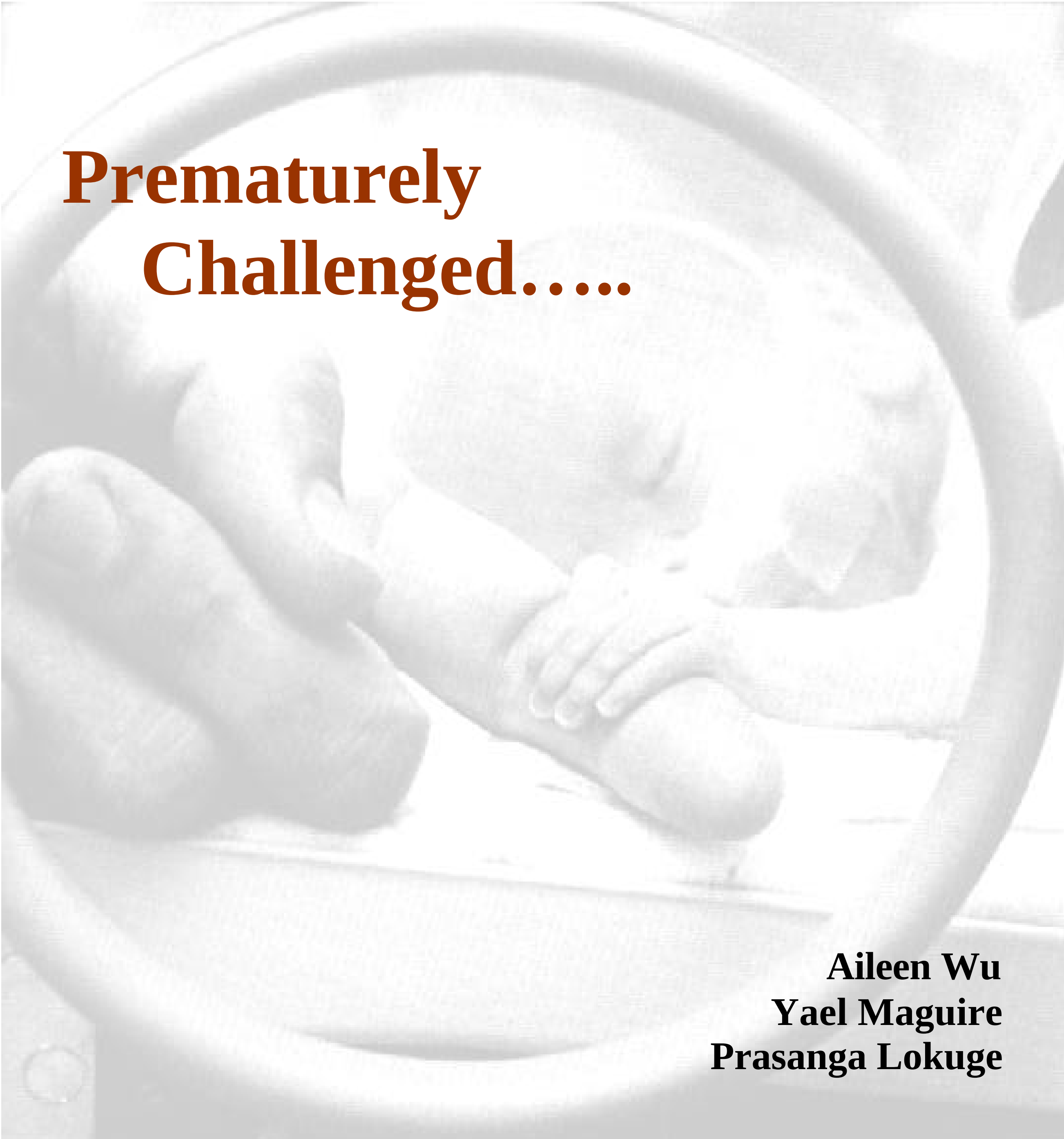


Prematurely Challenged…..

Aileen Wu
Yael Maguire
Prasanga Lokuge

Prematurely Challenged….

Background

As war and ethnic conflicts continue to grow at an alarming rate worldwide, there is an ever increasing population of people whose lives are affected, directly or indirectly. International relief workers flock to these areas of extreme political uncertainty, to provide support, and work in the most challenging circumstances to sustain lives. Breakouts of an epidemic, wounded civilians and complicated pregnancies are a few of the cases they deal with. The lack of clean drinking water and electricity in most parts of these countries is worsened by the deficiency of appropriate medical equipment to address these issues. Doctors without Borders (DWB) is one group working in this context for the past 30 years. Our primary contact at DWB, Dr. Kelly McQueen has had extensive experience with displaced refugees in several war torn parts of the world. However, to focus our design ideas to a particular community, we have concentrated on the Sinhala-Tamil border in Sri Lanka, where Dr. McQueen has spent an extensive period of time.

Sri Lanka is an island off the south east coast of India. It is home to 18 million people and a plethora of religions, traditions and cultures. However, the country has been in a state of ethnic war for the past two decades. The war has had a terrible impact on the civilian population of the country. One particular group of people that has been affected is the occupants of a town called Mallavi that lies in the border zone that separates the two ethnic territories. Our design targets the most vulnerable of these occupants - the prematurely born infants. With very poor maternal healthcare and nutrition, the occurrence of premature births in this region has increased over the past decade. Many deaths go unrecorded, since these births do not occur in hospitals. This number is just a tiny representation of a worldwide problem, where war has robbed many infants of life.

Our hope is to design a safe incubator that will run independently of electricity, be portable and robust in the given terrain, need minimal operating capabilities, and will keep the infant warm and hydrated.

Even though our current design is geared toward premature infants in war torn regions of the world, we believe the design will have broad applicability in any geographical context where portability, cost and energy are primary concerns.

Existing solutions:

Currently, there are no procedures in place in Mallavi to deal with premature infants. The best that can be done is to transfer the infants to a hospital further south of the border. However, many do not make it to the hospital in time. In this context, we have no existing solutions to compare our device to. Since the most basic needs of a premature infant are to be kept warm and hydrated, our device will perform the function. However, in other cases in which the infant may suffer from more severe complications such as respiratory failure our device may also serve as a transport incubator, to house the infant, until it reaches the city hospital.

Innovation

Our Solution:

Premature infants are at a disadvantage since their organs are underdeveloped and they lack thermoregulatory capabilities. They lose heat via evaporative, conductive, convective and radiative means. This also results in the loss of water from the body, causing an imbalance of salts and a potentially fatal build up of acid within their system. Since most premature infants have underdeveloped livers, they experience an accumulation of bilirubin resulting from the breakup of hemoglobin in their system, causing jaundice. Our device aims to provide the infant with the bare necessities required to combat these problems. These are:

- an ambient temperature of 34^{o}C-37^{o}C
- a humidity greater than 70% RH
- a sterile air supply
- visible light

With an average temperature of about 30^{o}C and an average relative humidity of 70% in the immediate environment, our most important design elements are:

- An ideal heat source/sink that can maintain the ambient temperature in the 34^{o}C – 37^{o}C range for as long as possible- ideally 24 hours, with minimal monitoring.
- An effective air purification system that will remove bacteria.
- An effective thermally driven air purification system that will provide the oxygen the infant needs while removing harmful bacteria and particulate material.
- An insulating, sound reducing container to house the infant and the heat source that will enable easy access to the infant when needed.
- A medium to allow visible light through to address the jaundice issue.
- A robust, portable container that can be easily dismantled and set up and will require minimal operation capabilities.

We have designed and are in the process of prototyping an incubator shell that will meet these needs. The design can be divided into the following segments:

The Incubator Case:

The basic design chosen for the incubator case is a small tent structure, chosen for cleanability, durability and simple, compact transport. We have chosen the simplest design for a dome tent with square base that is self-tensioning and uses the smallest amount of materials. Figure 1 is a 3D model of the design, with figures 2 and 3 showing

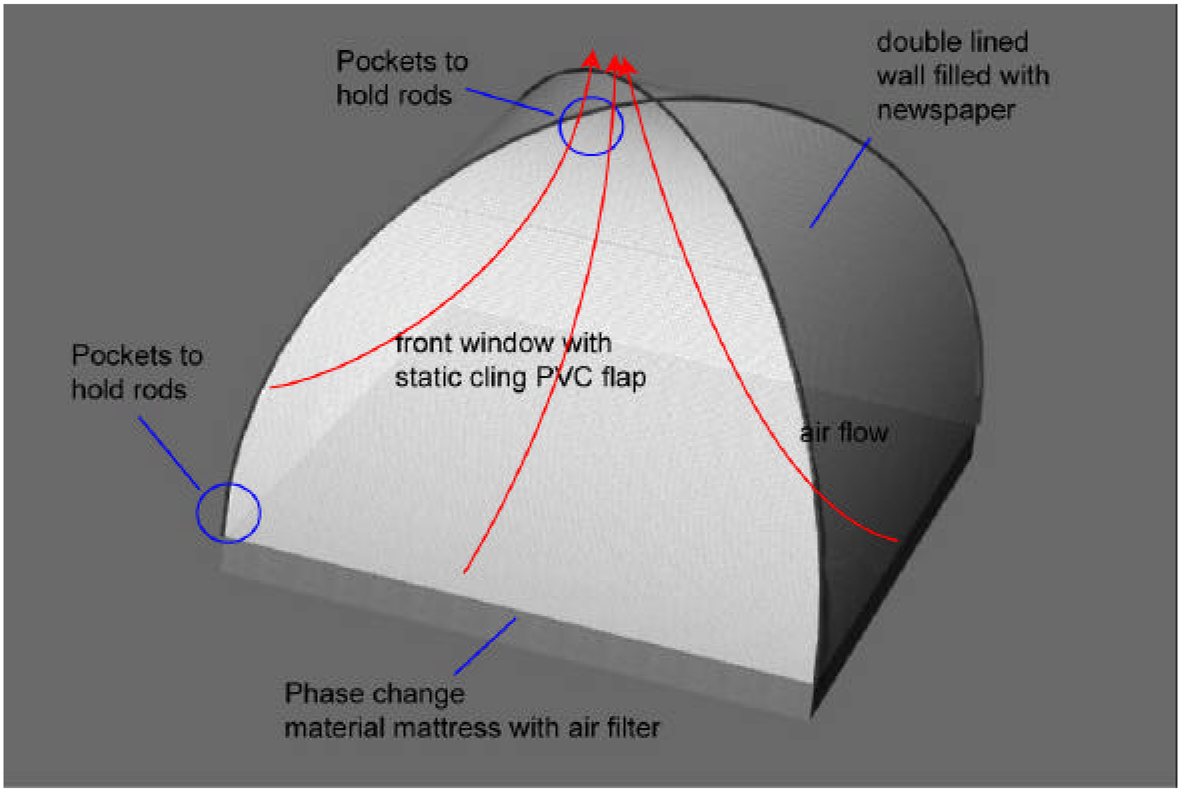


Figure 1 3D rendering of basic tent structure with phase change material mattress

early prototypes. The square base length is 15”, large enough to easily accommodate a 1.2kg infant with enough room to allow a nurse or doctor to maneuver inside. Two semicircular arcs made of spring steel, aluminum, hot-pulled carbon fiber or even pre-tensed wooden dowels are inserted into a single, sewn piece of fabric. There will be pockets at the four corners made of fabric that will hold the arcs in place from their originally straight geometry. Figure 2 shows the structure held together by string using carbon fiber rods. Guide paths made of fabric near the top of the dome will cross the two arcs holding everything in place. The fabric will have to be a reasonably air and water tight material like sailcloth (polyester or nylon fibres) so that air flow and heat loss can be controlled. As can be seen from Figure 1, there are four panels of fabric. Unlike a tent which has poor insulation, three panels of the incubator will be double layered and filled with newspaper to minimize radiative, convective and conductive heat loss. Under the suggestion of Professor Cravalho at MIT, multiple layers of newspaper serve as an excellent insulating material for both radiative and conductive heat loss. Newspapers should be readily accessible in most countries, including Sri Lanka. The fourth panel will be a clear polymer providing physical and visual accessibility. This will help address the need for visible light to treat jaundice. Zippers are expensive and don’t form good seals, so a flap will be incorporated into this window. Inside the flap will be an inexpensive reusable adhesive such as static cling vinyl that will form an airtight seal to prevent heat loss. It is possible that this window will provide loss of heat via radiative loss, but we hope that greenhouse effect from natural sunlight or room lights will compensate (or even overcompensate) for this loss.

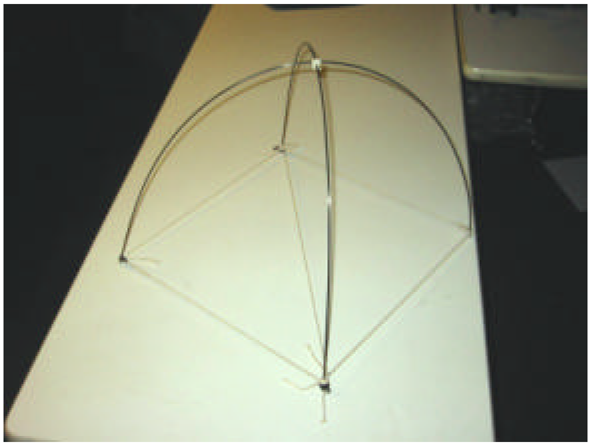
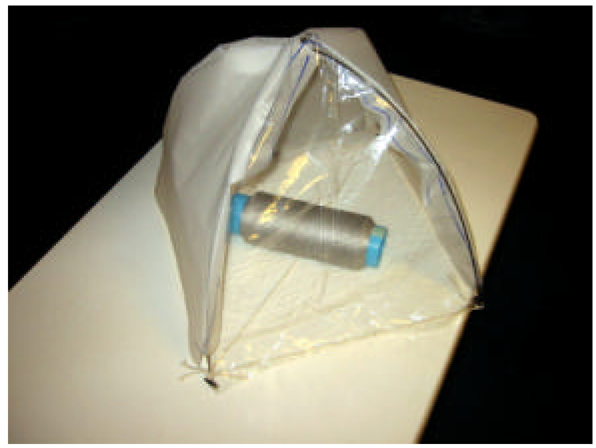


Figure 2 Frame structure of the tent showing the carbon fiber rods held together by string

Figure 3 Kite fabric with window cover. The pockets in the corners are not yet incorporated so the fabric is not under tension.



The bottom of the tent will be a double layered floor. It will contain an opening to slide in the heating mattress, made of a fabric/foam matrix of phase change material to be described below. Connecting the dome panels to the mattress will be a tight mesh that will filter the air of airborne particulate matter and biological agents such as bacteria. The filter and air supply will be driven by the difference in density of the hot air at the bottom and at the top (like a fireplace) with an exit port at the top of the dome.

This structure should be easy to take apart and re-assemble. One simply has to unhitch a rod out of its pocket and then the other three ends will easily come out. The phase change mattress can be slid in and out easily. With the water tightness of the fabric, the entire fabric can be washed in hot water or sprayed clean.

The Heating Element:

We are employing a passive thermoregulation system in our product that utilizes the chemical properties of phase change material. The unique self-regulatory property of PCM enables our incubator to be relatively low maintenance. The PCM material will be encapsulated within microspheres and housed in conductive foam encased in a waterproof sac. To operate, an attendant would simply need to heat the sack in a water bath. Photo chromic ink in the sack would indicate the right time to introduce the warm sack into the incubator.

Phase Change Material

When a PCM is adequately charged with energy, it is able to maintain a constant phase change temperature whether it is at its melting point or boiling point temperature. A material reacts to the addition of energy in different manners depending on its physical state. However, when the material reaches a state of phase change, the input energy, called the latent heat, will go to break chemical bonds instead of changing its temperature.

Figure 4.0 shows this phenomenon. We are looking into a number of paraffin wax based products that will maintain a temperature between 34ºC to 37ºC when it is at its melting point. Paraffin has a high specific heat capacity as well as a high enthalpy (or melt enthalpy) of fusion, making it an ideal PCM. The mechanism in which PCM maintains a constant temperature should compensate for the heat fluctuations a premature infant experiences. Typically, paraffin wax consists of a mixture of alkanes (C_nH_{2n+2}), a type of saturated hydrocarbon. After refining, this substance is odorless and nontoxic, making it ideal for use in a baby incubator.

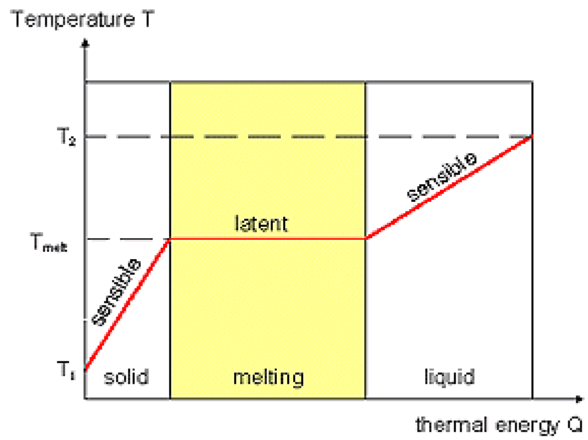


Figure 4 Phase Change Phenomenon

The Air Purification and Ventilation System:

Air Purification

Since a premature infant's immune system is so undeveloped, it should be kept in an environment which is as sterile as possible to prevent infection. The entrance of most bacteria and other air borne particles into the incubator can be prevented by filtering the incoming air. The use of non-woven, spunbond polypropylene fabric used in physician's surgical masks is being looked into. Not only is this option light and hypo-allergic, but it also has a 0.5 micron filtration efficiency greater than 95%, while the average size of bacteria is between 1-2 microns. This component is still under study.

Ventilation System:

A thermally driven air purification can be achieved by manipulating the air flow into and out of the incubator. Calculations for this process are still pending.

Justification of innovation:

The lack of electricity in this region of the world renders any high-tech electricity dependent premature incubator, worthless. The passive incubators currently available in some parts of the world are either still too expensive, or run on fuel that may be expensive or hazardous to health. Some are also bulky, weighing as much as 135 kg. Our solution is innovative in that it has a simple answer to most of the general concerns. It provides the relief workers with an incubator-in-a-bag that is portable, and can be set up and dismantled single handedly. It can be packed up to a compressed volume of 0.3 cubic feet. Our phase change material is cheap, non-toxic and easy to handle. The baby can be left unattended for 4-6 hours without concern of heat loss within the incubator. Unlike most incubators, our solution is very low maintenance and also requires minimal operational capabilities. Our only assumption of fuel needed is a fire to heat water for the heating element. This is already available for sterilization purposes as confirmed by Dr.

McQueen.

Since no solutions currently exist to deal with premature births, our idea will prevent the need for immediate postnatal transportation that may lead to severe stress in the infant. Our device serves to prevent the most common complications of prematurity: heat loss, dehydration and jaundice. In addition, if the infant is born with further complications such as respiratory problems, our device will serve as a transport incubator buying the infant more time. In the more developed county hospitals, this device could also be used as backup to the electric incubators during periods of power failure.

Implementation

Our project has four phases:

PHASE DESCRIPTION	***STATUS***
I.Problem Identification and Information Gathering	
1.Study the anatomy, pathophysiology and the basic needs of the premature infant.	✓
2.Meet with contacts in the field who have dealt with the care of preterm infants.	✓
3.Visit local hospitals to learn about the care of preterm infants in the developed world.	✓
4.Learn more about the workings of incubators, the history and evolutionary processes they have undergone.	✓
5.Research on alternative energy sources.	✓
II.Design Process	
1.Having gathered information, derive a solid set of design constraints	✓
2.Develop a design idea that will perform the required function.	✓
3.Document raw materials that will be needed.	✓
III.Prototyping Stage	
1.Procure raw materials	IN PROCESS
2.Fabricate life-sized model of the device.	✓
3.Experiment to validate, verify and test design.	PENDING
IV. Product Implementation and Technology transfer	
1.Having verified the workings of the device, successfully transfer technology to targeted end user.	PENDING

We are currently in Phase III of our project.

Implementation Plan:

Having achieved most of the design work already, we now intend to concentrate our efforts on building a prototype and eventually a final model of our design. This will enable a more thorough examination of the functionality of our device. We aim to spend the next few months carrying out trial tests on the finished device, allowing ample opportunity for redesign if needed. The following steps need to be taken:

- Creating a mattress with the right choice of PCM and Photochromic Ink
- Making the tent structure fool proof and air tight in the right places
- Testing the air filtration characteristics of the system
- Collecting data using an infant model/mannequin using digitally seeded thermometers
- Developing a means to test and monitor air exchange within the incubator
- Mechanism to quantify the visible light that is allowed in through the transparent side of the tent, and the heat that is lost.

When the device has passed its rigorous testing phase, we will proceed to Phase IV- our technology transfer phase, wherein our hope is that we are able to successfully introduce the idea to the relief workers in the targeted area. Since our primary targeted end user, Dr. McQueen will be involved in all stages of our device testing process, we are fairly confident that technology transfer will be smooth. Our final end user will be the local nurses and doctors, who will be introduced to the technology by Dr. McQueen and her colleagues who have already established reputable credibility within the community.

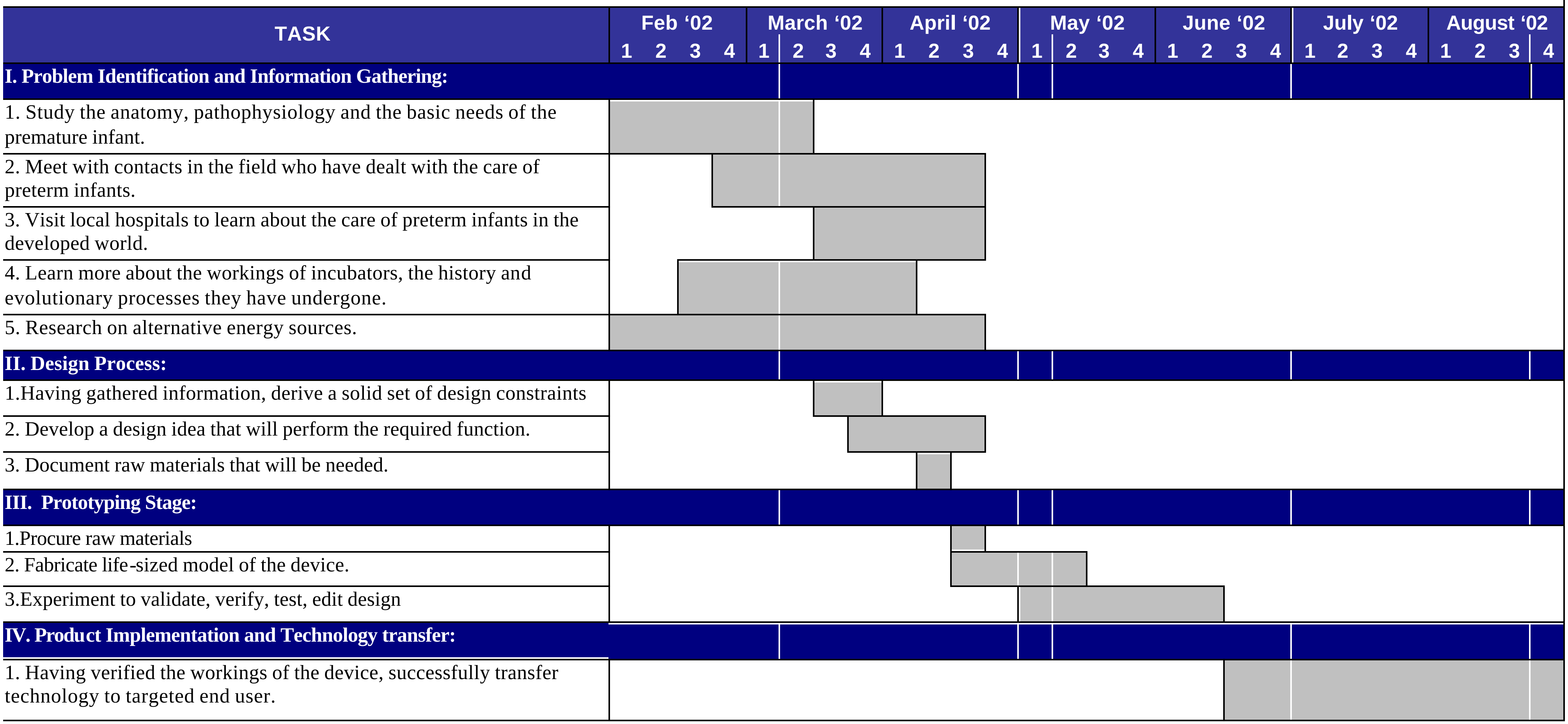
Scope:

In designing this device, our main aim has been to engineer a simple solution to a complex problem in the developing world while keeping the user minimally dependent on Western resources for sustainability of the device. We have aimed to use materials in our product that will be locally accessible. The existence of PCM material is still under question, and for the purposes of this design, it has been assumed that this component will need to be provided in the beginning stages. However, the reusability of the PCM is encouraging. Design blueprints can easily be made available to future manufacturers of the device. All manufacturing will take place locally. The design idea is simple and very intuitive. The use of newspapers for insulation is a cheap and effective method that can be reproduced with little difficulty. The operation of the device is intuitive and limited to simple set up of the tent and heating of the PCM sack. All the materials used will also be washable and therefore reusable. The filtration system may however need to be changed for each infant, to ensure sterility.

Timeline:

The Gantt Chart below gives a rough distribution of tasks over time.

TIMELINE FOR INCUBATOR PROJECT



Challenges:

Prototyping Phase: Our main challenge in this stage will be procuring the right materials. This process will be paralleled with complex thermodynamic analyses of each of the materials in order to locate the optimal items. Secondary to this, will be the challenge of simulating an external environment similar to that prevalent in the geographical region we are concerned with, within our laboratory space. We foresee our current design undergoing a few iterations along the way. We do not see laboratory space as a problem.

Technology Transfer: The successful transfer of technology may require a physical visit to the site, requiring financial resources and interacting on a huge scale with both doctors and patients in the area. It will also require extended involvement in the training of these local medical personnel.

Support Network:

Our support network consists of a balanced combination of experts from academia and medicine.

K.A. Kelly McQueen, M.D. (Doctors without Borders contact) [Field Mentor]

Kathryn Ann Kelly McQueen is an anesthesiologist in private practice in Phoenix, Arizona. She completed her residency and fellowship training in Anesthesiology at the Mayo Clinic, with special training in Obstetrical and Neurosurgical Anesthesia, in 1996. Since that time, she has practiced within a busy group of 102 Anesthesiologists in the Phoenix metropolitan area. Currently she is a full-time student at the Harvard School of Public Health where she is pursuing a MPH with a focus in International Health and Humanitarian Crises.

During her second year in medical school at the University Of Vermont College of Medicine, she traveled to the Dominican Republic to serve in a Catholic Mission Hospital. In the intervening 13 years, she has been committed to teaching and volunteering medical expertise within the community and with many international organizations. She has taught anesthesia in East Africa, consulted on Obstetrical anesthesia in Russia, and provided anesthesia for hundreds of children requiring repair of facial deformities in China, Jordan, Brazil and Peru. When possible she also volunteers for disaster relief medical work, and in 2001 worked for Medecins Sans Frontieres/Doctors Without Borders in Sri Lanka.

She is committed to both humanitarian aid and to healthcare education. Since completing her formal medical training, her interests and commitment to her community have broadened. She has published two children’s books on environmentally related topics, and continues to seek opportunities to teach young children about the world around them. She volunteers to provide anesthesia for victims of domestic violence during reconstructive surgery, and for the homeless requiring surgery through St. Vincent De Paul.

Steven Ringer, MD, Ph.D., Director of Newborn Services Brigham and Women's Hospital, Harvard Medical School, Boston MA. [Hospital Mentor]

Dr. Ringer received his MD from Case Western Reserve University School of Medicine in 1982. He completed his residency at the Pediatrics unit in Rainbow Babies and Children's Hospital and was a fellow at the Joint Program in Neonatology, Boston. He joined Brigham and Women's Neonatology Unit in 1988 and is currently the director of the hospital's Newborn Medicine Unit. Dr. Ringer's interests lie in Neonatology, Antenatal Consultation and Extreme Prematurity. He is currently working with Project Vietnam in the design of low cost incubators to be used in the region.

Professor Ernest Cravalho PhD (Professor of Mechanical Engineering, MIT) [Academic Mentor]

Professor Ernest Cravalho is the Edward Hood Taplin Prof of Medical Engineering & Mechanical Engineering. He was awarded his Bachelors, Masters and Doctoral degree from the University of California, Berkeley. Professor Cravalho joined MIT as an Assistant Professor in 1966, and was promoted to Associate Dean for Academic Programs, School of Engineering in 1975. He was elected the Matsushita Professor of Mechanical Engineering in Medicine between 1976-1986; Associate Director for Medical Engineering and Medical Physics, Harvard-MlT Division of Health Sciences and Technology, 1977-Present; Associate Director, Whitaker College of Health Sciences, Technology and Management, 1979-1983; Edward Hood Taplin Professor of Medical Engineering, Harvard-MlT Division of Health Sciences and Technology, 1986-Present; and Co-Director of the Program for Biomedical Engineering, 1993-Present.
He was elected to the National Academy of Sciences in 1981, and is a member of the American Society of Mechanical Engineers; Biomedical Engineering Society and the Society for Cryobiology.
Professor Cravalho's research interests lie in the field of Cryobiology; Biomedical Engineering Technologies for Patient Care. He currently teaches undergraduate and graduate classes in Thermodynamics and Heat Transfer.

Impact

Every year, over 4 million infants, worldwide, die within a month of birth. Of this number, 3.9 million belong to the developing world. 25% of the deaths are caused due to complications of prematurity, most often, the leading causes being heat and water loss. In developing countries, there is very limited access to high-tech incubators that are available to the western world. Though our design is currently geared toward a select community in a particular part of the world, this design has the potential to have a global impact! Its very affordable price will make it available to the 3.9 million infants in the developing world that need it.

The design, prototyping and transfer of this device have and will give our team the opportunity to experience first hand~~,~~ the varying challenging and fulfilling aspects of appropriate technology. It’s taught us that complex global solutions can only be solved using technology that is specific and appropriate to the given context, geographical region, resources and culture.

Budget:

ITEM	COST/$
Various types of rod materials to test elasticity at a radius of curvature of approximately 0.25m	500
Several yards of air tight, water tight polymer fabric	250
Several yards of static cling, vinyl material	100
Threads and needles	50
10s of yards of phase change materials embedded in various foams and fabrics from Outlast	1000
Temperature sensor and associated electronics	500
Pressure and humidity sensor and associated electronics	500
Light sensor and associated electronics	250
Photochromic ink materials	250
Non-woven, polypropylene filter material	250
Toaster oven	50
Miscellaneous supplies - scissors, balloons	50
Sewing machine	500
Shipping and handling	500
Communication – phones and faxes	250
Total Cost	**5000**

Team Info:

Members:
Aileen Wu
Prasanga Hiniduma Lokuge
Yael Maguire – also *Design that Matters* Instructor

Biographies:

Aileen Wu:

Aileen is an undergraduate student studying chemical and biomedical engineering at MIT. She has done research at the Continuum Electromechanics Lab in conjunction with Brigham and Women's Orthopedic Research Lab studying the effects of mechanical loading on bioengineered articular cartilage. She has also worked at the Biotechnology Process Engineering Center testing the liver cell bioreactor. Passion, initiative and creativity are the main characteristics that distinguish Aileen from the stereotypical science/engineering undergraduate at MIT. She developed fun lab-oriented science program for students in response to the poor elementary school science curriculum in New Jersey. Recently, she was awarded a grant from MIT's Council for the Arts to organize Interlude, a weekly concert series with musical performances by and for the MIT community. She has also held other significant positions such as co-director of events by Educational Studies Program and Spring Rush Chair of her sorority, Sigma Kappa.

Aileen's interest in solving the technological challenges of developing communities and promoting sustainable growth has led her to take classes such as Developmental Entrepreneurship and the Design that Matters. In the baby incubator project, Aileen has finally found some sort of relevant and meaningful application of her studies at MIT. She supports the group with her knowledge of chemistry, biology and chemical engineering. She is in charge of developing the phase change component and assists in organizing the filtration/ventilation system of the incubator.

Prasanga D. Hiniduma Lokuge:

Prasanga Hiniduma Lokuge is a M.S candidate in the Department of Mechanical Engineering at MIT. Her thesis work pertains to the design and prototyping of a remotely controlled suturing device for endoscopic surgery under the guidance of Professor Ernesto E. Blanco of the Mechanical Engineering Dept.

In addition to the design of the premature incubator, she has also been involved in the design of several other medical devices, during the past year: the design of an arthroscopic device in conjunction with the Massachusetts General Hospital and the design of a cardiac septal occluder to address a congenital heart condition in young infants in collaboration with the Children's Hospital in Boston. Prasanga completed her undergraduate degree in Chemical Engineering at MIT with a concentration in Japanese, graduating as a member of the Class of 2000; she spent her Junior year at the Imperial College of Science, Technology and Medicine in London, U.K as an occasional student pursuing both Engineering and foreign languages. She was awarded a Central Fellowship from MIT. Prasanga's interests lie in humanitarian aid, and applying appropriate technology to solve medical issues in the Third World.

Prasanga has been involved with the incubator group since its conception this semester. She led the initial information gathering and mentor search for the project. She is currently helping in the design stage of the project, and will be strongly involved in the technology transfer process.

Yael Maguire:

Yael Maguire is a PhD candidate at the MIT Media Laboratory. He is currently working on developing new tools for biology using Nuclear Magnetic Resonance and quantum information processing. Yael worked on advanced web programming and sensor fusion in collaboration with the UnPrivate House exhibit at the Museum of Modern Art in New York. This installation has won numerous awards, (including a Silver Medal in I.D. Magazine's Interactive Media Design Review 2000) for "its social dynamic and its capacity to integrate technology into a domestic space." Yael also co-founded Thinkcycle (www.thinkcycle.org), an organization using "Brain cycles" of university students worldwide to solve interesting technical challenges in the developing world. Yael is currently teaching Design That Matters, a class simultaneously being taught at MIT and Bangalore bringing students together to work on projects from the Thinkcycle database. Yael has an undergraduate degree in Engineering Physics from Queen's University in Canada and holds a master's in Media Arts and Sciences from MIT. Yael has been awarded an IBM Student Fellow and NSERC fellowship from Canada.

Yael is helping with physical fabrication of prototypes for the incubator team as well as providing thermodynamic and mechanical assistance. He is an instructor for the student initiative Design That Matters and has thus been guiding this project from the beginning.