype. The space infusion syringe pump system created by B. Braun Medical functions in an analogous manner as Load-A-Dose and includes a similar docking station [31]. This device automates syringe medication delivery through a linear actuated mechanism. The main similarities of these devices include ID matching via electromagnetic tagging, a docking station for charging and data submission via Bluetooth, accurate measuring of injectable pharmaceuticals, and audible and visual outputs.

Bibliography

[1] World Health Organization. “Global Report on Diabetes”. Print. ISBN 978 92 4 156525 7

[2]Mayo Clinic. “Diabetic hypoglycemia”. May 10, 2018. https://www.mayoclinic.org/diseases-conditions/diabetic-hypoglycemia/symptoms-causes/syc-20371525

[3] Mayo Clinic Staff. "Peripheral artery disease (PAD)." Mayo Clinic. August 12, 2017. http://www.mayoclinic.org/diseases-conditions/peripheral-artery-disease/symptoms-causes/syc-20350557.

[4] "Facts About Diabetic Eye Disease." National Eye Institute. September 01, 2015. Accessed December 14, 2017. https://nei.nih.gov/health/diabetic/retinopathy.

[5] National Center for Health Statistics, National Health Interview Survey, 2011, www.cdc.gov/nchs/nhis.htm. For further information, see "Schiller, J.S., & Peregoy, J.A. (2012). Provisional Report: Summary health statistics for U.S. adults: National Health Interview Survey, 2011. National Center for Health Statistics. Vital Health Stat 10(256)." (http://www.afb.org/info/blindness-statistics/adults/special-report-on-aging-and-vision-loss/235)

[6] Eli Carmeli, Hagar Patish, Raymond Coleman; The Aging Hand, *The Journals of Gerontology: Series A*, Volume 58, Issue 2, 1 February 2003, Pages M146–M152, https://doi.org/10.1093/gerona/58.2.M146

[7] Centers for Disease Control and Prevention. Diabetes Public Health Resource. Available from www.cdc.gov/diabetes. Accessed 27 September 2012

[8] Geller, Andrew I. et al. “National Estimates of Insulin-Related Hypoglycemia and Errors Leading to Emergency Department Visits and Hospitalizations.” *JAMA internal medicine* 174.5 (2014): 678–686. *PMC*. Web. 15 Mar. 2018.

[9] American Diabetes Association. “Economic Costs of Diabetes in the U.S. in 2012.” *Diabetes Care* 36.4 (2013): 1033–1046. *PMC*. Web. 15 Mar. 2018.

[10] “History of Diabetes”. May 9, 2014. http://www.diabetes.org/research-and-practice/student-resources/history-of-diabetes.html?referrer=https://www.google.com/

[11] "Insulin Delivery Devices Market Analysis By Product (Insulin Syringes, Insulin Pens, Insulin Pumps, Insulin Injectors), By End Use (Hospitals, Homecare, Assisted Living Centers, & Nursing Homes), And Segment Forecasts, 2014 - 2025." Insulin Delivery Devices Market Analysis | Global Industry Report, 2025. November 2016. Accessed December 14, 2017. https://www.grandviewresearch.com/industry-analysis/insulin-delivery-devices-market.

[12] W. Dubois, BS, AAS, CPT, TPT, “Everything You Ever Wanted to Know About Insulin Injections,” *Diabetes Self-Management*, 21-Jan-2014. [Online]. Available: https://www.diabetesselfmanagement.com/managing-diabetes/treatment-approaches/everything-you-ever-wanted-to-know-about-injecting-insulin/. [Accessed: 13-Dec-2017].

[13] A. M. Research, “Global Smart Insulin Pens Market Expected to Reach $117 Million by 2023 - Allied Market Research,” *PR Newswire: news distribution, targeting and monitoring*, 04-Oct-2017. [Online]. Available: https://www.prnewswire.com/news-releases/global-smart-insulin-pens-market-expected-to-reach-117-million-by-2023---allied-market-research-649439883.html. [Accessed: 14-Dec-2017].

[14] “Insulin pump,” *Wikipedia*, 09-Dec-2017. [Online]. Available: https://en.wikipedia.org/wiki/Insulin_pump. [Accessed: 14-Dec-2017].

[15] C. K. R. N. B. S. N. CDE, “Tools and Techniques for Visual Impairment,” *Diabetes Self-Management*, 30-Jan-2007. [Online]. Available: https://www.diabetesselfmanagement.com/managing-diabetes/complications-prevention/tools-and-techniques-for-visual-impairment/. [Accessed: 14-Dec-2017].

[16] Centers for Disease Control and Prevention. National Diabetes Fact Sheet: General Information and National Estimates on Diabetes in the United States, 2011. Atlanta, Georgia, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, 2011

[17] “ISO 16142-1:2016”. https://www.iso.org/obp/ui/#iso:std:iso:16142:-1:ed-1:v1:en

[18] IAC Acoustics. “Comparative Examples of Noise Levels” http://www.industrialnoisecontrol.com/comparative-noise-examples.htm

[19] Leibs, Andrew. “Talking Book Library” https://www.lifewire.com/talking-book-free-audiobooks-blind-persons-3862775

[20] European Patent Office. “What is Prior Art?”. https://www.epo.org/learning-events/materials/inventors-handbook/novelty/prior-art.html

[21] D. Farbstein. “Single use disposable syringe”. U.S. Patent Number 5085638A. Filed December 29, 1988

[22] Long, Michael. “What is a syringe pump?”. April 26, 2018. www.chemyx.com

[23] XTRACT Solutions 510(k) Summary. https://www.accessdata.fda.gov/cdrh_docs/pdf9/k091200.pdf

[24] T. A. Piscitelli, "Injection Device with Audio Output" U.S. Patent Application 20160058945, issued March 3, 2016.

[25] C. Wood, "Kit for loading and disposal of hypodermic syringes used for administering medication" U.S. Patent 6,439,276, issued August 27, 2002.

[26] Shah, Rima, Patel, Manhar, Maahs, David, and Shah, Viral. "Insulin Delivery Methods: Past, Present and Future." *International Journal of Pharmaceutical Investigation* 6, no. 1 (2016): 1-9.

[27] Centers for Medicare & Medicaid Services. [print] “Medicare’s Coverage of Diabetes Supplies & Services”.

[28] Rouse, Margaret. “ICD-10-CM (International Classification of Diseases Tenth Revision, Clinical Modification)”. https://searchhealthit.techtarget.com/definition/ICD-10-CM

[29] https://www.icd10data.com/ICD10CM/Codes/H00-H59

[30] AAPC. “What is CPT”. https://www.aapc.com/resources/medical-coding/cpt.aspx

[31] https://www.accessdata.fda.gov/cdrh_docs/pdf9/K092313.pdf

Appendices

A. Design Concepts and Evaluations

1. *Computerized automated insulin loading device* (design description found in the main body of this report). This design concept has #1 ranking based on the QFD exercises for both the technical and competitive benchmark due to its emphasis on automation and accuracy of insulin measurements.
2. *Count-A-Dose adapter* (design description found in the main body of this report). This design concept has #2 ranking for both the competitive and technical benchmarking. Although this design doesn't include automated drawing of insulin it has automated monitoring of insulin, and for that reason it was able to get higher rankings.
3. Flow regulators

Syringe needle flow regulator: an attachment to syringe that monitors and regulates amount of insulin going in *and out* of the syringe—this design restricts the patient from injecting more than the specified amount therefore addresses over dosing issues, but possibly not under-dosing issues.

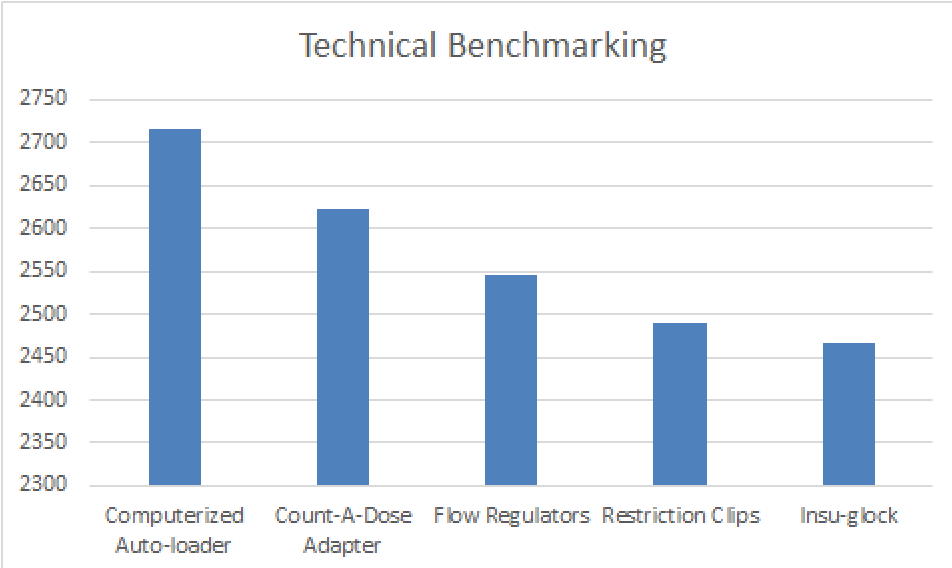
Vial regulator : an attachment to insulin vial that monitors and regulates the amount of insulin going out of the vial.

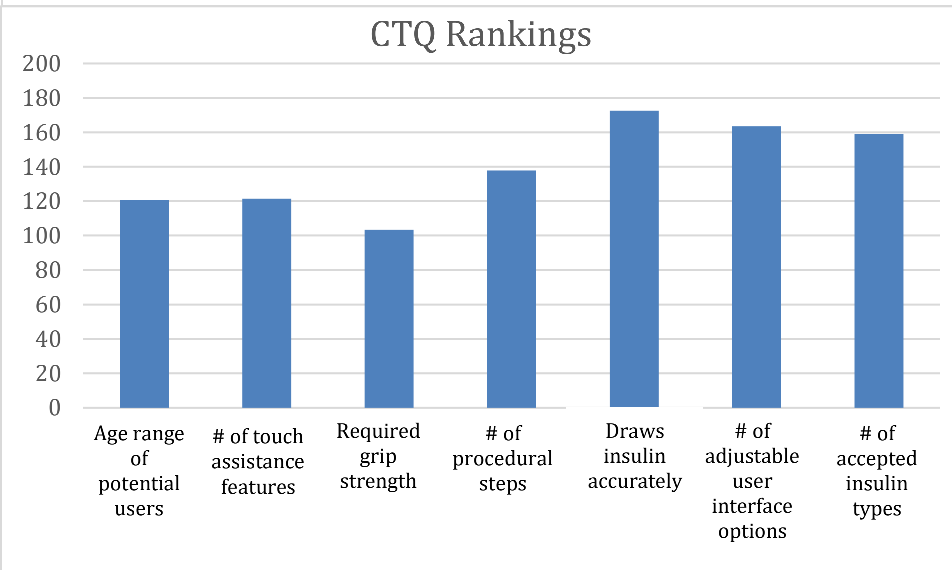
Both of these regulators were evaluated as a single design concept and they ranked #3. Although they can measure amounts of drawn insulin, they do not perform an automated drawing of insulin—as a result they have smaller rankings.

4. *Restriction clips*: small clips that are each associated with a preset dosage –could be color coded for different dosage amounts—that are attachable to syringes and restrict the patient from drawing more insulin than the preset amount. This design concept ranked #4 in our QFD analysis because it lacks the ability to draw insulin and its ability to measure drawn insulin only extends to the maximum allowable dosage—meaning with the restriction clips patients may not overdose but they can still under-dose, which also has adverse health impacts.
5. *An ergonomically shaped injection device* (referred to as "Insu-glock" in our QFD). This device would be handheld and it would have a compartment for different types of insulin. Based on specified amount and type of insulin it will load a syringe. It would be durable and smaller in size—however these aren't qualities that we've given an lot of emphasis to. At this time mechanics of the loading are not as clearly defined as it is for the computerized insulin loading design concept. For these reasons it has the lowest ranking of all our current design concepts.

Two charts of the rankings of our current design concepts are given below in Appendices B and C. Notice that results of the technical and competitive benchmarking mirror each other.

B. Technical Benchmarking





C. QFD Results

Insulin Self-Injector QFD					Design Specifications (CTQs)							COMPETITIVE BENCHMARK						
					#1	#2	#3	#4	#5	#6	#7							
Relative weight of customer	*1.00*	*0.75*	*0.25*															
Critical to Customer (CTC)	Patients w/ low visual acuity	Clinicians	Insurance Company	PRIORITY SCORE	Measures and draws insulin with a safety tolerance	Volumetric Size	Weight (lb)	Strength of Material	# of Insulin Types can be accepted	# of Procedural Steps	Procedural Time	Count-A-Dose	Insulin Pump	Count-A-Dose Adapter	Computerized Auto-loader	Flow Regulators	Restriction Clips	Insu-glock
Accuracy	5	5	4	9.75	5	0	0	0	4.5	2	2	4	5	5	5	5	5	4
Automated drawing of insulin	5	4	3	8.75	5	0	0	1	2	3	4	0	5	1	5	1	0	1
Intuitive	5	4	3	8.75	4	0	0	0	3	5	4	3.5	2	5	5	3	4	3
Transportable	4	3	1	6.5	1	5	5	2	1	0	0	5	5	4	3	5	5	3.5
Durability	3	2	5	5.75	0	4	3.5	5	0	0	0	3	2	3	2	2	4	4
Acceptability of different insulin	4	4	4	8	5	3	2	0	5	3	2	5	1	5	5	5	5	5
Unbiased verification feedback	5	4	3	8.75	2	3	0	0	3.5	2.5	3	2	4	5	5	5	3	2.5
CTQ IMPORTANCE					147.75	105.75	68.625	41.75	147.25	109.13	96.75	176.875	197	228.25	251	211.5	205.5	181.625

TECHNICAL BENCHMARKING			#1	#2	#3	#4	#5	#6	#7
	2433.5	Count-A-Dose	1	4	4	3	5	4	3
	2504.75	Insulin Pump	4	5	5	2	1	3	5
	2622.3125	Count-A-Dose Adapter	3.5	3	3	3	5	3.5	3.5
	2717.125	Computerized Auto-loader	5	2	1	1	5	4	5
	2544.75	Flow Regulators	2.5	4	3	2	5	4	3
	2489.5	Restriction Clips	0	5	5	4	5	3	4
	2467	Insu-glock	3	3	2	4	5	3	3.5

D. Design Drawings and Schematics

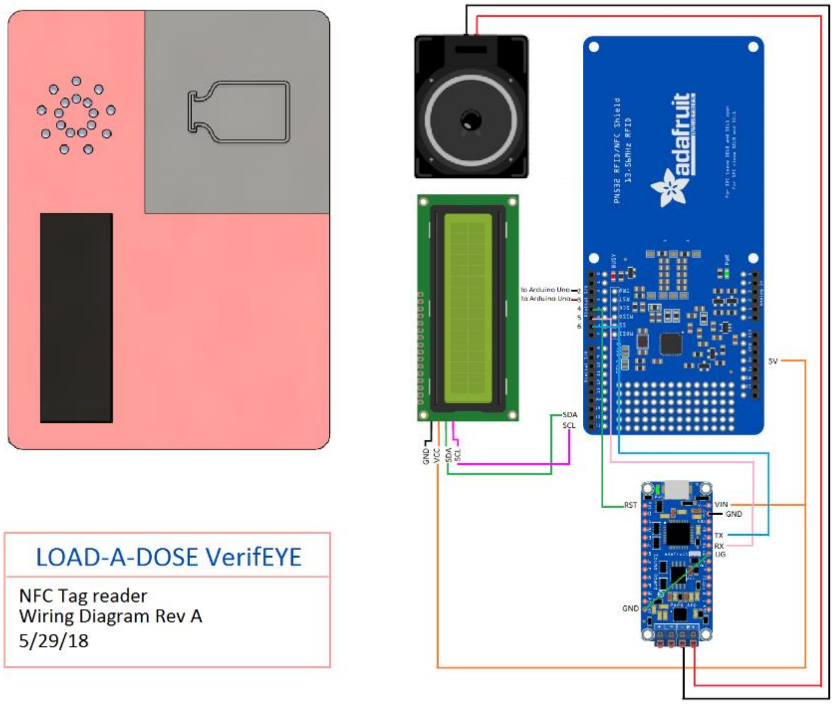


Figure D-1: wiring schematic for VerifEYE, an RF ID tag reader used to assist with identification of vial contents to verify medication type prior to loading within Load-A-Dose. First, the user places an appropriately labeled vial onto the gray pad seen above. The unit then audibly and visually depicts vial contents to prevent medication mix-ups.

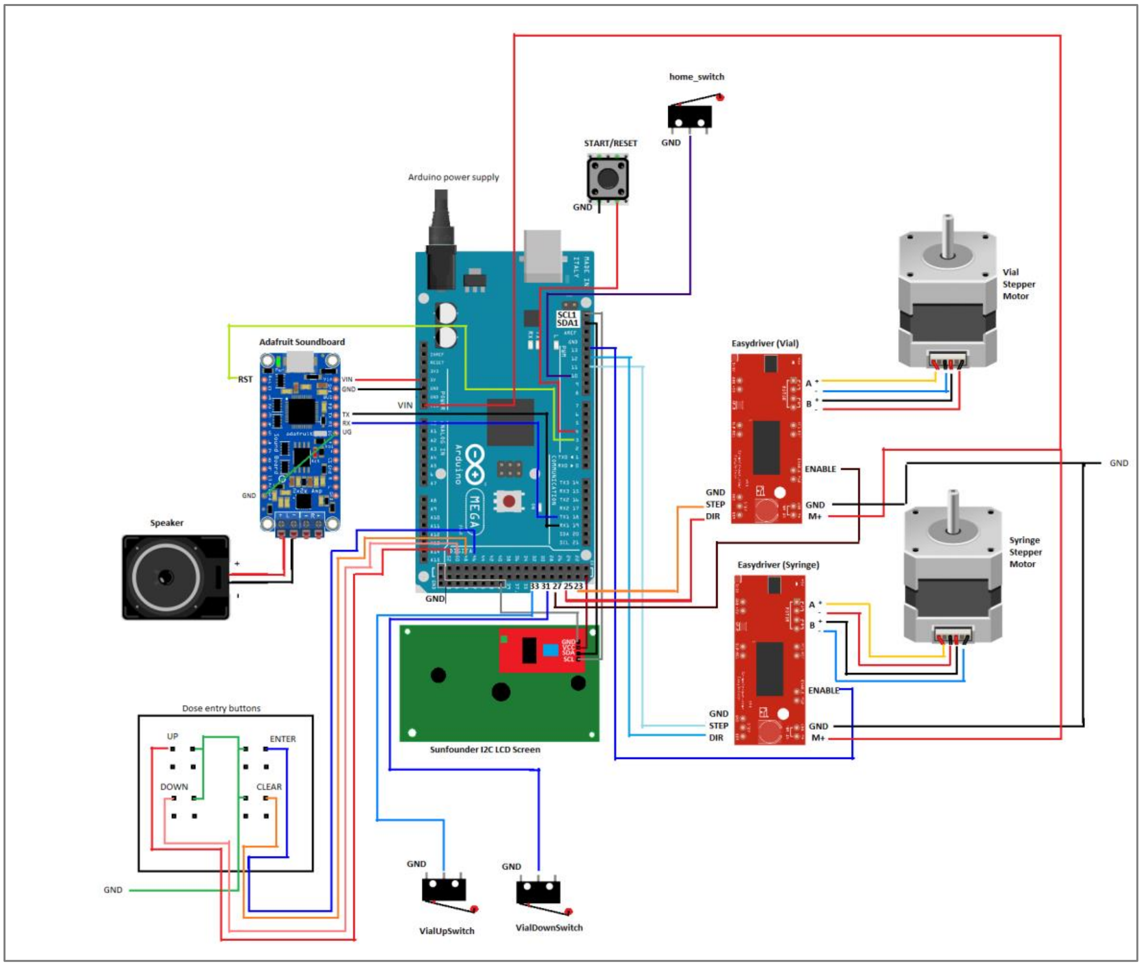


Figure D-2: wiring schematic for Load-A-Dose.

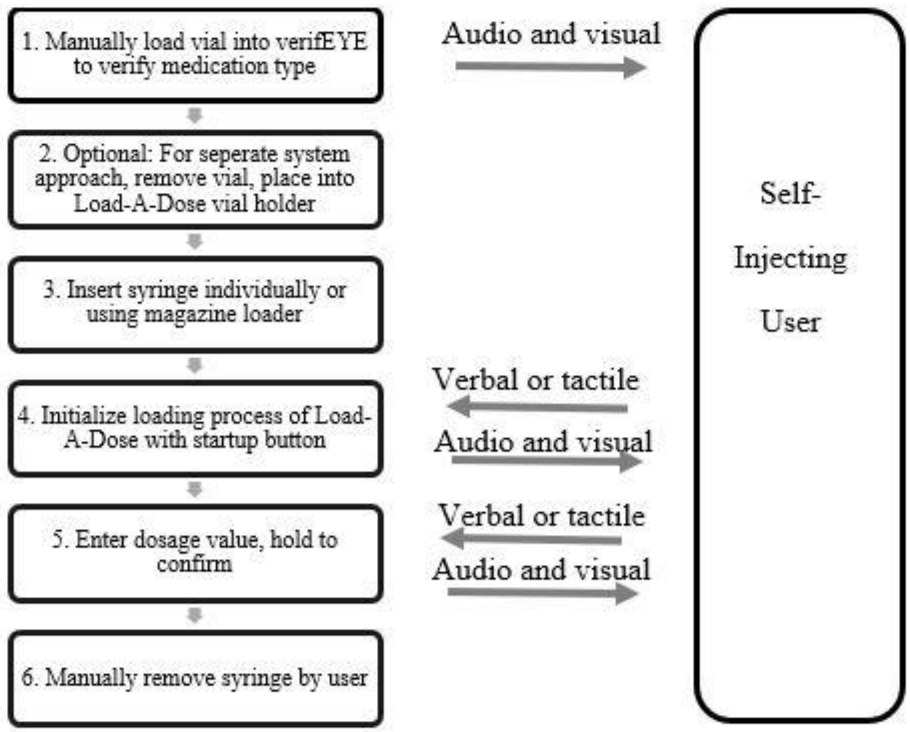
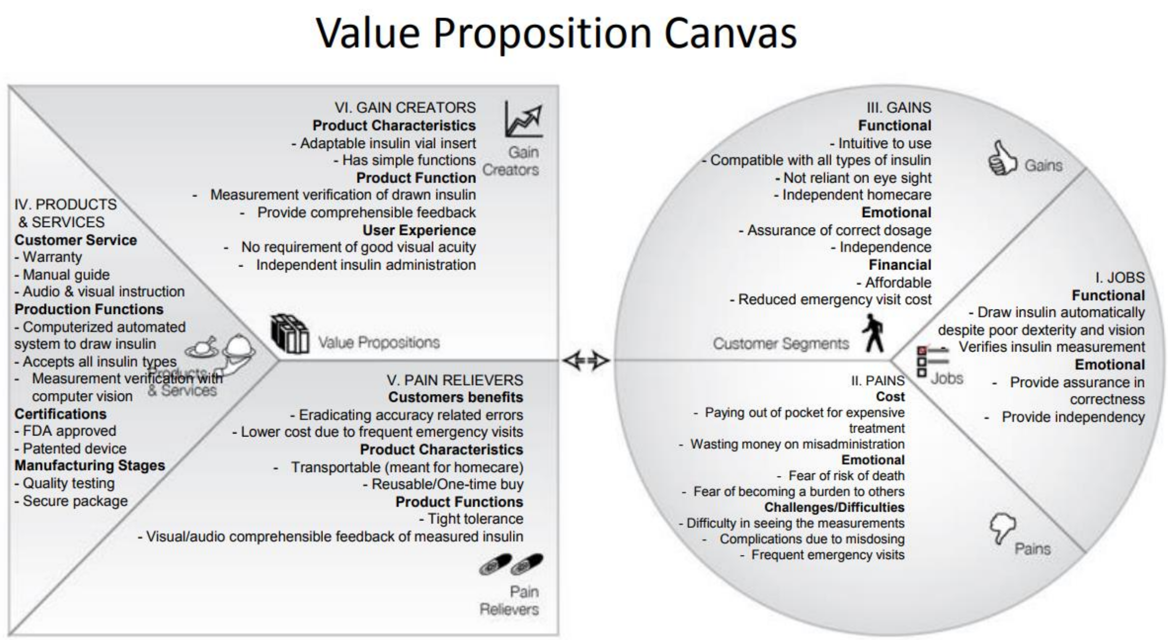


Figure D-3: process overview for Load-A-Dose use by a self-injecting user indicating directionality of feedback or input, respectively.

E. Value Proposition Canvas & Lean Canvas



Lean Canvas

Insulin Self Injector

12-5-17

Problem

1) Customers cannot clearly see the measurement increments on existing insulin devices, which can lead to dosing error.

2) Customers have to use multiple insulin devices to administer different types of insulin, which can be cumbersome and costly.

3) Depending on level of visual acuity, customers may have to rely on others to administer an accurate dose.

Solution

1) Audio, visual, and or tactile feedback of drawin insulin

2) Spring or other mechanism to accept different kinds of insulin vial.

3) Low number of procedural steps (i.e. specify dose, draw, check and inject insulin) and easy to follow instructions (i.e pictorial instructions)

Key Metrics

Key action: Completion of a prototype

Success metrics:

- Create a CAD model and assembly
- Detailed cost analysis of materials and manufacturing
- Blind folded test

Unique Value Proposition

To reduce health complications and manage diabetes, our device provides an accurate dose of insulin by an automated integrated dose verification system for diabetic patients with low visual acuity who want an accurate self-injection.

Unfair Advantage

Unlike insulin pumps, our device caters to people with low visual acuity and works with all types of insulin.

Unlike all the current solutions, our device will provide dose verification before injecting, independent of visual acuity of patients.

Channels

Using media to advertise through outlets such as,

- Dr. Oz
- Facebook insider videos
- Health magazines
- Advocate group newsletters

Additionally,

- Word of mouth
- Health expos

Customer Segments

Diabetic patients with low visual acuity, who self-administers insulin on daily basis. (users)

Early Adopters

Diabetic patients who have experienced health complications due to the wrong dosage as a result of their poor eyesight.

Cost Structure

- Manufacturing
- Research
- Making prototypes
- Overhead

Revenue Streams

Razor blade model: Device and needles sold separately. Device is a one time cost, needles purchased regularly.

Physicians and advocate groups for people with diabetes and people with low visual acuity get free samples to promote product to potential users.

PRODUCT | MARKET

Accomplishments & Acknowledgements

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