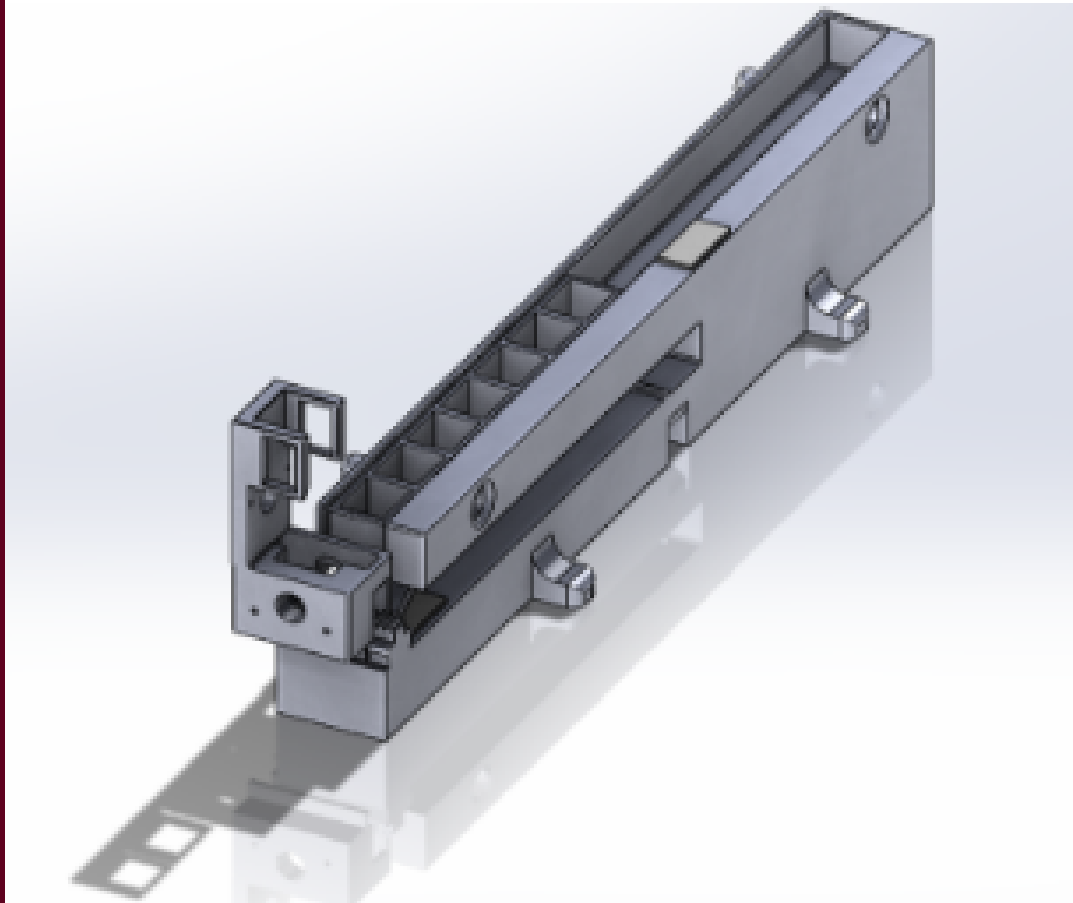


Medicine Dispensing Devices to Help Increase Patient Adherence



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WPI



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AN INTERACTIVE QUALIFYING PROJECT
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DEGREE OF BACHELOR OF SCIENCE

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Abstract

Medication nonadherence is a pressing issue in northern India. This problem causes many deaths & allows communicable diseases to spread. The goal of our project was to determine if an automatic medicine dispensing device could be used to help improve nonadherence in Himachal Pradesh. Through interviews & surveys with doctors, pharmacists, caregivers, & patients, we established that nonadherence is a serious issue. Also, the majority of stakeholders showed interest in a device & believed it would increase adherence. Utilizing an iterative cycle of design and revision, we created a prototype to meet the needs identified by our stakeholders. While medication nonadherence is very complex, we believe our design could help patients to remain independent while improving their medication routines.

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Authorship Page

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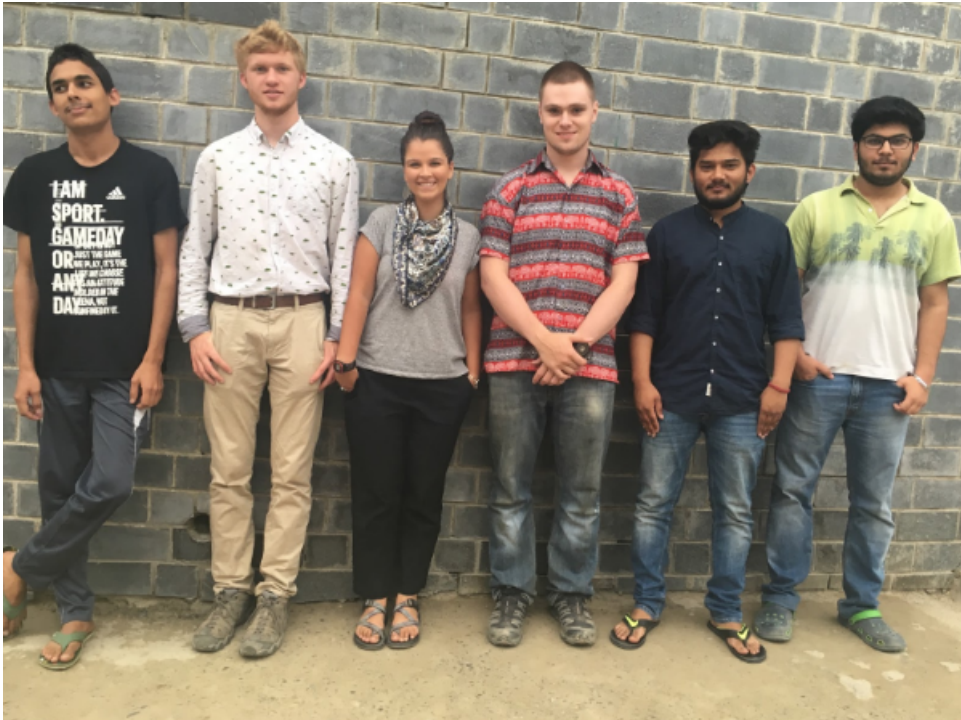
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Prototype Design: All team members actively contributed to the design of the prototype.

Prototype Manufacturing: Mechanical work completed by Dillon Arnold. Electrical and computer programming completed by Simon Redding and Pankaj Sheoran.

Final Presentation Poster: Designed by Jacqueline Garcia



Executive Summary

Medication Nonadherence: A global issue

Throughout the world medication is being prescribed to manage a wide range of illnesses. This includes communicable and chronic diseases. Each condition poses its own challenge and requires its own therapy plan which can often be lengthy and complicated. Medication nonadherence leads to antibiotic resistance, poor management of chronic illnesses, and the spreading of communicable diseases. Globally it is estimated that only 50% of prescribed medications are taken correctly (Sabaté, 2003). Personal consequences of patients failing to properly take prescribed medications include wasted medicine, overdose or injury, or in the most serious cases, lead to unnecessary death (Choudhry et. al., 2014).

To address the problem of medication nonadherence, our team collaborated at the Indian Institute of Technology Mandi to determine whether or not a medication-dispensing device can be used effectively to help improve medication nonadherence in Himachal Pradesh, India utilizing the objectives in Figure 1.



Figure 1: Goal and objectives

Assessing medication nonadherence in Himachal Pradesh

We utilized interviews and surveys with 11 medical professionals at multiple hospitals, 60 patients, and 10 caregivers in Mandi town and the surrounding villages to gain a greater understanding of the current state of medication nonadherence. These doctors worked in a variety of fields, from pediatrics to skin care. Of eleven doctors surveyed:

- 91% of doctors surveyed said that patient nonadherence is a pressing issue in Himachal Pradesh
- 91% of doctors surveyed reported that there are immediate and potentially serious consequences of nonadherence
- 55% of doctors surveyed said that their patients generally manage medicine routines through only verbal or written instructions, without any additional help.

When interviewing patients, we asked questions about specific medication routines. We found that:

- 60% of patients surveyed sometimes forget their medicine.
- 40% of patients surveyed said they need or want aid of some kind to take their medicine.
- 44% of patients surveyed said they have medicine routines complex enough to hinder adherence.

Caregivers were interviewed to assess how family members and hired aids play a role in medication routines and adherence. Seven out of ten caregivers played an active role in managing a medication routine because the patient would forget to follow their prescribed therapy.

Addressing medication nonadherence in Himachal Pradesh

Once we identified that medication adherence is an issue in Himachal Pradesh, we presented the idea of an automatic medication dispenser to doctors, patients, and caregivers. 91% of the interviewed doctors stated that a device could help patients adhere to a prescribed medication routine. 78% of patients surveyed said that they would be interested in using a medicine dispensing device. 80% of caregivers interviewed said they would utilize a device to help the individual taking medication on a routine basis.

We created a list of features commonly found in medicine dispensers currently on the market. Key features were identified by doctors to highlight what users find appealing, easy to use, or effective for both the unimpaired or for those that face physical, mental, or linguistic restrictions. We used this list to identify potential features of device (see Figure 2). It was confirmed that ease-of-use and affordability were absolutely essential to the device, as our initial interviews suggested. Also scoring highly were audible alarms, refill notifications, and the ability to lock the container. All of these features guided the design and were incorporated into the prototype. The design was revisited and reevaluated to ensure, to the best of our ability, that the device was as close as possible to meeting the needs of the stakeholders.

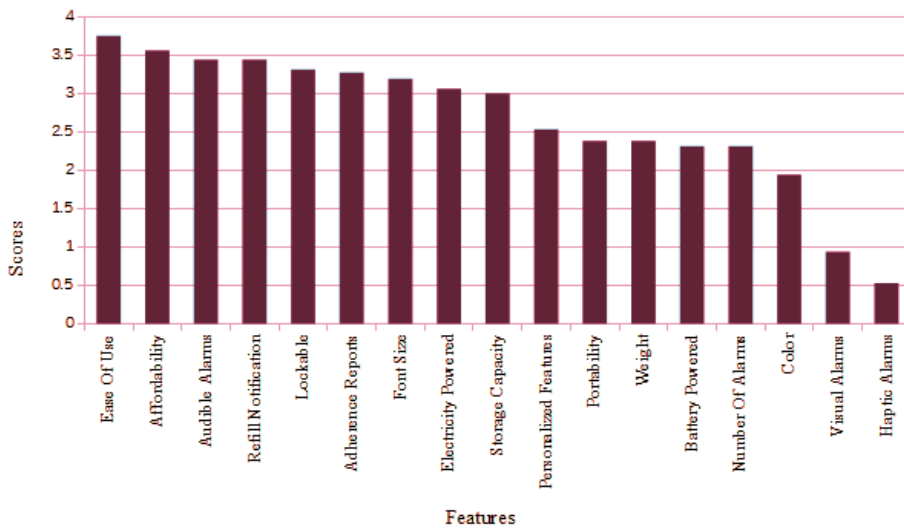


Figure 2: Ranking of features by average importance

The device was made with ease-of-use in mind. After the medicine schedule is programed into the device via a keypad and the medicine has been loaded into easy-to-fill trays, the device automates the entire process of dispensing, providing alarms, and emergency and refill notifications. Figure 3, below, shows a CAD illustration of one module of the device.

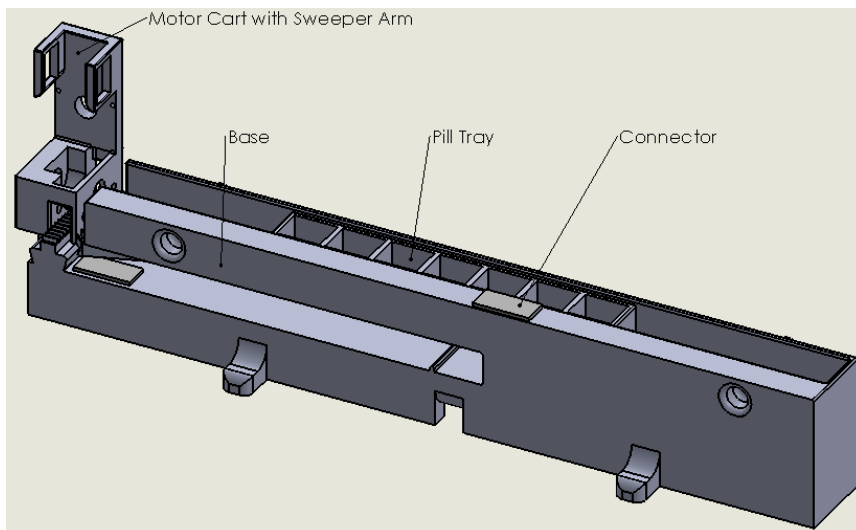


Figure 3: Design illustration

Our project aimed to deliver a prototype of an automatic medicine dispenser designed to increase medication adherence. We developed an initial prototype that could help patients to remain independent while improving their medication routines. Improvements that could be made in the future include adding a battery system, new motors, and creating a more compact model.

Our analysis of patient, caregiver, and doctors' concerns brought us greater empathy for the experiences of patients and the causes for prescription nonadherence in Himachal Pradesh. As we move towards a world where people are living longer, and with less support from extended families, there is a need to adapt and modernize our approach to medicine. Simple devices like this can save money and lives, and can also create healthy medication routines that lower hospital readmission rates and stop the spread of communicable diseases. Ultimately, we hope that our final design and prototype represent a medicine-dispensing device that will reduce medication nonadherence in the state of Himachal Pradesh.

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Addressing Medication Nonadherence in Himachal Pradesh

A tremendous challenge in modern healthcare is ensuring patient adherence and dosage accuracy of prescribed medications. Globally it is estimated that only 50% of prescribed medication is taken correctly (Sabaté, 2003). Consequences of patients failing to properly take prescribed medications include wasted medicine, overdose or injury, or in the most serious cases, lead to unnecessary death (Choudhry et. al., 2014). Throughout the world, medication is being prescribed to manage a wide range of illnesses. This includes communicable and chronic diseases. Each condition poses its own challenge and a unique therapy plan which can often be lengthy and complicated. Medication nonadherence leads to antibiotic resistance, poor management of chronic illnesses, and the spreading of communicable diseases.

Medication adherence is defined as “the extent to which a person’s behavior, such as taking medication, corresponds with agreed recommendations from a health care provider” (Sabaté, 2003). Therefore, when an individual does not follow the recommended medication routine, they become nonadherent. Medication nonadherence is complex and influenced by a wide range of factors. There are many challenges that exacerbate improper use of medication, including accessibility to pharmacies for refills, cognitive difficulties in remembering medication schedule or dosage amount, and even a recent trend away from family support and caregiving (Greenberg et. al., 2013). Additional factors include intentional nonadherence, which stems from the cost of medication, the adverse side effects, or, in places like India, a lack of education about or trust in western medicine (Greenberg et. al., 2013).

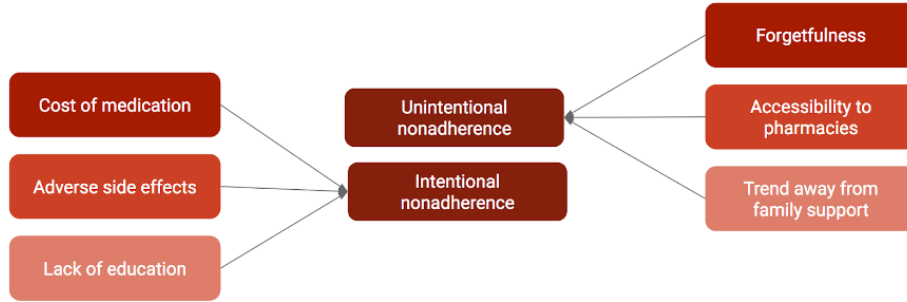


Figure 4: Factors influencing intentional and unintentional nonadherence

Another problem to consider is that rural communities face challenges in healthcare delivery. Parts of the world with small villages in very steep and mountainous terrain, poor road connections, and great distances to clinics are particularly vulnerable. These conditions can make it difficult for some patients to acquire their medications or interact regularly with a doctor (Aggarwal et. al., 2016).

To address this problem, our team collaborated at the Indian Institute of Technology Mandi to determine whether or not a medication-dispensing device can be used to help improve medication adherence in Himachal Pradesh, India. Our first objective was to understand challenges faced by patients, caregivers, and medical professionals regarding a prescribed medication intentional and unintentional nonadherence. Our second objective was to identify design criteria and gauge both the practicality and potential effectiveness of a device. Finally, we aimed to create and test a criteria-compliant device that would be designed by and for the people of Himachal Pradesh.

Considering the experiences, beliefs, behaviors, and suggestions of patients and doctors allowed us to understand the obstacles related to medication adherence and the addition of new technology to a prescribed therapy plan. A device that can safely store medicine, remind its user when it is time to take a dose, and accurately prepare the correct dosage autonomously, can aid and prolong the lives of those who wish to remain independent or who are “aging in place”.

Major factors influencing medication nonadherence

Many factors play a role in medication adherence and nonadherence. To begin, in many parts of the world, patients have traditionally been dependent on family members during the process of aging or times of sickness (Mirza et. al., 2016). Today, a transition away from extended family support has left a gap in caregivers and leaves a vulnerable population alone during the workweek. In 2011, 14% of India’s elderly population was living independently

of care of family members or additional aid, as compared to 1961 where only 10% lived independently (Liebig, 2011). With a trend away from family care, individuals must independently remember prescribed medication routines and also administer the correct dosage autonomously which can be challenging when individuals are managing an illness. It has been shown that 50% of medications being prescribed are given to elderly individuals. Many conditions that become more prevalent with old age are often classified as chronic illnesses and must be managed with routine medication. Consequently, when individuals suffer from multiple chronic conditions, medication routines can become incredibly complex (Sabaté, 2003). While it is unknown how many individuals are currently taking medication in India it is known that 61% of deaths in the country are due to chronic illnesses (Dey, 2017). These diseases are most commonly hypertension, diabetes, and cancers and must be managed with routine medication. These routines are often complex, which makes it difficult to remember one or more routines without the aid of someone or something else.

A second factor that affects individuals regardless of age is socioeconomic status. It has been shown that chronic illnesses have a greater effect on those at or below the poverty line (Risk Factors Collaborators, 2015). These individuals are exposed to risks that make the likelihood of developing a chronic illness much higher, including poor diet, exposure to tobacco, and limited access to pharmacies and medical help. Since chronic illnesses must be managed continuously, medication can easily become so costly that patients may stop taking their prescribed therapies. In 2011, it was documented that 21.2% of India's population was at or below the poverty level (World Bank Group, 2011). This puts a large number of individuals higher risk for chronic conditions.

Third, patients may stop taking medicine because of adverse side-effects, or they may feel better after a short time and believe that the medicine is no longer necessary. These actions are classified as intentional nonadherence. Others face challenges that can be exacerbated by the medical condition that is being treated, known as unintentional nonadherence. Patients can be forgetful due to old age, face limitations such cognitive impairments caused by illnesses like Alzheimer's and Dementia, or struggle with physical mobility challenges caused by conditions like Arthritis which make removing medication from packaging more difficult (see figure 5) (Patton et. al., 2018). Medications may also have negative side effects and cause individuals to stop taking the full dose without consulting a doctor (Tordoff et. al., 2010).

Finally, cost often plays a role in why individuals choose to not adhere to a prescribed routine. Medicine can be expensive, and patients may simply not want to purchase it or be unable to afford it. When individuals choose not to take medication with the intention of saving money, they actually create a bigger cost on a national level. In the United States, \$100 billion dollars is spent annually on treating patients that have been hospitalized for medical issues attributed to nonadherence ("Prescriptions", 2018). In addition to the money spent directly on these hospital admissions, it is estimated that up to \$300 billion could be saved annually by solving adherence-related problems ("Prescriptions," 2018). Because of this, it is arguable that macro-level improvements to medication adherence issues could save taxpayers and patients money or allow national health budgets to be spent elsewhere (Seabury, 2014). While this has been shown to be a compelling incentive in the U.S., similar implications can be expected for coordinated health care systems anywhere in the world



Figure 5: Medicine packets

Improving adherence rates

There are many approaches that can be taken when looking at improving adherence, which could each help solve different factors of the nonadherence issue. We specifically focused on medical devices that have been implemented. With these devices we examined the features that increased adherence and identified aspects that could be improved. While these studies were not carried out specifically in India, each have innovations that could be applied to a device that meets the needs of our stakeholders. To begin, we evaluated some common strategies employed by commercial devices.

One approach towards improving patient adherence rates is to identify factors that can

be positively influenced or addressed, including physical and cognitive barriers that can lead to missed doses. Many devices exist that can store medicine, remind the patient when it is time for their dose, and provide it to them in an easily accessible container. There are some approaches to these problems that can be effective. Table 1, found in Appendix A, gives a brief example of the range of devices currently on the market in the United States of America that offer a wide range of features. Table 2, in Appendix A, examines common features and similarities of each device. These devices range from simple containers to complex systems with multiple features shown in Figures 6 and 7.



Figure 6: A simple device

A case study examines how an alarmed device increased medication adherence in Mombasa, Kenya (Frick et. al., 2001). A randomized clinical trial was conducted to determine if an alarm device could aid in an increase of medication adherence. Results show that 82% of the women with alarmed devices had good adherence, defined as ingesting more than 94% of their prescribed medication. In comparison, only 36% of women with a device without an alarm had good adherence. In addition, after this trial, 99% of participants said they would use an alarmed device if they ever needed to manage a chronic illness. Another great aspect of this case study showed that these alarmed devices could also accurately compile a patient report in regards to adherence versus patient self-reporting which commonly overestimates adherence.



Figure 7: A complex device

Identifying the target demographic

There are many factors to consider when designing a device for north Indian patients, including understanding attitudes towards western medication, literacy rates, and problems with access to medication. These factors have been identified as challenges to assess due to past research in the area and from studies in similar countries around the world (Aggarwal et. al., 2016; Shi et. al., 2010). Many other cultural factors play an important role in medication adherence and also the acceptance of a device into a community. When designing a device we took these cultural factors into consideration so that the device would have the potential to be accepted by the culture. We assessed the current beliefs and behaviors of local doctors and patients, and took them into consideration when designing the device. Our proposed prototype comes directly from the suggestions, preferences, and needs of our stakeholders. Medication devices often offer a promise of better health but often fall short if a design is not created with stakeholders in mind. There are a large number of organizations and individuals who are involved in the innovation process when it comes to creating a device as seen in Figure 8.

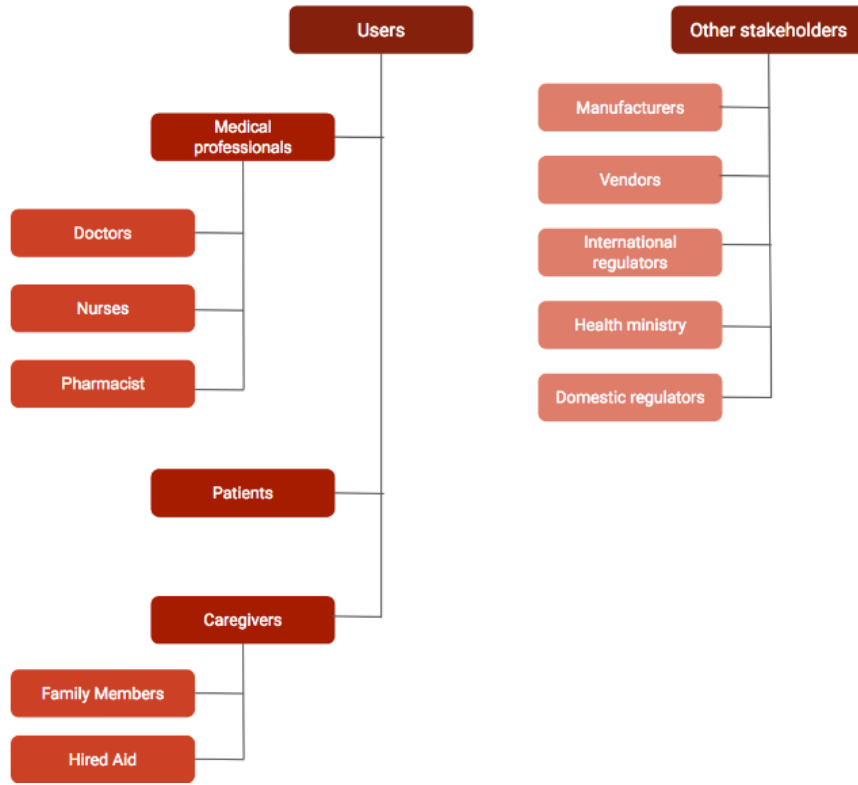


Figure 8: Stakeholders considered throughout project

For the case of this study we mainly focused on users, but also kept other stakeholders in mind when designing the prototype. Primary stakeholders include individuals who take medication on a routine basis. This includes patients of any age, condition, or disability. Secondary stakeholders include caregivers, hired aid, and medical professionals. Caregivers also must be engaged and involved in some cases when following a medication routines may be interacting with a device. Medical professionals, such as doctors and pharmacists, are at the heart of most medication routines since they oversee the prescribing of medications and educate their patients on illness and disease. Medical professionals must educate and encourage patients to adhere to their prescribed routine.

One challenge faced by our stakeholders is due to the environment in which they live. The state of Himachal Pradesh hosts many regional health centers. There are smaller health centers or sub-centers that serve communities and to help with their medical needs. Pharmacies are often located close to hospitals (see Figure 9), which are further away than these small health centers which means that refilling prescriptions requires traveling great distances over a variety of challenging and dangerous terrain (Aggarwal et. al., 2016). In addition to this inconvenient spacing of health centers, hospitals and pharmacies are over-crowded, potentially making a quick trip to pick up or be prescribed medication turn into a day-long painstaking task (Bundhun, 2014).



Figure 9: Pharmacy in Mandi Town

Approach

Our strategies for data collection were organized by objective, as illustrated in Figure 10, below.



Figure 10: Goal and objectives

Objective 1: Understand patients', caregivers', and medical professionals' needs

Interviews and surveys were used to gain a greater understanding of what leads to missed medication and how a device can or cannot aid in increasing medication adherence. The survey process was designed to protect the anonymity of all participants.

We conducted 11 structured interviews with doctors to understand their concerns regarding medication nonadherence by visiting Mandav Hospital in Mandi, Neelkanth Hospital in Mandi, Primary Health Clinic in Kataula, Zonal Hospital Mandi, and Jagriti Hospital Mandi. An interview guide can be found in Appendix B. We identified which device features are regarded as important by these secondary stakeholders.

We selected patients for the survey through two main methods. First, we used a sample of convenience at local hospitals and pharmacies. This allowed us to find local patients who were actively taking medicine. Secondly, we asked some willing doctors and nurses to perform surveys for us. Together, these methods gave us 50 complete surveys from a broad sample of patients. The Medication Adherence Questionnaire can be found in Appendix C.

We identified caregivers to be family members or hired help who interact frequently with individuals who take medication on a regimented schedule. These caregivers were selected through a sample of convenience by choosing families local to the area. This provided us with another point of view towards the current state of medication nonadherence in Himachal Pradesh. The Caregiver Survey can be found in Appendix D.

Objective 2: Identify design criteria

Our second objective was to study currently-available medicine dispensing products and gauge both their practicality and their effectiveness in the state of Himachal Pradesh. We searched current markets online for available products, and we interviewed pharmacists and doctors to see which products they would recommend to their patients and why. This allowed for individuals to directly influence which features were included in our device.

We created a grid of features commonly found in medicine dispensers currently on the market. We then asked doctors and patients whether or not they thought each one would be useful in a device of our making. Key features were identified to highlight what users find appealing, easy to use, or effective for both the unimpaired or for those that face physical, mental, or linguistic restrictions. The members that reviewed these features were selected through a sample of convenience. For sample questions, see the Feature Importance Grid in Appendix E.

To further map these criteria, we developed a rubric of design traits through a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of each feature based on the interviews and surveys. With the results from our Feature Importance Grid and multiple SWOT analyses, we distinguished which product features were worth including in our product, and ensured that our final device is effective, affordable, and designed by and for the stakeholders of Himachal Pradesh.

Objective 3: Create and test a criterion-compliant device

We used the results collected from objectives 1 and 2 to develop a design rubric that addresses the problem of medication nonadherence while meeting the needs identified by medical professionals, patients, and caregivers. Design began with looking at user preferences determined by our evaluation rubric and carefully choosing the best features to include in our product. We used 3D modeling software to design a product without wasting material. After the model was tested for safe and consistent operation, we began a process known as rapid prototyping. This includes 3D printing parts, welding, and using wood and plastics to prove a concept while having a fast development cycle. Parts were ordered that could not be made by hand such as an Arduino MEGA and an LCD screen. Once we worked through the design phase, we sent the prototype to the second phase of the cycle to undergo testing in the revision stage.

The revision stage allowed for the prototype to be tested in the field through various studies and then improved upon based on feedback. This entailed improving ease-of-use of the product along with adaptation the product to different environments. Doctors and pharmacists were shown the device to collect any feedback about the prototype. As engineers of the prototype, we utilized Empathic Intelligence Testing. With this, we mimicked physical impairments on ourselves by operating the device while wearing blurred glasses and gloves filled with sand. We used this method to better understand for ourselves the challenges associated with adhering to a medication routine. By observing how both the users and ourselves interacted with the product as well as analyzing their responses to our questions, we gathered insight on how the product needed to be revised. No real medication was used in these tests; rather, we studied only the physical interactions.

Results and Discussion

The findings from our data collection are presented here by first assessing medication adherence and then addressing the problems with a medication device.

Medication nonadherence in the state of Himachal Pradesh

We began our project by interviewing eleven doctors at multiple hospitals, both private and public, in Mandi town and the surrounding villages. These doctors worked in a variety of fields, from pediatrics to skin care. Of eleven doctors surveyed:

- 91% of doctors interviewed regularly treated both chronic and acute patients
- 91% said that patient nonadherence is a pressing issue in Himachal Pradesh
- 80% claimed that intentional nonadherence is a significant problem
- 91% reported that there are immediate and potentially serious consequences of nonadherence
- 45% stated that a significant portion of their patients had the help of a relative or caregiver, and that more could if needed.
- 55% said that their patients generally manage medicine routines through only verbal or written instructions, without any additional help.
 - These instructions are always written in English, but sometimes contain diagrams to help illiterate people understand their routine.

Many doctors expressed that literacy rate played a critical part in how their patients adhere to their prescribed therapies. If individuals lack education they rely heavily on remembering the verbal instructions given by doctors and pharmacists. Without being literate, they are unable to refer back to written directions which can cause a level of confusion especially if a medication routine is complex or the individual is suffering from a condition that impairs their memory. Whether or not literacy is the direct cause, our surveys do show a correlation between literacy and nonadherence - both intentional and not.

Additionally, doctors express that a number of their patients will research prescribed medications and determine if they believe the potential side effects will be worth the benefits of taking the medicine. This causes many individuals to choose to not take their medication or only take it until they are feeling better. They do not trust the judgement of doctors and choose to medicate based on the information found on the internet.

To understand patient needs, we collected information about their age, education, type of family, and the type of condition they were managing, because these areas have been shown to be factors of medication adherence (Sabaté, 2003). The demographics of the region can be seen in Figure 11.

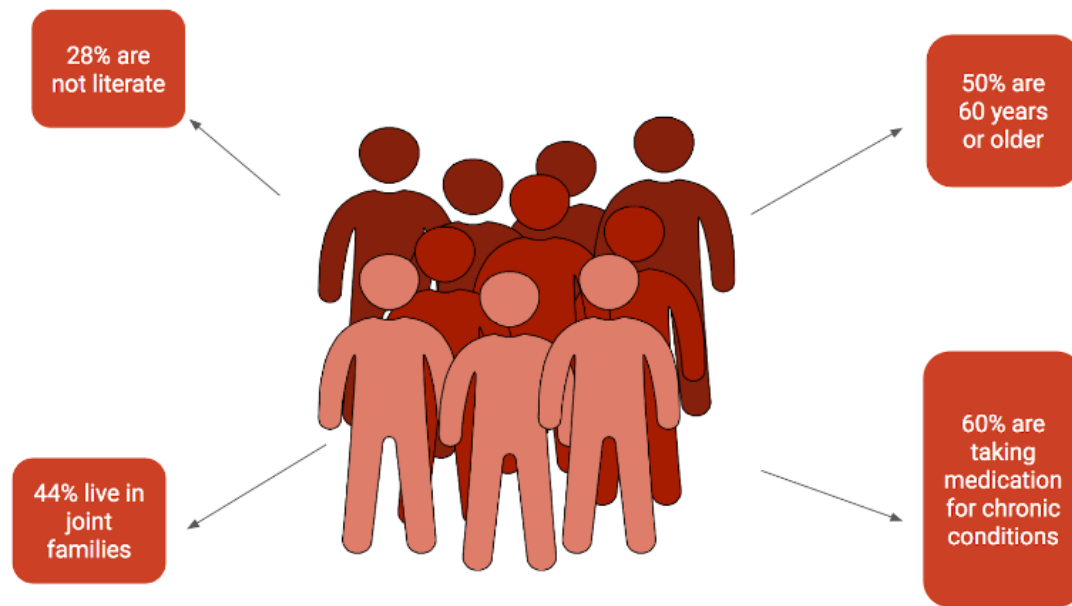


Figure 11: Patient survey demographic information

After collecting basic demographic information, we began asking questions about specific medication routines. We found that:

- The average number of pills taken each day was 4.46
 - This number increased by 0.4 when looking at only patients with chronic illnesses
- The average frequency of nonadherence, rated on a 1-4 scale (1 being rarely missing a dose, 4 being almost always missing), was 2.13.
 - Strangely, this number did not change much for either chronic or elderly patients
- 60% of patients surveyed sometimes forget their medicine.
 - Illiterate patients were 26% more likely to forget medication than those who were not.
 - Patients at or above the age of 60 were 16% more likely to forget medicine than those who were not.
- 28% of patients surveyed sometimes intentionally chose not to take their medicine.
 - Illiterate patients were 20% more likely to intentionally skip medication than literate ones.
- 40% of patients surveyed said they need or want aid of some kind to take their medicine.
- 44% of patients surveyed said they have medicine routines complex enough to hinder adherence.
- 42% of patients surveyed said that they had trouble dispensing their medication.

Caregivers were interviewed to assess how family members and highered aid play a role in medication routines and adherence. It was found that seven out of ten caregivers played an active role in managing a medication routine because the patient would forget to follow their proscribed therapy. Additional reasons listed by caregivers as reasons for medication nonadherence by the patient were as follows: they start feeling better and see no need for the prescribed medication, they have a casual attitude regarding their medication, or they are not educated on the medication that is prescribed to them, and therefore they do not know how the medication will benefit them.

Interest of an automatic medicine dispenser

Overall, the doctors that we interviewed thought that a device would be useful. When asked about the feasibility of an automatic medicine dispenser, 91% of the interviewed doctors stated that a device could help patients adhere to a prescribed medication routine. They particularly noted its usefulness for bedridden or severely sick patients, as well as those suffering from conditions that may affect memory. 73% doctors thought that patients would use a device if it was free or nearly free, and 64% made it known that including an emergency alert system for missed pills would be a valuable addition. Many doctors we interviewed also expressed interest in a generated report from the device that would allow them to survey the level of medication adherence from their patient and look for ways to increase this number or alter a prescribed routine to best fit the lifestyle of the patient.

Patients generally agreed that a device would be a good idea. When they were presented with the idea of a medication device, 78% of those surveyed said that they would be interested in using alarmed-automatic medicine dispensing device. From their responses, we determined that a device has the potential to be effective and well-received by patients taking medication. However, the vast majority stated that the device must be extremely affordable and easy to use or they would not consider purchasing it. Very few were not receptive to a device.

Caregivers who were interviewed all agreed that they believe an automatic medicine dispensing device would aid in increasing medication adherence. However, only 8 of the 10 who were interviewed said they would utilize a device to help the individual taking medication on a routine basis. This may be because some individuals currently have ways to effectively handle medication, such as simple medication boxes, or simply may not need a device at all.

Our Feature Grid surveys allowed us to determine what patients, caregivers, and medical professionals thought of each potential feature or aspect of the device. We allowed them to choose the importance of each feature on a scale of 0-4 (0 being not important at all, and 4 being essential). In all, 17 individuals were surveyed. The averages of the results are as follows:

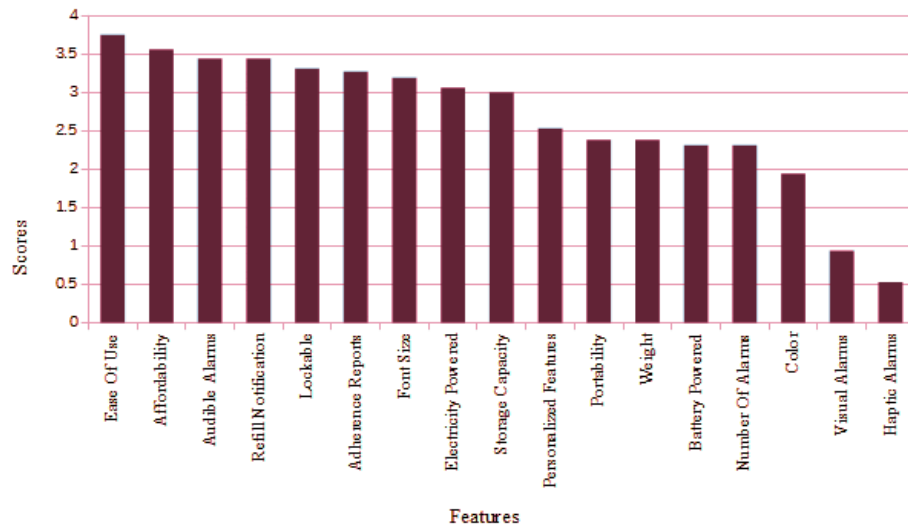


Figure 12: Ranking of features by average importance

The feature grids highlighted some important design choices in our project. For example, they confirmed for us that ease-of-use and affordability were absolutely essential to the device, as our initial interviews suggested. These scores were averages with slightly varying denominators due to people leaving features unranked. Top scoring features were also audible alarms, refill notifications, and the ability to lock the container. Interestingly, the question about the number of alarms saw mixed results, and haptic alarms were almost unanimously

determined as not being important. Some other features were also suggested: one person noted that the device should be transparent, so that medicine may be visible, and another noted that it should be marked with a red cross, or other medical symbol. We used these results to focus our device design, and ultimately created a device that provided the core features listed here.

Design of the prototype

In our design stage, we used the information we had gathered from the surveys and evaluation rubric to determine a list of features needed in our device. From this, we began production and created a prototype. The design of a single module is shown below in Figure 13, with detailed specifications available in Appendix F.

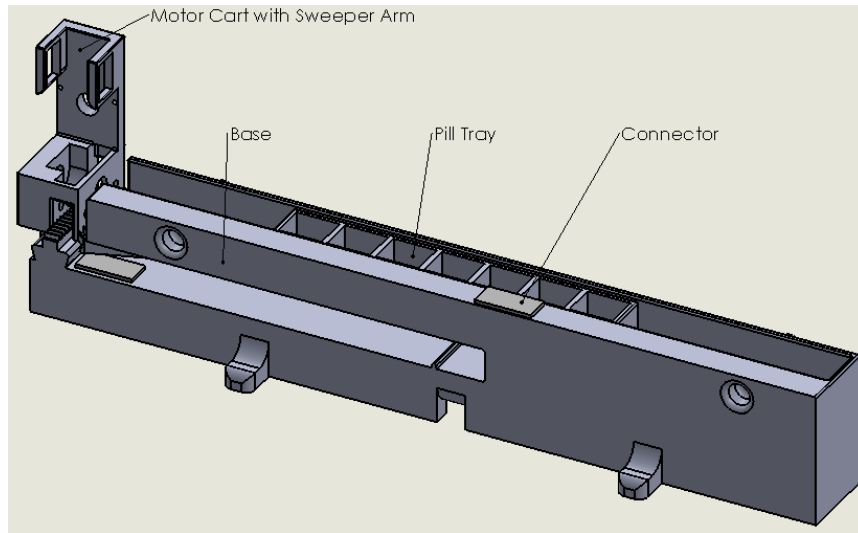


Figure 13: Design illustration

The device was made with ease-of-use in mind. After the medicine schedule is programed into the device via a keypad and the medicine has been loaded into easy-to-fill trays, the device automates the entire process of dispensing, providing alarms, and emergency and refill notifications.

The design is modular, allowing users to purchase inexpensive modules if they take more types of medicine or require a larger capacity. This allows cost to be minimized, as users do not need to pay for more material than they need. New modules can be easily added simply by clicking them in to built-in pegs. Additionally, the entire device is driven with only two motors, and one computer. This number does not increase as modules are added, which further reduces costs. This ultimately allows the device to be produced inexpensively, albeit at the cost of physical size.

Additionally, the device is lockable, can provide adherence reports, and the storage capacity can be increased according to the patient's needs. Unfortunately, the device does have some shortcomings. In order to focus on certain features, we had to make sacrifices to other aspects of the device. Specifically, our design lacks portability, a battery failsafe, and is somewhat heavy. These are issues that can potentially be addressed by other products, or future designs.

Empathic intelligence testing was critical in the development of our design and can be seen in Figures 14 and 15. Through its practice, we determined that our device was easy to operate even with limitations to visibility and dexterity. The trays were large enough to allow for easy loading, and the device's construction minimized operating difficulty. We did find, however, that removing pills from containers or picking up dropped pills could be difficult.



Figure 14: Empathic intelligence testing



Figure 15: Loading the device with simulated impairments

Stakeholders' reactions and suggestions

In order to identify areas of improvement in our device, we went back to three of the doctors we interviewed who showed interest in seeing the final prototype work. The general response was a positive one with remarks such as “the device is good and it is beneficial to the patients”. However, one doctor in particular, rose the concern that companies in India may not produce the device on a large scale while selling it at an affordable cost to the patient. He said that the device should be made even cheaper so that any individual would be able to afford it. The prototype design was well received and we were commended for our efforts by the doctors. They are eager to see the device grow and become incorporated into the medical field.

Discussion

Through our interviews and surveys, we established that medication nonadherence is a complex issue in the state of Himachal Pradesh. Due to the multitude of factors that influence adherence, no single approach will solve the problem completely. However, through our interviews with doctors and patients, we found that a great majority were enthusiastic about a device that could be utilized by patients and medical professionals. They believed that a device could be helpful for a number of patients, especially if the device was affordable.

While a device can be used to aid a number of people, we cannot confidently state that our proposed device will meet all the needs of individuals taking medication. There are a large number of barriers that must be overcome when it comes to new innovations. The diffusion of a new medical technology into a community is just as complex as medication adherence. Medication devices seem to promise better health and well-being but are often perceived as expensive. We worked to address the concerns and needs of the stakeholders in the region in order to avoid creating a product that would fail to be integrated into the community. Even with keeping the needs of medical professionals, patients, and caregivers in mind, our prototype would still have many obstacles it would have to overcome if the design is ever manufactured.

We learned that some issues are outside the scope of the device, including miscommunication between doctors and their patients. Both patients and doctors need to work together in order to address the root causes of medication nonadherence. Medication adherence is a shared responsibility of doctors and pharmacists, not solely the patient. To optimize a device, doctors would have to work to educate their patients on the benefits of utilizing the device, how to operate it, and be open to answer questions continuously. If a device were to be implemented without an educational or training aspect, it would be significantly less effective.

It was acknowledge that there is a strong likelihood of individuals misreporting their levels of adherence. Some cases of inaccurate reporting may be intentional misreporting because individuals may feel ashamed for forgetting to take medication or embarrassed to say they

want to spread their dosages out to save money. Other patients may not even know they are taking their medication incorrectly if their routine was communicated poorly to them in the beginning.

Project outcomes

To advance the idea of the automated medicine dispenser, and the improvement of medication adherence overall, we have several recommendations.

Device

First, we recommend adding 3 features to a design in a future prototype. These are features that our project simply did not have the time or resources to address:

- A battery system that can ensure operation during a power failure
- New motors with encoders could be used to allow for better and more reliable motor control
- Refining the design to be streamlined and more compact

Further testing

Next, more research is needed on the use and effectiveness of the device and whether or not it would be accepted and utilized throughout the community. This may require in-depth testing or a case study. This would allow for the overall effectiveness of a device to be evaluated and observed firsthand, and is necessary to identify and address problems that may be encountered with introducing such a device to Himachal Pradesh.

Patient communication and support

Finally, the greater context of medication adherence should be further explored in more detail, as there are many factors that contribute to a patient's nonadherence. Firstly, more interviews and surveys should be conducted with a larger sample size to better understand these factors. In one interview with a large group of doctors, they all communicated that the device may help some patients, but that no device could address the underlying problems of the medical system and medication adherence practices in Himachal Pradesh. Namely, these problems stem from a lack of education in the general population, which leads to misuse or mistrust of the medical system, as well as the general disorganization of the government hospitals and treatment process. This was supported by our survey results, which showed that literacy can be an important factor in medication nonadherence, and particularly in intentional nonadherence.

Furthermore, the doctors noted that the government hospitals saw many, many patients in a day, and each patient spends hours waiting to see a doctor, then hours more to get their medicine from a pharmacy. If this process was streamlined, they predict, significant improvements could be seen in medication adherence. Concerns, particularly those about education, were also raised throughout many of our other interviews with medical professionals. These both presented significant topics for future studies.

Ultimately, the concept of our device was accepted by medical professionals, patients, and caregivers in the region. They supported the creation of our prototype, and believed that introducing a device would help patients maintain consistent habits regarding their medication routines and aid in increasing medication adherence.

Conclusion

Our project aimed to develop a prototype of an automatic medicine dispenser to increase medication adherence. We created a device that could help patients to remain independent while improving their medication routines. Balancing a routine medication schedule can be daunting, confusing, and incredibly difficult for many patients and caregivers. We designed a product that works to support the quality of patient life, lessen medication waste, and establish a healthy medication routine.

Our analysis of patient, caregiver, and doctors' concerns brought us greater empathy for the experiences of patients and the causes for prescription nonadherence in Himachal Pradesh. As we move towards a world where people are living longer, and with less support from extended families, there is a need to adapt and modernize our approach to medicine. Simple devices like this can save money and lives, and can also create healthy medication routines that lower hospital readmission rates and stop the spread of communicable diseases. Ultimately, we hope that our final design and prototype represent a medicine-dispensing device that will reduce medication nonadherence in the state of Himachal Pradesh.

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Supplemental Material

Appendix A: Tables

Table 1: Devices Currently Available

Attributes of products currently available

(In the US - we have not found any devices at all in pharmacies throughout Himachal Pradesh)

Device Name	Company	Cost*	Features	Image
ForgettingThePill: Four-Alarm Pill Organizer	ForgettingThePill	\$17.99	- Affordable - Extremely portable - Audible and vibrating alarm	
e-pill Multi-Alarm TimeCap - Simple Pill Timer (One Medication)	e-pill	\$29.95	- Multiple Alarms - Tracks when meds are taken - Visual and audible alarm	
MedCenter Monthly Pill Box with 4 Alarm Timer	e-pill	\$84.95	- Large capacity - Multiple alarms - Easy-to-read display - Easy to access compartment	

Philips MD.2	Philips Lifeline	\$59.95 Per Month	- Large capacity - 18-hour emergency battery - Reminders for non-pill medications - Reminders for medication instructions - Lockable - Caregiver alerts	
MedMinder: Jon – Locked Pill Dispenser and Medical Alert	MedMinder	\$64.99 Per Month	• Easy-to-use • Usage Reports • Emergency Alerts • Custom Greetings • Large Capacity	
e-pill MedSmart PLUS Monitored Automatic Pill Dispenser Free Lifetime Monitoring	e-pill	\$789.95	• Automatically dispenses each dose. • Caregiver Alerts • Refill notice • Lifetime monitoring • Lockable • 6-month battery • Large capacity	

**All prices are \$USD, recorded at the time of writing*

Table 2: Analysis of Common Product Features

Feature	Cost (Generalized)
Multiple Alarms; Audible and visual alarms	Low cost. Almost every device we have seen has this capability, regardless of price.
Portability	Low cost. This feature is almost unique to the low-cost devices, with few more expensive products offering portable options.
Battery Life (If applicable)	Low cost. All devices that require power tend to have long battery lives, regardless of price.
Storage Capacity	Medium cost. Cheaper devices can only store limited amounts, but more expensive devices quickly reach month-long capacity.
Ease of use (for the patient)	Medium cost. Although seems to be proportional to price across the entire price range, design and manufacturing options allow some cheaper devices to be easy as well.
Lockable	Medium cost. Cheaper devices tend to disregard this feature.
Emergency alarms, caregiver alerts, or other adherence-reporting	High cost. Devices that exhibit these features tend to be very expensive.

Appendix B: Interview Guide for Medical Professionals

1. How are your patients currently managing their medication routines?
2. What are the most common causes for medication nonadherence?
3. Do individuals more commonly forget to take medication or choose not to take medication? Why?
4. Do patients rely on a caregiver to take their medication? (Yes or No) Why?
5. How frequently do you observe hospitalization for medication nonadherence?
6. Do you believe a device could aid in increasing medication adherence? Why or why not?
7. Do you believe patients would utilize an automatic medication dispenser? Why or why not?
8. Do you feel it is necessary to have a safety feature that notifies emergency personnel if a dose is missed? (Yes or No)
9. What locations would be best for administering surveys to patients? Why?
10. What changes could be made to the patient and caregiver questionnaires?

Appendix C: Medication Adherence Questionnaire

Age- Gender- Literate -

1. Do you sometimes forget to take your prescribed medication?
2. Do you ever choose to not take your medication? If so, what are your reasons for doing so?
3. Do you need any aid to take medication?
4. Does the complexity of your medication schedule affect how you are taking your medication?
5. Is it difficult to acquire the correct dosage?
6. Are there other factors that we have not addressed that make taking medication more difficult?
7. Are you taking medication for a chronic/acute disease?
8. Are you living in a joint/nuclear family?
9. How many pills are you taking daily?
10. How often do you not take your medication? (Circle one) |
Never/Rarely.....1
Once in a while.....2
Sometimes.....3
Usually.....4
Always.....5
11. Can you think of anything that would improve your medication routine?
12. Would you like to use a device that automatically dispenses your medicine? Why?

Appendix D: Caregiver Survey - Medication Adherence

(This survey is to be answered with regard to an individual who is taking medication on a routine basis.)

1. How do you currently monitor medication routines?

2. Do(es) the patient(s) receiving your care forget to take their medication?

3. How often do they not take their medication? (Circle one)

Never/Rarely.....1

Once in a while.....2

Sometimes.....3

Usually.....4

Always.....5

4. What causes them to not to adhere to a medication routine?

5. Does this individual ever choose to stop taking medication? (Yes or No)

6. Would giving care to your patient be easier with the use of an automatic medication dispenser? If yes, will you purchase such device?

7. Do you feel it is necessary to have a safety feature that notifies emergency personnel if a dose is missed? (Yes or No)

Appendix E: Feature Importance Grid

(to be filled out by medical professionals, patients, and caregivers)

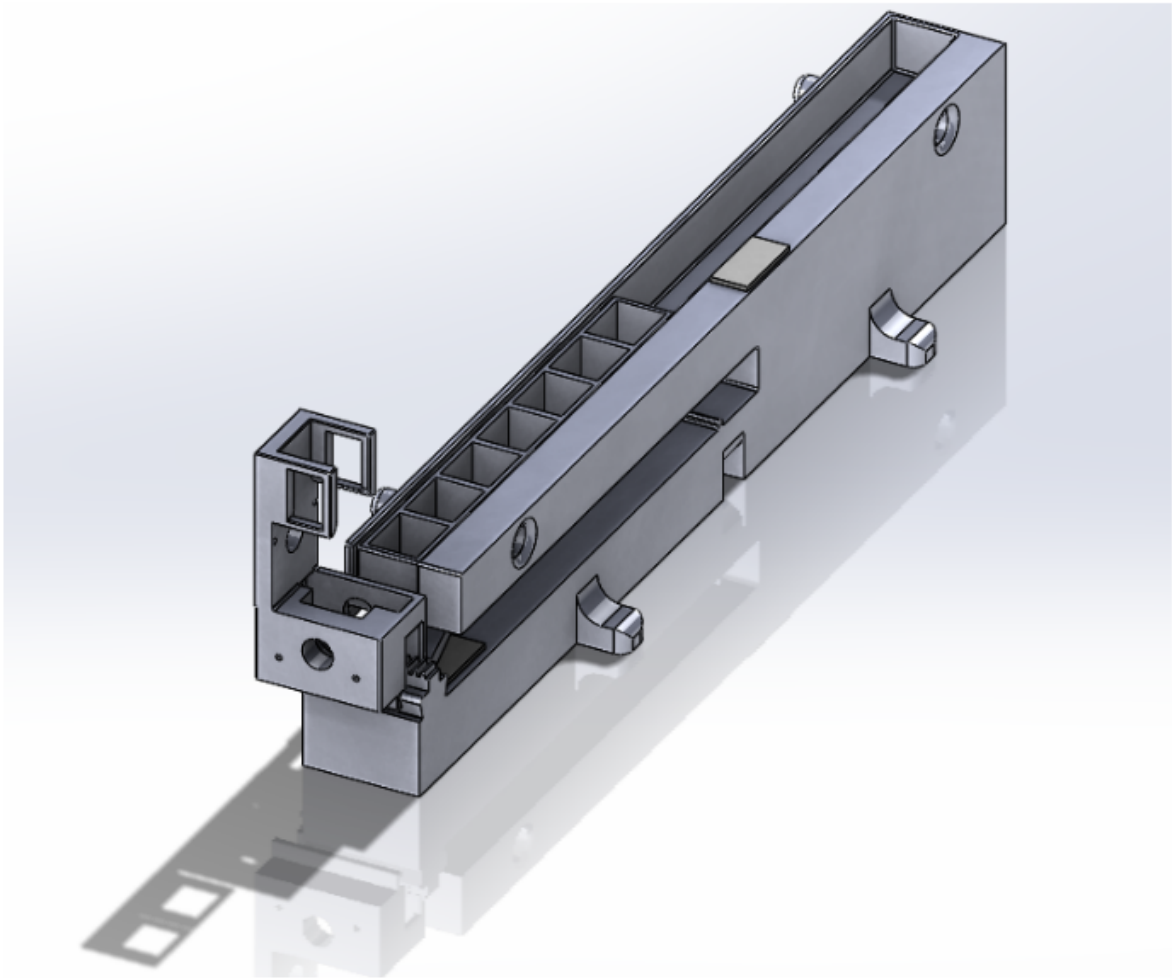
What is important in a medicine dispenser: Please check mark the box you feel is most appropriate for each feature.

	Not important at all	Slightly important	Moderately important	Very important	Extremely important
Color					
Weight					
Font Size					
Portability					
Battery Operated					
Electricity Operated					
Ease of use					
Affordability					
Storage capacity					
Number of Alarms					
Audible alarms					
Haptic alarms					
Visual alarms					

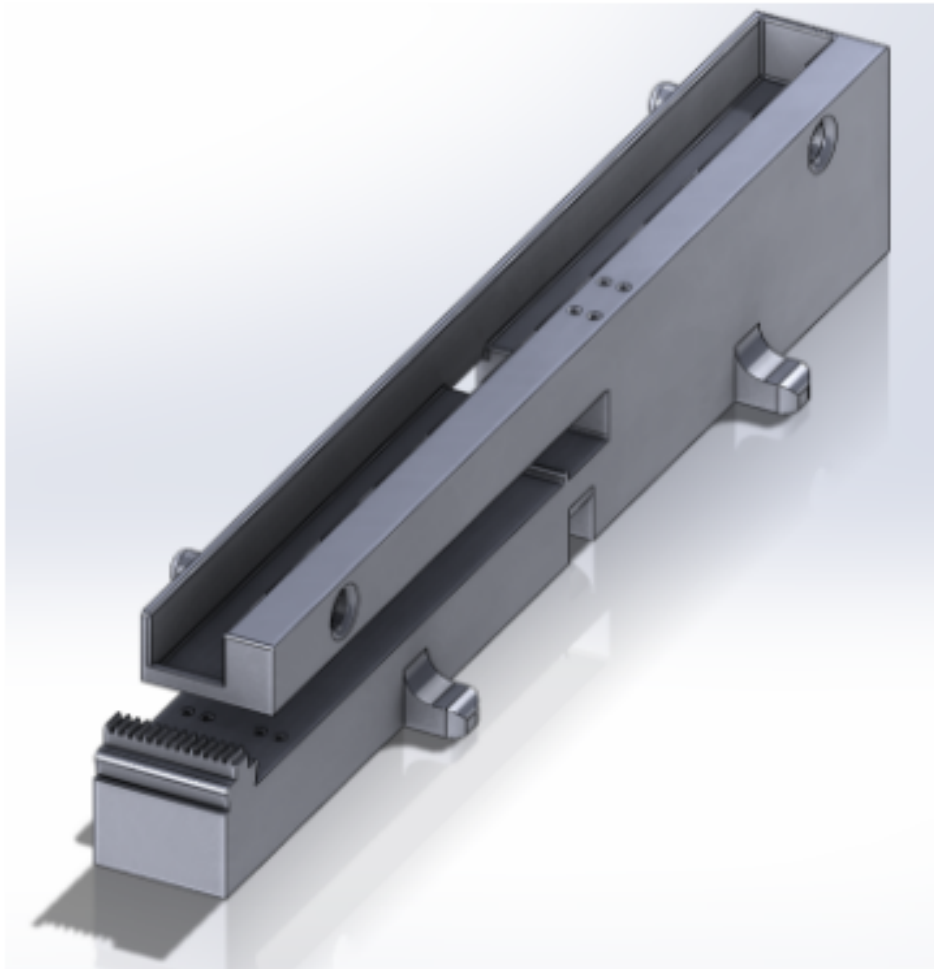
Lockable					
Refill notification					
Adherence reports					
Personalized features					
Other (specify)					

Appendix F: CAD Drawings

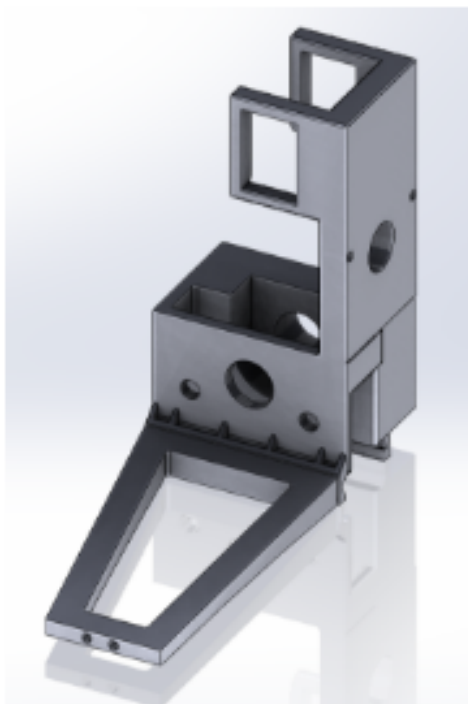
Full Module



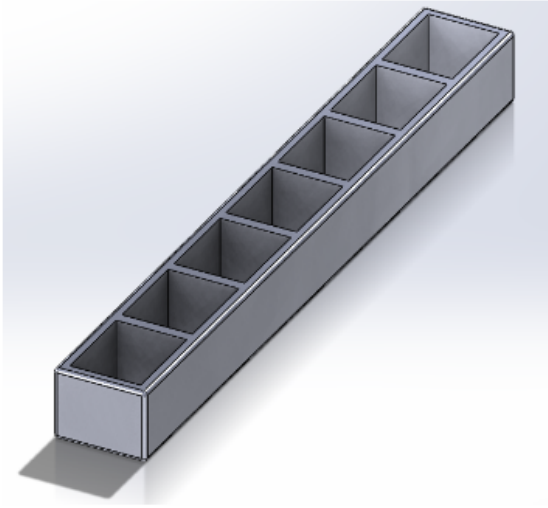
Module Base



Motor Cart



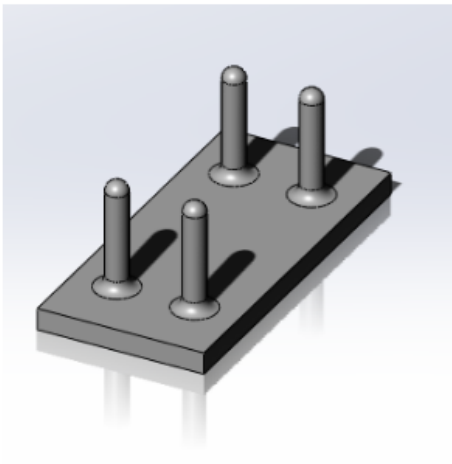
Pill Tray



Sweeper Arm



Connector



Appendix G: Detailed Timeline

Below is the proposed timeline for the project until completion for the duration that we are in India. It has recurring events on the timeline to account for product progress and revision. It is split into three parts.

Weeks 1-3:

PROJECT TITLE				EZ Medicine Dispenser		ORGANIZATION		Worcester Polytechnic Institute and IIT Mandi										
						DATE		3/12/18										
TASK TITLE	START DATE	DUE DATE	DURATION	WEEK 1					WEEK 2					WEEK 3				
				M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Social Interaction																		
Site Calibration/Orientation Course	3/12/18	3/16/18	5															
Data Collection (Surveys / Interviews)	3/19/18	3/28/18	10															
Field Test Current Products	3/26/18	3/28/18	3															
Focus Group (Test Prototype)	4/9/18	4/13/18	5															
Field Test/Deploy Product	4/18/18	4/25/18	8															
Gather Feedback On Product	4/23/18	4/25/18	3															
Product																		
Brainstorm Possible Designs	3/26/2018	3/27/18	2															
Model The Design	3/28/2018	3/29/18	2															
Prototype The Model	3/30/2018	4/11/18	13															
Revise The Prototype	4/11/18	4/17/18	7															
Finalize Product	4/26/18	4/27/18	2															
Report																		
Structure Report	Reoccurring	Reoccurring																
General Report Writing	Reoccurring	Reoccurring																
Document Findings And Progress In Report	Reoccurring	Reoccurring																
Finalize Report Based On Data Feedback	4/30/18	5/1/18	2															
Turn In Report	5/1/18	5/1/18	1															

Weeks 4-6:

TASK TITLE	START DATE	DUE DATE	DURATION	WEEK 4					WEEK 5					WEEK 6				
				M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Social Interaction																		
Site Calibration/Orientation Course	3/12/18	3/16/18	5															
Data Collection (Surveys / Interviews)	3/19/18	3/28/18	10															
Field Test Current Products	3/26/18	3/28/18	3															
Focus Group (Test Prototype)	4/9/18	4/13/18	5															
Field Test/Deploy Product	4/18/18	4/25/18	8															
Gather Feedback On Product	4/23/18	4/25/18	3															
Product																		
Brainstorm Possible Designs	3/26/2018	3/27/18	2															
Model The Design	3/28/2018	3/29/18	2															
Prototype The Model	3/30/2018	4/11/18	13															
Revise The Prototype	4/11/18	4/17/18	7															
Finalize Product	4/26/18	4/27/18	2															
Report																		
Structure Report	Reoccurring	Reoccurring																
General Report Writing	Reoccurring	Reoccurring																
Document Findings And Progress In Report	Reoccurring	Reoccurring																
Finalize Report Based On Data Feedback	4/30/18	5/1/18	2															
Turn In Report	5/1/18	5/1/18	1															

Week 7:

TASK TITLE	START DATE	DUE DATE	DURATION	WEEK 7					WEEK 8				
				M	T	W	R	F	M	T	W	R	F
Social Interaction													
Site Calibration/Orientation Course	3/12/18	3/16/18	5										
Data Collection (Surveys / Interviews)	3/19/18	3/28/18	10										
Field Test Current Products	3/26/18	3/28/18	3										
Focus Group (Test Prototype)	4/9/18	4/13/18	5										
Field Test/Deploy Product	4/18/18	4/25/18	8										
Gather Feedback On Product	4/23/18	4/25/18	3										
Product													
Brainstorm Possible Designs	3/26/2018	3/27/18	2										
Model The Design	3/28/2018	3/29/18	2										
Prototype The Model	3/30/2018	4/11/18	13										
Revise The Prototype	4/11/18	4/17/18	7										
Finalize Product	4/26/18	4/27/18	2										
Report													
Structure Report	Reoccurring	Reoccurring											
General Report Writing	Reoccurring	Reoccurring											
Document Findings And Progress In Report	Reoccurring	Reoccurring											
Finalize Report Based On Data Feedback	4/30/18	5/1/18	2										
Turn In Report	5/1/18	5/1/18	1										

MEDICATION DISPENSING DEVICE TO IMPROVE ADHERENCE

Authors: Dillon Arnold, Jacqueline Garcia, Amit Ghanghas, Anshu Puri, Simon Redding, & Pankaj Sheoran
Advisors: Dr. Vishal S Chauhan Dr. Ingrid Shockey, & Dr. Seth Tuler



—Abstract—

Medication nonadherence is a pressing issue in northern India. This problem causes many deaths and allows communicable diseases to develop drug resistance. A medicine-dispensing device offers a potential way to help patients strengthen medication routines and improve their overall adherence. Data specific to this region was gathered through interviews and surveys with doctors, pharmacists, caregivers, and patients in the state of Himachal Pradesh. A prototype was developed to explore the potential of a medicine-dispensing device to improve adherence in the region. The prototype was shown to stakeholders with positive reception.



— Medication Nonadherence —



50% of medication globally is not taken according to prescribed therapy.



14% of India's elderly population is living independently.



17% of individuals in Himachal Pradesh are illiterate.



20% of India's population is suffering from a chronic condition.



21.2% of India's population is at or below the poverty level.

— Implications in Himachal Pradesh —

Doctors

91% said that nonadherence is a pressing issue.

91% reported there are serious consequences of nonadherence.

55% said patients manage routines through verbal or written instructions.

Patients

28% are not literate.

50% are 60 years or older.

60% manage chronic conditions.

44% live in joint families.

60% of patients occasionally forget to take their medicine.

Illiterate patients were 26% more likely to forget medication than those who were not.

Patients at or above the age of 60 were 16% more likely to forget medicine than those who were not.

28% of patients surveyed sometimes intentionally chose not to take their medicine.

Illiterate patients were 20% more likely to intentionally skip medication than literate ones.

44% of patients surveyed said they have medicine routines complex enough to hinder adherence.

Caregivers

"Start feeling better and see no need for the prescribed medication."

"Have a casual attitude regarding their medication."

"Not educated on the medication that is prescribed to them, and do not know how the medication will benefit them."

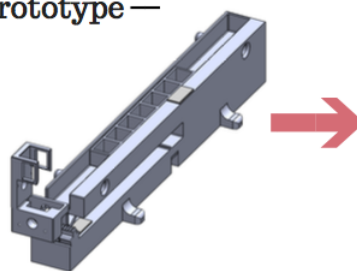
91% OF DOCTORS BELIEVED A DEVICE COULD HELP PATIENTS ADHERE TO A PRESCRIBED MEDICATION ROUTINE.

78% OF PATIENTS SAID THEY WOULD BE INTERESTED IN USING AUTOMATIC MEDICINE DISPENSING DEVICE.

80% OF CAREGIVERS SAID THEY WOULD UTILIZE A DEVICE TO HELP THE INDIVIDUAL TAKING MEDICATION.

— Proposed Prototype —

EASE OF USE
AFFORDABILITY
AUDIBLE ALARMS
REFILL NOTIFICATIONS
LOCKABLE



— Recommendations —

Device Improvements

- A battery system that can ensure operation during a power failure.
- New motors with encoders could be used to allow for better and more reliable motor control.
- Refining the design to be streamlined and more compact.

Testing

- In-depth testing or a case study.
- Effectiveness of a device should be evaluated and observed.
- Identify and address problems that may be encountered with introducing such a device.

Educational Programs

- Increase schooling and education in the area. Lack of education in the general population leads to misuse or mistrust of the medical system, as well as the general disorganization of the government hospitals and treatment process.



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