NSF Annual Report
Jalalabad Fab Lab
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Abstract

In May 2008 a Fab Lab was installed in the village of Bagrami near Jalalabad, Nangarhar Province, in eastern Afghanistan with funding from the National Science Foundation's (NSF) Small Grants for Exploratory Research (SGER) program. This fab lab is a continuation of a program started in 2002 by the Massachusetts Institute of Technology's (MIT) Center for Bits and Atoms (CBA). Currently there are nearly 40 such labs in 11 countries interconnected by internet and broadband videoconference.

The goal of the Jalalabad Fab Lab was to investigate post-war and disaster recovery applications of digital fabrication to see how communities might benefit from access to on-demand, local, custom production capabilities rather than relying on long, slow, and expensive supply chains. The Jalalabad lab anticipated special emphasis on health care needs that require on-site customization for individuals.

We have established a fab lab that has become a community resource. After 8 months this resource show positive signs of becoming self-sustaining. There are community members that are learning basic economic and business principles by creating product in the lab for sale in local markets. In this informal setting, through hands-on projects and peer-to-peer learning structure, people are gaining technical knowledge and experience using state-of-the-art digital fabrication tools. This experience stimulates motivation to learn more deeply about science, math and engineering and develop skills that are valued around the world. Additionally we have established educational infrastructure that extend learning beyond what a fab lab can teach. We have also created a wireless network throughout the community that gives access to the internet, for free, opening up the vast knowldege resources that the internet offers, and providing a gateway to the rest of the world.

Fielding a fab lab in Jalalabad has shown that prototyping tools for digital fabrication can function in a post-war, community-stressed setting like Afghanistan and have significant, immediate applications. We've identified applications in Information Communications Technology (ICT), civil engineering, and first line health care that can benefit enormously from the capabilities in a fab lab.

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[1] http://www.nsf.gov/pubs/gpg/nsf04_23/6.jsp#VIH1

Contents


we make things
no war
Fab Lab
Afghanistan

1 Introduction

A fab lab is a high tech workshop where ordinary people design machines and conduct science to improve the quality of their lives. Lab participants use computer controlled manufacturing tools to address local problems, their products have included wind-powered lanterns, long range communications antennas, agricultural equipment, robots, even small customization businesses. A fab lab operates as a self-organized community workshop where participants can learn about science and engineering either through formal classes or informal "free time".

Fab labs provide widespread access to modern means for invention. They began as an outreach project from MIT's Center for Bits + Atoms (CBA). CBA assembled millions of dollars in machines for research in digital fabrication, ultimately aiming at developing programmable molecular assemblers that will be able to make almost anything. Fab labs fall between these extremes, comprising roughly fifty thousand dollars in equipment and materials that can be used today to do what will be possible with tomorrow's all-in-one desktop fabricators.

In May 2008 a fab lab was installed in the village of Bagrami near Jalalabad, Afghanistan with funding from the National Science Foundation's (NSF) Small Grants for Exploratory Research (SGER) program. Currently there are nearly 40 such labs in 11 countries all interconnected by internet and broadband video-conference. The goal of the Jalalabad fab lab was to investigate post-war and disaster recovery applications of digital fabrication to see how a community might benefit from access to on-demand, local, custom production capabilities rather than relying on long, slow, and expensive supply chains. The Jalalabad lab anticipated special health care needs that require on-site customization for individuals.

Lab users have increased from 45 a day at 6 months in operation, to 120 at 8 months, to 240 at 10 months. Afghanis visit the lab daily to attend courses or to work on personal projects. Users range in age and educational level, but they are all share one common passion: to develop technology that betters life in Afghanistan.

The Fab Lab promotes local solutions from start to finish—technology which originates from local people instead of being "translated" from a foreign culture. The Fab Lab provides access to tools with which local communities can explore design concepts and build physical solutions to problems.

The intended outcome is to develop a highly-skilled, local workforce: Afghanis who can look at a common problem, conceptualize a solution, and then build it with advanced tools. Some participants will turn these solutions into products that can be sold on the local market. Others will gain credentials and desperately-needed skills to help rebuild Afghanistan.

The Afghanistan Fab Lab is one in an international network of labs. All are connected via high speed internet and a global video conferencing system—allowing Fab Lab users in Lorain County, Ohio and the South Bronx, New York, for example, to exchange ideas with other users in South Africa and Iceland. Over the last several years, Fab Lab users have made a wide array of projects including: RF components in Norway, copier gears in India, and even robotic crafts in the inner city of Boston.

2 Participants, Collaborators, Partners, and other Contacts

Participants with more than 160 hours help on project:

- Berkoben, Keith : Mr. Berkoben led the FabFi project development and implementation in Jalalabad. He contributed significantly to the FabFi web site, documentation, and distribution package and the continued maintenance and support of the FabFi in various labs and locations. Mr. Berkoben has a BS in Biomedical Engineering Sciences from Harvard University and founded a medical devices startup in the Cambridge, Massachusetts area.
- Cheung, Kenny : Mr. Cheung designed and manufactured the prototype FabFi reflectors and participated in characterization and testing in the greater Cambridge, Massachusetts area. Mr. Cheung is a PhD student at MIT and has an MS and BS in Architecture from MIT and Cornell University, respectively.
- Guðmundsson, Andreas : Mr. Guðmundsson installed and trained local users on the digital knowledge network infrastructure. Additionally, he trained teachers in computer use and configured the OLPCs for field trials. He contributed significantly to the Jalalabad Fab Lab web presence. He was also key contributor in the field implementation of the FabFi system. Mr. Guðmundsson has a B.S. in Mathematics from the University of Iceland.
- Kakar, Wahida : Ms. Kakar organized and led the fab lab teachers in preparing and delivering curriculum, leading several classes herself. She is the Fab Lab coordinator. She graduated in March 2009 from Nangarhar University, majoring in English with plans to teach.
- Lassiter, Sherry : Ms. Lassiter is the Program Manager for the Center for Bits and Atoms. She developed curriculum goals and metrics for lab training and coordinated iEARN and MIT OpenCourseware integration in the lab. Ms. Lassiter also coordinated all equipment and materials, shipment and customs details, funds accounting and banking, transportation and logistics, as well as back office support for the lab.
- Lynn, Kerry : Mr. Lynn designed and developed the deployed FabFi system, in particular the software and configuration of the radio. He was significantly involved in testing and characterization of the integrated system. Mr. Lynn is a senior engineer at Cisco.
- McCarthy, Smári : Mr. McCarthy configured and trained local users on the Ubuntu (Linux) computers and open source applications. He contributed significantly to the Jalalabad Fab Lab and FabFi project web presence. He was also key contributor in the field implementation of the FabFi system. Mr. McCarthy studied Mathematics at the University of Iceland and is currently working for the Nýsköpunarmiðstö ðIslands, Iceland, as an IT projects manager.
- Mendoza, Art : Dr. Mendoza led the digital pathology, incubator, and telemedicine investigation projects. He is the Medical Director of Pathology at Sharp Mary Birch Hospital for Women in San Diego, California.
- Mendoza, Brandon : Mr. Mendoza instructed users on basic computer usage and was instrumental in the siting, fielding, and maintenance of the FabFi system in Jalalabad. Mr. Mendoza has a BS in Political Science from Amherst College in Amherst, Massachusetts.
- Rasheedi, Naqeeb : Mr. Rasheedi participated in and arranged for the digital pathology installation at the Medical School. He was also instrumental in the fielding and ongoing maintenance of the long-range FabFi installation at the Nangarhar Public Hospital. Mr. Rasheedi is a medical student at the Nangarhar Medical Faculty and the IT officer of the computer lab in the same school.
- Scheffler, Carl : Mr. Scheffler instructed users on electronics, programming, and mathematics. He is a PhD candidate in the Physics department at the University of Cambridge in the United Kingdom. He was previously an instructor at the African Institute of Mathematical Sciences in Muizenberg, South Africa. Mr. Scheffler has BS and MS degrees in Computer Science.

- Seraj, Israruddin : Mr. Seraj organized and led the fab lab teachers in preparing and delivering curriculum, leading several classes himself. He is the Fab Lab assistant and lead FabFi user in Jalalabad. He graduated in March 2009 from Nangarhar University.

- Sun, Amy : Ms. Sun was head of field implementation and projects leader. Ms. Sun is a PhD candidate at MIT, has a dual BS in Electrical Engineering and Computer Engineering from Purdue University, and an MS from MIT where her thesis was concerned with the field fabrication of solar powered steam turbines.

- Tam, Ryan : Dr. Tam trained and mentored students to establish income-generating clubs which make and sell personalized objects. He instructed lab users on documentation and online record keeping for lab administration. Dr. Tam has a PhD from MIT in Urban Planning and is now working on the Hawaii airport light rail project.

- Arnold, Steve; Huffman, Todd; Pettyjohn, Kellie; Nelson, Kate; Williams, Lucy : Volunteers who traveled to Jalalabad for 10 days or more to instruct users in computers, math, basic business, or English.

Other Organizations Involved as Partners:

- San Diego - Jalalabad Sister Cities Organization
  In the fall of 2007, CBA and Heads on Fire[5] (HOF) launched a fab lab in an inner city community center in San Diego. San Diego has a sister city relationship with Jalalabad, Afghanistan, with a variety of local organizations participating in on-the-ground development. The San Diego - Jalalabad Sister City Organization[11] (SDJSCO) was involved in the logistics of lab installation, financial adminstration, and provided contacts and support.

- Taj Mahal Guest House: Free Range International and MindTel
  The Jalalabad fab lab is housed in a building within the Taj Mahal Guest House compound. The site is leased and operated by a collaboration of international organizations, predominantly Free Range International[3] (FRI) and MindTel LLC[8]. FRI has provided on-the-ground logistics, local contacts and task management, assistance with local banking transactions, general care and feeding of the facilities, manages payroll for local support personnel, and coordinated lodging, meals, and transportation for international personnel. MindTel handled technology export / import customs documentation, communications (satellite downlink and internal local networking) installation and maintenance, generator and associated delivery and installation, and site selection and negotiations.

- Nangarhar University International Learning Center
  The International Learning Center[9] (ILC) at Nangarhar University (NU) in Jalalabad, Afghanistan has provided local technical networking and computer support.

- Operation Mercy
  Operation Mercy Afghanistan[10] (Op Mercy), a non-governmental organization, has staff in Jalalabad city where they implement teaching and education programs, disaster relief assistance, and other involvement addressing quality of life needs. Op Mercy has collaborated on the development, deployment, monitoring, and statistics gathering for the FabFi project (see section 3.3.1) with interest in deploying FabFi and future communications infrastructure and devices into rural or disconnected areas and in disaster relief activities.

- Fab Labs
  Participants from the global Fab Labs contributed to user training and projects deployed at the lab. In particular, significant help or interaction came from Vestmannaeyjar, Iceland, Barcelona, Spain, Pretoria, South Africa, Soshanguve, South Africa, Boston, USA and MIT, USA.

Other Collaborators or Contacts:

Afghan Government Appointed Personnel :

- Mumammad Iqbal Azizi, Head of Education Department, Nangarhar Province
- Dr. Amanullah Hamidzai, MD, MPH: Chancellor, Nangarhar University
- Lal Agha Kaker : Mayor of Jalalabad and Deputy Governor, Nangarhar Province
- Dr. Mohammad Tahir Kaker : Dean of Veterinary Science Faculty, Nangarhar University
- Dr. Pardis : Chief Medical Officer, Jalalabad Public Hospital
- Dr. Ab. Shakoor : Jalalabad Hospital Medical Director, Nangarhar Public Health Directorate
- Gul Agha Sherzai : Governor, Nangarhar Province

International Government and Non-Government Aid Organizations, Companies, and Individuals:

- Commanding Officer and staff, Eastern Region Provincial Reconstruction Team
- Human Terrain Team, US Foward Operating Base Fenty
- USAID Eastern Region Field Officer
- Alternative Livelihoods Program, Eastern Region, Development Alternatives, Inc.
- Local Governance & Community Development, Development Alternatives, Inc.
- Japan International Cooperation Agency, Afghanistan Office
- German Technical Cooperation, Project for Alternative Livelihoods in Eastern Afghanistan
- Jalalabad Programs, Relief International Afghanistan
- Dr. Kristian Olson, internist/pediatrician on staff at the Massachusetts General Hospital. Created the infant resuscitation device and incubator (see section 3.3.3).
- Click Diagnostics, Inc. Mobile telemedicine via cellular phones. http://www.clickdiagnostics.com/
- MoCa Mobile, open source medical diagnostics platform for mobile devices. http://www.mocamobile.org/

3 Activities and Findings

3.1 Installation

The Jalalabad Fab Lab is comprised of aproximately $1\frac{1}{2}$ tons of materials and equipment. The core fab lab equipment and supplies[2] were augmented with a few additional computer controlled machines, extra computers, and approximately two years of comsumable supplies. The lab was assembled at MIT and shipped to Afghanistan from Cambridge, Massachusetts, in May 2008.

Figure 1: *1.5 tons of fab lab equipment arrive in Jalalabad, Afghanistan*

3.1.1 Site Selection

Site selection was performed by Mindtel LLC personnel in winter/spring 2008. Sites under consideration included 1) the Taj Mahal complex in Bagrami, 2) Nangarhar University in Duronta, 3) a girl's high school built and supported by an American Rotary Club, and 4) a computer and English training center inside the government run Department of Education compound. The first two sites are 2 km and 5 km from Jalalabad City center while the latter two sites are located inside the city.

Final selection was made in early May 2008. The Taj Mahal compound is the only western-style, internationally-run guesthouse in the Jalalabad area. Reasons for the co-location of the lab and guesthouse include: control of the equipment, facility infrastructure, a secure compound and the ability for international volunteers to live and work at the site without guards and drivers. Another primary selection criteria was lab jurisdiction and ownership which would have been complex and unclear at the other potential sites.

Poverty and the security situation in Afghanistan makes transportation to/from the lab difficult for most Afghans – owning a car is limited to the very wealthy. It is unusual for young students to own a bicycle. As a result, the lab primarily serves walking-distance residents of Bagrami, Duronta, and to a lesser extent the inhabitants of the scattered isolated villages directly across the Kabul River. [2] The total population within walking distance is estimated to be 10,000 - 15,000 persons. Some lab users commute from Jalalabad city to the fab lab by tuk-tuk taxis which cost between US$1 and US$2 (unaffordable on a regular basis).

3.1.2 Site Preparation

The fab lab building is in a partitioned portion of the Taj Mahal compound with a separate entrance and parking area from the guesthouse. The building, grounds, and entrance were improved to United Nations (UN) Afghanistan-specific Minimum Operational Security Standards (MOSS) with the installation of exterior lights, concertina wire and exterior walls, crash bar, concrete barriers, and associated guard

[2] The wide and rushing Kabul River is a harsh dividing line for villagers who cannot traverse the ragged terrain to the bridge several kilometers away. In warmer months boys will float across the river on inner tubes to visit the lab or find laborer jobs in the area.

structures. Revised bunker/safe haven and emergency procedures and access system for locals was defined and put in to place including hiring and training f outside guards who control access to the fab lab building.

A new 110 kVA, 220/380V diesel generator was installed at the compound and wired in to the power system to supply electricity to run the lab machines. The compound does not have city grid electricity and all electrical power is provided through generators. The guesthouse compound is electrified 24 hours a day by cycling generators as there is no battery bank. Already on site are a Russian 75 kVA 208/400V generator and a Japanese 25 kVA 110/220V generator both which underpower most of the 220V equipment or 110V equipment running through transformers. Output power from the generators is directly branched to each building and small stabilizers are provided for sensitive equipment. A grounding stake was installed and wired to the exterior circuit box at the fab lab, but grounding problems persist because the generators and other structures do not share a ground connection. A large, grounded battery bank would solve floating ground, generator switch over, fuel efficiency and other problems. While the electrical system has been greatly improved by the fab lab installation, the local infrastructure is substandard, inefficient, and damaging to the equipment[3].

A high speed internet connection is provided via Intelsat satellite connection. The satellite dish is an inflatable radome[4] with standard feed elements at the focal point and standard downstream electronics (satellite modem, switch, etc.) The radome is installed on the roof of the tallest building with a view of the southern horizon and a long ethernet cable running to the fab lab building. A transparent caching proxy, gateway, file server, MIT Open Courseware (OCW) server, and Wikipedia mirror were installed and configured (see section 3.2.4). A compound-wide wireless cloud was installed and a wired network connection was pulled to each room in all buildings.

A computer controlled laser cutter, mini-mill, cutter, embroidery machine, computers, printer and scanner were installed on an intranet with internet access via Intelsat connection. Electronics assembly and instrumentation as well as periphery power tools were installed.

The fab lab building's electrical wiring infrastructure was partially reconstructed and a newer larger circuit breakers were installed. Conduits were installed to run network and power cables into all rooms. Rooms required heavy cleaning, construction, and painting. Several small uninterruptible power supplies (UPS) were installed. Summer time temperatures in Jalalabad reach 60°C/ 140°F so air conditioners and fans were installed or reconditioned. Windows and screens were repaired[4].

Wood and plastic tables, plastic chairs, and curtains were made or procured over the course of the summer. However, the poor quality of the furniture and large numbers of users have left nearly all furnishings broken or unusable in eight months.

3.1.3 Lab Management and Adminstration

Over the long-run, the FabLab is intended to be a self-managed and self-sustaining community. A portion of the staff's salaries are paid by earnings from user's income-generating projects. The Fab Lab employs several teachers who manage different aspects of the Fab Lab community. The FabLab provides young Afghani women and men with valuable management experiences. The staff and users collectively discussed and came to resolutions on operating procedures[5] and staff roles[6]. Together, the lab staff maintains a daily online lab journal[7] as well as a monthly budget and inventory.

[3] The lab experiences a high turnover of UPSs and voltage stabilizers due to under and over power conditions and floating ground.

[4] Ants devoured the plastic installation from data and power cables inside computers, causing shorts and errors when the computers were powered on. Mice caused similar, but more obviously visible damage to power cables.

[5] http://wiki.fablab.af/index.php/Operating_procedures

[6] http://wiki.fablab.af/index.php/Staffing

[7] http://blog.fablab.af

3.2 Education and Outreach

Figure 2: *Fab lab users learning "nearly everything", then teaching what they've learned to new users.*

3.2.1 "How to Make (Almost) Anything" : Fab Lab basic training

The one week version of the "How to Make (Almost) Anything" (HTM(A)A) course, intended to give a tour of the machines and capabilities, was taught several times during summer and fall 2008. Class members included: female university students studying to be teachers, male and female youth under 12, university engineering and computer students, members of the local village, and members of the city[8] . Several one or two day workshops targeting specific machines or capabilities were also taught, mostly involving the computer controlled knife or laser cutter. The teachers we trained also led their own subsequent HTMAA lessons, demonstrating knowledge transfer.

After the initial training period, self-appointed teachers continued to lead the HTM(A)A course, elongating it to a several months long course. With little exception, the course material did not change, most teachers rigidly taught the same projects and examples week after week. It was disappointing to see learning wasn't happening in a deep or flexible way. However, there were a few user/teachers who demonstrated more flexible knowledge by integrating skills in new ways not previously modeled by the installation team. It was important to encourage these user/teachers to take the lead and demonstrate personal project-based learning rather than rote duplication. This required changing the traditional teaching model and governance hierarchy.

[8]The lab has a wide variety of users and visitors, spanning ages, gender, cultural background, social standing, and educational background.

HTM(A)A continues to be taught during a two hour time slot six days a week. By the eighth month of operation, 240 students crowd into a lab lead by four teachers. With only 17 desktop computers, hands on learning can be slow and frustrating[9].

Figure 3: *In one HTM(A)A lesson, users learn to make a box using a system of precisely cut slots and tabs instead of glues and fasteners. The simple concept is modified to create objects of increasing complexity.*

Learning to use computers and machines to design and fabricate brings joy to the user however poor the quality of their output. In the first few months of unsupervised operation, users were prolific. Their reaction to the excitement and praise engendered by their output was to create a large quantity of duplicates. However, in order to make useful products for market, "getting it right" becomes more important. Careful and persistent guidance was needed to transition users from the "any output is exciting" phase to spending focused time and concentration to produce quality results. External infrastructure and influences make it extremely frustrating for users to embark on projects requiring significant time investments. But forming income-generating "clubs" (see section 3.3.4) partially addressed the quality concern as users learned quickly that poor results result in poor monetary returns.

Another difficultly we encountered was secrecy – that is the tendency for users not to allow other users to see their work. This was most prevalent in older users, a result of being embaressed about not knowing how to do things and "looking stupid". Users approached internationals in private, asking to be taught various topics in secret. International volunteers modeled appropriate lab protocol - asking each other for help, not ridiculing each other for mistakes, and emphasizing that each of us bring a different knowledge or skill base. This helped, but we've learned that it is more acceptable to be be seen learning in some topics than in others.

As internet access was a new phenomenon, we had to help users and teachers establish appropriate protocols, including socially and emotionally appropriate uses of connectivity. Students were embaressed about seeking personal help, for example about facial hair removal, or tracking their favorite cricket team. In these cases, we modeled an approach for teachers that turned ordinary experiences in to learning opportunities. Additionally, computers were arranged so that no one could hide what they were viewing or doing.

Material and resource hoarding, a problem noted in other fab labs shortly after deployment, was a problem in Jalalabad as well. Fortunately, the lab coordinator and staff quickly grasped the importance of sharing access and resources. They facilitated long discussions with the entire user population about fairness, sharing, censorship, entitlement, and communal lab ownership and governance.

[9] In Bagrami village school, the average class size is over 100 students led by a single teacher. Fab lab teachers have concluded that more than a 15:1 student-to-computer ratio is insufficient for learning.

3.2.2 Bagrami School Teachers Computer Training

Approximately one quarter of the teachers at the local village school were loaned laptop computers and trained to use basic internet, word processing, spreadsheets, and photo/video functions in English and Pashto[10]. There were slightly more female than male teachers. The teachers came to the lab between 5 to 6 days a week for instruction, to charge the laptops, connect to the internet, and use the printer and other output devices.

We found the primary interest for teachers was to explore the uses of the lab and associated resources in their curriculum and to find resources for their own continuing education. They were very interested in the MIT Open Courseware[7] material but the content and language barrier made the material inaccessible. Teachers spent most of their time online reading Wikipedia entries in their areas of interest, reading current news, or practising email and chat communications. A difficulty encountered was that most teachers did not want to be in the lab at the same time as their students as they considered it embaressing and shameful for their students to see them learning.

Figure 4: *Teachers committed to learn and explore ways to integrate digital technologies in to their curriculum.*

[10]Pashto language support in most applications were extrememly limited. However, a growing Pashto language Wikipedia was explored. Teachers were generally more interested in learning English as well as computers and preferred to keep the computers in English keyboard mode.

3.2.3 Project Based Learning

FabLab students use a number of games and projects to develop skills in engineering and science. These projects often include stamps, music boxes, microcontroller-based circuits, Pico-crickets and Scratch graphical game design and programming. They are done at a user's own pace in a self-discovery manner or organized as group workshops with a facilitator.

Figure 5: *Prototyping with Picocricket[11] allows users to experiment with sensors, actuators and mechanical design to make various robotic vehicles.*

Figure 6: *Users combine mechanical and electrical design to make a desk lamp.*

Fab lab users visited several villages, national development project sites, and training centers. These visits were generally day-long where users and hosts interacted on an informal level to discover personal or small needs which might be fulfilled with relatively simple techniques or products. We were sometimes joined by observers from international military or local authorities who were surprised to see how much could be accomplished by addressing small problems and their net effect. A common comment was how quickly villagers could learn something that might be considered very technical and in particular when the teacher and learner do not share a common language. The key to these successful interactions was working on a project that the user is interested in, a project that is personally meaningful. On return visits we would often find that a user had continued to investigate and iterate on the project and applied locally available resources.

An example of a simple afternoon leading to meaningful local problem solving is learning to use a digital camera. Villagers are excited and interested to see the photos vistors take when visting their village or site. Digital cameras are relatively inexpensive and reasonably rugged and we turn the devices over to kids. The kids and those present during the "training" quickly teach other kids how to use the cameras. Some immediately run off and take photos of everything and everyone. Some investigate the effect of the other buttons or want to know how a camera works. All excitedly share what they learn and discover. Within an hour, the cameras and the kids' picture taking skills shift from a novel toy to a useful tool: they and their elders begin discussing ways they could use a photo recording device to monitor changes – suggestions

Figure 7: *A common example of viral, hands-on, experimental learning: I a teach boy, the boy teaches more boys, those boys teach more boys. Unable to speak their language, I start by placing a boy's finger on the shutter button and press down on his finger. I then grasp and use his finger to switch the camera in to display mode. We iterate through some common errors, such as moving the camera (resulting in a blurred image) or pressing and releasing the button too quickly (resulting in no image). The boys teach each other through a combination of hands-on training as well as verbal instruction.*

have included learning about the water level of a nearby river to comparing crop performance with different processes – to using the camera as an educational tool by using the playback feature as a "Powerpoint" presentation.

These conversations begin with "low hanging fruit" (ie, simply taking a picture of something) and quickly evolve to concerns that seem tangential (ie, monitoring crop changes over time). These are off-ramps into project driven learning about other solutions to the problem. Sometimes users discover a way to solve the problem using local resources and needing access to some tools, other times they will discover that the solution they believed they needed solved the wrong problem. The importance of being able to communicate among each other and turn to the resources and help of others is paramount - both through live consultations (via phone, videoconference, or email) or through books and recorded lectures.

A *digital* camera is important - learning is facilitated by the short cycle time between taking and viewing photos. The cost of mistakes is low in dollars and time. The results are sharable and can be transferred to many different media. The fab lab can be viewed the same way. The lab is comprised of commericially available, low cost rapid prototyping machines which present a low threshold barrier to learn to use. Initially projects are simple - using the laser cutter to make a keychain, for example - then evolve quickly to become viewed as tools to solve problems. The video and internet connection are the keys to knowledge sharing.

3.2.4 Digital Learning Infrastructure

An auxillary goal of the fab lab is to investigate modern learning resources enabled by digital communications and fabrication. The following groundwork was accomplished for educational resource access:

- Transparent caching proxy server
  A proxy server[12] was installed between the Internet and the FabFi network. Much web content doesn't change very quickly and a copy kept in country, synced only once in a while, means ridiculously fast "internet" and significantly eased load on the satellite link. This means that most of the traffic is only within the country. The current FabFi has 4.5Mbps bandwidth; the connection to the Internet is limited by the satellite bandwidth. The proxy server keeps a copy of all retrieved items (with some exceptions). When another request comes for the same content, it provides the requestor with the cached copy instead of going out to the wider internet.

- Wikipedia mirror
  English and Pashto Wikipedia were downloaded to the local server. The transparent proxy server (above) seamlessly switches between serving the user local cached content or retrieving the content from the internet. This scheme is highly suitable for other open educational and informational sources.

- MIT Open Courseware
  Every undergraduate class and many of the graduate classes taught at the Massachusetts Institute of Technology (MIT) has been painstakingly recorded, indexed, transcribed and compiled along with all the materials from the classes.

  MIT Open CourseWare[7] can be accessed by anyone through the internet without charge. Having a local copy in Jalalabad offers significant increase in speed in part because the local intranet is much faster than the bottlenecked connection to the wider internet.

- iEARN : internet based, collaborative project based learning
  The iEARN[6] Collaboration Centre enables youth to learn with, rather than simply about, the world. The system is generally for elementary through high school aged students. Students and teachers all over the world participate in projects and share resources. An iEarn account was established for the Jalalabad and greater fab network. Users will be introduced to the network in the coming quarter.

  "International Education and Resource Network (iEARN) is a non-profit organization made up of over 27,000 schools and youth organizations in more than 125 countries. iEARN empowers teachers and young people to work together online using the Internet and other new communications technologies. Over 2,000,000 students each day are engaged in collaborative project work worldwide. Since 1988, iEARN has pioneered on-line school linkages to enable students to engage in meaningful educational projects with peers in their countries and around the world."[13]

[12] see http://www.squid-cache.org/
[13] retrieved from http://www.iearn.org/about/ on April 3, 2009.

- Multipoint Video Conference
  An easy to use multipoint video conference system was installed, allowing regular users to casually

Figure 8: *Multipoint Video Conferencing: A Window Into The World*

connect with global lab users. The conference system was also highly useful for coordination with international volunteers, especially for access to experienced personnel in the United States to help fix machines.

An unexpected reaction to the video conference unit was the observation that it was technology that would allow people to tell of and discover truth for themselves rather than relying on radio, TV, and newspapers which are distrusted to varying degrees. A visiting Afghan journalist described that it was impossible for an Afghan journalist to remain in that occupation for long regardless of the type of reporting they do for fear of retribution from people and organizations that are not cast in a positive way.

Digitizing voice and video and transmitting as IP means that the distance reached is not proportional to electrical power and the store-and-forward nature of the internet means messages are not ephemeral. Thus, the ordinary people are able to transcend distances and barriers.

- Bagrami School Online

  The congruence of the FabFi network (section 3.3.1) and teacher computer training (section 3.2.2) projects led to installing a FabFi connection at the school in our village of Bagrami, a suburb of Jalalabad. The school serves more than 2,000 school aged children of the village with average class sizes over 100. The headmaster and department of education have agreed to allow anyone to use the school rooms (and internet connection) outside of school hours. A wireless access point was installed at the Bagrami school and a small radius of houses nearby can also connect to the network without being inside the school walls. There is great interest in the small village of Bagrami (aproximately 4,000 to 5,000 inhabitants) to extend the coverage across all of Bagrami.[14]

  Most of the daily users at the lab are Bagrami residents so they are ideally poised to fabricate as many antennas as they wish. This is a village that does not have grid electricity or running water. Some residents share the cost of running a single generator, the others simply don't have electricity. The FabFi and access point are powered by a small battery which is transported by foot to be recharged at the Fab Lab. Eleven Bagrami residents own laptops and the Fab Lab loans out 16 laptops for take-home use.

(a) (b) (c) (d) (e)

Figure 9: *(a,b): Bagrami school serves aproximately 2,000 children in grades 1-12. The school has no running water, no electricity, doesn't use tables and chairs, and there is often not enough books and school supplies for all students. Teachers have one tool: a piece of chalk. There are so many students and so few teachers that school is taught in two sessions - each student attends for only half of the day. (c,d,e): The network connection on the roof of the school building opens a door to educational resources and self-discovery.*

[14] In places like Bagrami, access to computers and the internet can be life-changing. Naqibulah's brother, for instance, is interested in medicine but has absolutely no access to any information on the subject. A simple google search for "health" had him excited in no time at all, and I was glad to watch the attending group devour a page on woman's health (including sexual health) without even batting an eyelash. In contrast to his brother, Naqibulah was more interested in information about Afghanistan and Islam. The tension between traditional cultural values / religious beliefs and the desire for the opportunities of western (for lack of a better term) society is palpable in these moments of discovery. "Are there Muslims in America?" "When you have a guest in your house would you have tea together?"

3.3 Major Projects

Since the Afghanistan FabLab opened in late summer 2008, local users have focused on basic craft and utility projects—including printed t-shirts, small art projects, and long range wireless antennas. As the community gains more advanced skills, they will begin to tackle more difficult projects that address local, personal and community needs. Over the long-term, the FabLab is well-suited to address immmediate needs in health care and other areas which are currently constrained by the need for long supply chains or large local inventories. Some recent and ongoing projects in the Afghanistan FabLab focus on either enhanced communications or skills training for Afghans.

3.3.1 FabFi: Long Range Wireless Network Connectivity

FabFi is an open-source, FabLab-grown system using common building materials and off-the-shelf electronics to transmit wireless ethernet signals across distances of up to several miles. With FabFi, communities can build their own wireless networks to gain high-speed internet connectivity - thus enabling them to access online educational, medical, and other resources.

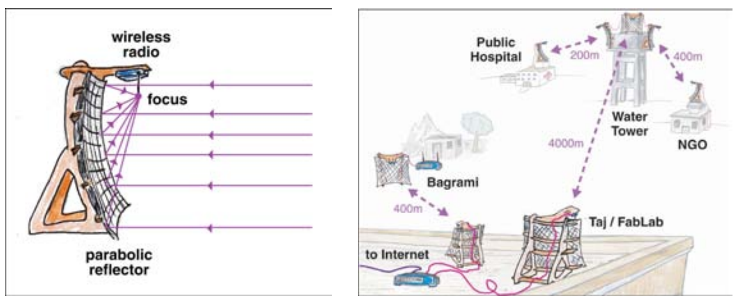
Figure 10: *FabFi antennas are easy to construct and provide high speed long range wireless connection to the internet. FabFi antennas have been made and installed in several locations near Jalalabad, Afghanistan.*

A team of international visitors, expatriates, and local nationals used the equipment in the Jalalabad Fab Lab to construct, configure, and install five remote FabFi links. These links were used to extend the Fab Lab's high speed satellite connection[15] to a village, hospital, university, and a non-governmental organization. The low cost networks can be easily spread across isolated villages and towns, placing them in touch with the outside world and facilitating soci-economic development from the ground up.

After a month of intensive training through repeated hands-on experience, a team of local nationals constructed and brought up a link at an orphanage in Jalalabad with minimal assistance from American volunteering at the orphanage as an English teacher. Two additional links were constructed at Nangarhar University in Duronta.

Five months and several strong storms later, the system continues to be used and maintained by a collective of local users. Initially there were many problems which were most often were traced to parts unpowered or unplugged and quarrels over ownership and access. The prize of free, extremely high speed wired and wireless internet access prevailed and a true community ownership model has been slowly emerging.

FabFi is an extensible point-to-point long range wireless broadband transmission infrastructure. It operates on the simple principle that by focusing the energy from a weak off-the-shelf WiFi transmitter into a narrow beam, one can communicate directionally for very long distances. In practice, we mount commercial wireless routers on a fabbed radio frequency (RF)reflector with a wire mesh surface that redirects the RF energy. Reflector gain depends on the materials used and the size of the reflector; the gain has been measured as high as 15 dBi.



(a) (b)

Figure 11: *(a)The FabFi antenna is a parabolic reflector that focuses the signal to the antenna of an ordinary computer wireless access point. (b) The FabFi network is extensible by everyone and allows a variety of users to share digital resources.*

As of April 2009,

- the longest permanent link is 3,880 m (2.41 miles)
- data throughput in the FabFi system is 4.5 Mbps
- materials to make a link are available locally and cost less than US$200
- the system is, and has been, extensible by anyone

The successful implementation of the FabFi system in Jalalabad has inspired users at several other labs to make FabFi's at their own site. A comprehensive website with all files was created[1] so anyone with Fab Lab equipment could duplicate the system. GATR, the inflatable radome provider, is modeling the existing reflector design and note their military and disaster relief clients have similar ad hoc satellite downlink expansion needs and have been actively following the field results in Jalalabad.

15 satellite internet connection speeds were measured on several occasions: 2+ Mbps down / 485+ kbps up

3.3.2 Digital Pathology / Telepathology

Led by Dr. Art Mendoza, a pathologist and member of the San Diego - Jalalabad Sister Cities Association, a team of internationals and local nationals performed a biopsy with remote diagnosis - sometimes refered to as "telepathology". We installed, integrated and demonstrated to medical staff and students at the Jalalabad Medical School the use of a frozen section machine, digital microscope, and internet connection to obtain real time remote pathology consultations on a tissue sample.

Histology is the study of tissues (as opposed to cytology, the study of cells) and is most commonly used in a hospital setting to determine if a growth is malignant (ie, cancerous). If the growth is not cancerous, the surgeon will only remove whats necessary to relieve whatever secondary symptoms the growth might be causing - reduced vision, breathing, etc. But if the growth is cancerous, the surgeon will be more aggressive in removing tissue so that all the cancerous cells are removed.

An ordinary *permanent mount* preparation will take ten to twenty hours from the time the tissue is removed from the patient to when a pathologist can look at a thin piece of the tissue under a microscope. While decades old histology machines exist in Jalalabad, power is available no more than a few hours a day and samples are preserved and sent to Pakistan for evaluation. In eastern Afghanistan, the patient often cannot be located or reached after a diagnosis is made.

A frozen section machine rapidly freezes a sample and scrapes off a three to six micron thin slice to be mounted on a viewing slide. The sample is frozen while oriented vertically, held in place by a thick viscous liquid that is frozen along with the sample. The ideal temperature is -20˚F to -40˚F (the temperature at which the sample is neither mushy nor powdery) and the cooling is accomplished with an electrically powered condenser. In addition to the ensuing fixing and staining protocol, the entire process can take as little as 10 minutes.

Figure 12: *Dr. Mendoza demonstrates the use of the frozen section machine and biopsy mount preparation protocol. The medical director (trained as a pathologist), a pathology faculty member, and a senior medical student look on.*

A pathologist only needs to see the overall organization of cells comprising the tissue sample rather than the interior of each cell. Magnification between 20X and 100X are needed to make a determination of the sample. A microscope with integrated USB camera was used at the medical faculty demonstration. Additionally, an ordinary point-and-shoot digital camera was used to record images through the eyepiece. Images were sent by email to Dr. Mendoza's mobile device.

Members of the medical faculty successfully sent digital images of mounted specimens to Dr. Mendoza after he returned to San Diego, California.

There is interest in establishing a small private pathology lab in Jalalabad to serve the eastern region of Afghanistan. The diagnoses would range from dermatology to pathology and the use of fab lab made digital communications technologies and infrastructure would enable consultations at remote rural sites, especially those where cell phone coverage is not available. Fab lab rapid prototyping and world wide collaboration could be used to experiment with different ways to prepare the mount without relying on grid electricity that are more appropriate for rural field use by untrained health workers.

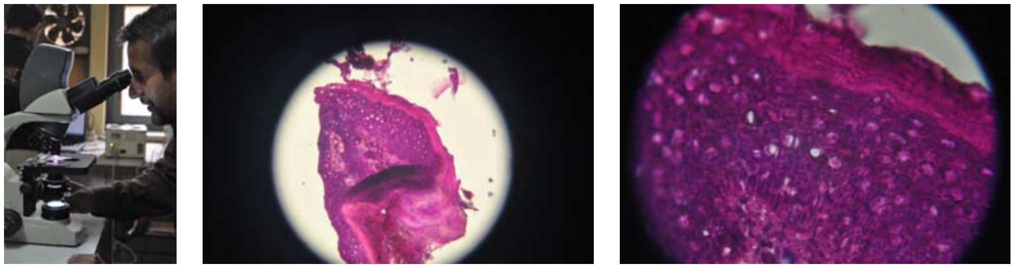


Figure 13: *Dr. Shakoor takes a look at the mount and captures digital images which are transmitted to Dr. Mendoza via e-mail. Both agree - the growth is benign.*

3.3.3 Medical Devices: Infant Resuscitation Devices and Incubators

Dr. Pardis, the Medical Director of the Nangarhar Public Hospital, invited us to see the machines and technologies needed at the largest of the area's three hospitals. The Public Hospital handles a caseload approximately the same as the Brigham and Woman's in Boston, MA but has only the resources of a large clinic. The men's and women's intensive care unit (ICU) are little more than beds lined up against a wall in a large room with small window fans. The tour of medical machines is a short one.

Figure 14: *The male intensive care unit (ICU) at the Nangarhar Public Hospital, the largest hospital in the eastern region. Note the lack of bedside machines and instruments.*

An immediate and critical need Dr. Pardis identified is infant resuscitation and incubation, in particular devices that could be made and distributed to health care workers living in rural areas some distance from the hospital.

Drs. Olsen, Mendoza, and other colleagues and collaborators set out to establish a project evaluating and creating these devices at the fab lab. Dr. Olsen has successfully fielded a low cost resuscitation device that can be used to revive infants that are not breathing on their own shortly after birth, as well as an incubator made entirely of parts scavenged from a car[16]. The resuscitation device requires some training to use but can be utilized by health care workers rather than professionally trained medical staff. The resuscitation device - essentially a tube and mask - is not complex and may be designed and fabricated by fab lab users using local materials. A fab lab club is being formed that takes in to consideration the physically distributed nature of the need.

[16] "He is 'The Man' of life-saving devices", Boston Globe "Health" Column, 15 December 2008

3.3.4 User Clubs: Small Businesses

User clubs are a hands-on approach to developing sustainable projects while learning. Members of the fablab to organize “clubs” where members make and sell customized things - from simple personalized items like t-shirts and trinkets to antennas and incubators. The goal of these clubs is to focus the user on learning to use the equipment carefully and skillfully by providing an economic incentive. Just as a lemonade stand might be a good introduction to business for an entrepreneurial student in America, the user clubs also teach simple accounting and business concepts. The clubs are not meant to be a long-term income source for the user and so the clubs have a forced graduation once the user becomes very good at a particular skill. Before leaving the program the user serves as a mentor for another incoming novice apprentice in any given skill. The user clubs foster the motivation to raise the standard of output by providing a reward for high quality work.

Established clubs include:

- T-shirt Club : The T-shirt club makes and sells custom T-shirt at a small profit, providing an incentive for students to learn basic digital 2D fabrication methods and business skills. The club uses this practical training to learn skills such as pricing, accountability, stock management, and quality control. They use a computer drawing program and the internet for designs and a computer-controlled knife cutter to make the silk screen mask. Then they print the shirt (or anything) by hand. Club members also use a computer spreadsheet to keep their orders and cash ledger. The T-shirt club is comprised entirely of youth under 16 years old and has been highly successful, the bulk of orders coming from expatriates and members of Afghan athletic teams.

Figure 15: *The t-shirt club has been a lucrative undertaking. In addition to custom mask making techniques, club members are getting valuable small business and accounting skills.*

- Challenge Coins (Medals) Club and Stamp Making : Through the design, production, and sale of souvenir tokens for local organizations, the challenge coin program provides an incentive structure for students to learn more advanced digital 3D fabrication methods and management skills than the t-shirt club. A prototypical methodology was developed in November 2008 and demonstrated to members of the FabLab community.
- Taj Fab Shop : Technology jobs-for-hire focusing on apprenticeship-style skills training. The first of these jobs are expected to be implemented in summer 2009.

Figure 16: *Making custom stamps by machining rubber erasers with a 3-axis mill is a fast, safe, and rewarding way to learn 3D design.*

Figure 17: *Custom coins or medals are cast from urethane molds. In this process, users create a 3D image in a block of wax using the precise 3-axis computer controlled mill. A negative urethane mold is made from the wax coin. The mold can be used repeatedly without a releasing agent to make copies of the coin in a variety of materials.*

4 Research and teaching skills and experience provided to those who worked on the project

Application of computer controlled and digital tools in :

- wireless, ad hoc meshing and point to point networking
- telemedicine
- agriculture and farming
- business, accounting, and management

These contribute to on-going curriculum development in basic math, science, and engineering as well as basic literacy.

5 Outreach activities undertaken to increase public understanding of, and participation in, science and technology

- Most international travelers kept blogs or maintained other public social networking sites with their experiences and findings.
- Dr. Tam and Ms. Sun delivered a presentation on the Afghanistan Fab Lab and activities to Cambridge Rotary Club (November 2008).
- Dr. Tam delivered a presentation on his experiences and evaluation of the Afghanistan Fab Lab, open to the public and held at MIT (December 2008).
- Tours, demonstrations, and interviews with media organizations such as ABC World News Report, Wired Online, and International Security Assistance Force (ISAF) were published or broadcast.

6 Publications, Internet sites, and other Output

Publications as a result of this work:

- An IEEE Spectrum paper is expected on the FabFi project and a related Fab Lab project, the Thinner Client, developed in South Africa.

Web site or other Internet sites created:

- http://www.fablab.af/ : main home page for Jalalabad Fab Lab; this includes a daily lab journal, wiki, donations page, and user pages
- http://fabfi.fabfolk.com/ : FabFi project page including open distribtion
- http://blog.fablab.af/ : online daily lab journal
- http://amy.fablab.af/ : blog of activities including other global labs and activities

Other specific products (databases, physical collections, educational aids, software, instruments, or the like) developed:

- The entire FabFi system - reflector design, radio access point configuration and software, and instructions - are available for download.

7 Contributions

Fielding a fab lab in Jalalabad has shown that prototyping tools for digital fabrication can function in a post-war, community-stressed setting like Afghanistan and have significant, immediate applications.

We've identified applications in Information Communications Technology (ICT), civil engineering, and first line health care that can benefit enormously from the capabilities in a fab lab.

Hundreds of school aged children have come to the Jalalabad fab lab. In this informal setting, through hands-on projects and peer-to-peer learning structure, children are gaining technical knowledge and experience using state-of-the-art digital fabrication tools. This experience stimulates motivation to learn more deeply about science, math and engineering and develop skills that are valued around the world.

We have established a fab lab that has become a community resource. After 8 months this resource show positive signs of becoming self-sustaining. The fab lab has developed close ties and collaborative projects with the grammar and high schools, hospital and university in the immediate vicinity. There are community members that are learning basic economic and business principles by creating product in the lab for sale in local markets. Additionally we have included in the lab educational resources that extend learning beyond what a fab lab can teach, through the addition of the Open Courseware Project data from MIT. We have also created a wireless network throughout the community that gives access to the internet, for free, opening up the vast knowldege resources that the internet offers, and providing a gateway to the rest of the world.

The successful fielding of the Fab Lab and FabFi caught the attention of Linton Wells who leads the National Defense University's Sustainable Technologies, Accelerated Research - Transportable Infrastructures for Development and Emergency Support (STAR-TIDES) program. Mr. Wells cites the Fab Lab and FabFi project as models of ground-up, ultimately sustainable reconstruction and aid.[12]

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