Global Health Technology 2.0

By Aya Caldwell, Anna Young, Jose Gomez-Marquez, and Kristian R. Olson

Leaping Over the Gap with Collaborative Invention

Global health development assistance has increased threefold in the last decade, and policymakers are recognizing the need for accessible health technologies aimed at low- and middle-income countries (LMICs) [1], [2]. However, developing such technologies is not simple [2]. It requires a delicate departure from top-down, sophisticated engineering toward user-enabled designs that are elegant, simple, and field tested and tailored. In this scenario, the stakes are higher, technologies must succeed with a unique set of design challenges and address a higher burden of global illness. To ensure that these technologies are aligned with end users' needs, codevelopment with innovators in LMICs and multiple iterations with end users' feedback are needed for ultimate translation to practical use.

Boston has emerged as a cluster of biomedical innovation for global health. The area's leading academic institutions in medicine and engineering have coupled their collaborations across the globe to create design and invention spaces for impact-driven research in global health. In this rich environment, now is the time for Global Health Technology 2.0. We define Global Health Technology 2.0 as practical applications of science that are effective and sustainable in their intended care delivery settings. Here, technology stands as an independent determinant of global health rather than as an aspect of policy that gets folded in as systems mature. In our work toward this model of technologies in health, we outline a new way of doing research and development. The practice of Global Health Technology 2.0 equally balances attributes of collaborative research, cocreation, and user-driven insight to drive the invention of innovative projects.

The Global Health Initiative (GHI) at the Center for Integration of Medicine and

MAP: ©COMSTOCK, STETHOSCOPE: ©PHOTODISC

Digital Object Identifier 10.1109/MPUL.2011.941459
Date of publication: 21 July 2011

Innovative Technology, the Center for Global Health at Massachusetts General Hospital (MGH), and Innovations in International Health (IIH) at Massachusetts Institute of Technology (IIH@MIT) have formed a collaboration that puts our research and development model, Global Health Technology 2.0, to work and advances a growing global health portfolio. Using device examples, we highlight a series of design innovation practices.

CIMIT GHI, Center for Global Health at MGH, and IIH@MIT—A Collaborative Approach Based on Cocreation

CIMIT GHI and the Center of Global Health at MGH are multi-institutional collaborative effort focused on LMIC health-care provider training and supports the integration of medical technologies and trainings. These two groups work in Indonesia, Cambodia, and Ethiopia. For example, they helped design a network of more than 500 midwives in rural Aceh province after the 2004 Asian Tsunami and civil conflict that greatly disrupted the health-care system and resulted in midwives receiving no continuing medical education. This training aimed at maternal and newborn care and included the implementation of a novel resuscitation device at delivery. From this experience, they have begun helping with the training network of new birth attendants in Ethiopia. In addition, CIMIT GHI and the Center for Global Health at MGH continue to use their field positions to codevelop medical devices, such as the Car-Part incubator and CoolComply [3]. All the training and technologies aim at enhancing providers where human resources are critically lacking.

Across the Charles River in Cambridge, IIH@MIT works with CIMIT and the Center for Global Health at MGH to invent and fabricate low-cost medical devices by bringing together multidisciplinary teams in a Skunkworks environment, where collaborative relationships augment traditional laboratory resources. Through this model of lean, interdisciplinary teams, IIH accelerates medical technology design for LMICs. IIH uses rapid prototyping technology and the latest advances in applied engineering techniques to create early stage prototypes of even the most high-risk medical device ideas. The core innovation strategy of IIH relies on a network of on-the-ground collaborators in LMICs willing to give early feedback on the device prototypes, answering design, and functionality questions that could never be solved from the laboratory in Cambridge. In fact, the IIH portfolio includes a research project called *Medical Education Design and Innovation Kit (MEDIKit)*, which focuses specifically on enabling physicians and nurses in LMICs to create rapid prototypes of their own ideas for device solutions to global health challenges.

The interdisciplinary and communal network creates an environment that encourages investing time in high-risk, early stage technologies, knowing that funding is just a prototype away and believing that this is the quickest strategy to develop a solution that will improve the lives of patients. This approach has a growing portfolio of inventions that are at different stages of deployment. These include an inhalable vaccine delivery technology, behavioral diagnostics for medication adherence promotion, paper microfluidic diagnostics for remote populations, and low-cost incubators for rapid tuberculosis detection. With the presence in more than 15 countries, we are well poised to accelerate medical technology transfers, create models for scale, and in turn, focus on high-impact technologies.

IIH, CGH, and CIMIT GHI are committed to a belief in cocreation and the advancement of Global Health Technology 2.0. Figure 1 demonstrates how this idea of cocreation has evolved, beginning with the concept of appropriate technology, which

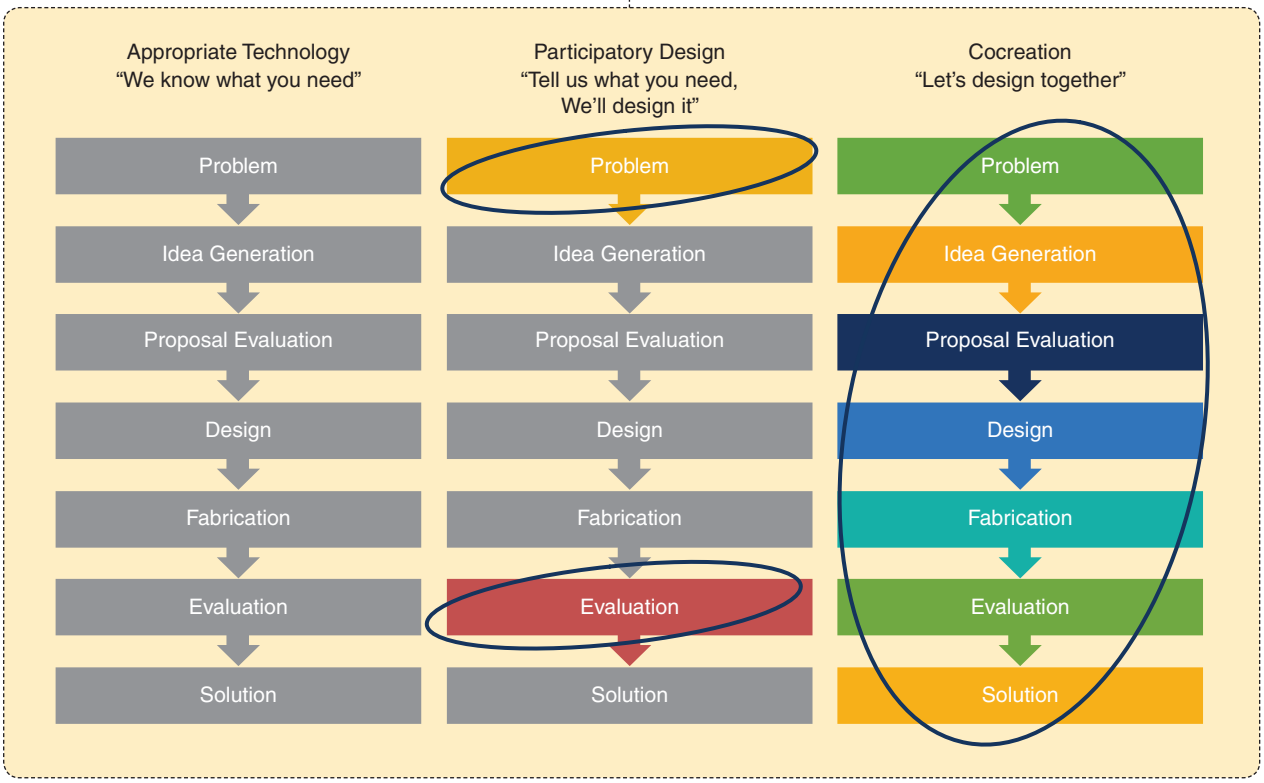


FIGURE 1 Cocreation—the need to catalyze Global Health Technology 2.0.

was popularized by E.F. Schumacher in the 1970s with his book *Small is Beautiful* [4]. Appropriate technology has many connotations across various fields of development. For our purposes, we define appropriate technology as health technologies that take the users' needs and context into consideration. Appropriate technology changed the paradigm of design development to focus on the needs of the community; however, innovators in LMICs had limited involvement throughout the product development value chain. To compensate for this, participatory design focused on bringing innovators into the product development phase but failed to create a truly iterative process that engages the innovators in the field in every stage of product development.

Our approach, cocreation, takes participatory design one step further and is integral to Global Health Technology 2.0. Cocreation allows for true collaborations where innovators across the globe continuously exchange ideas throughout the entire product development process. We understand innovators to be any individual who is motivated to develop a solution to a problem. Consequently, this innovator could be anyone from a doctor at a prestigious hospital in Boston to a car mechanic in a repair shop in rural Indonesia. This methodology empowers end users of the technology to graduate from being the recipients of solutions into technological innovators. Through cocreation, the relationship changes from designer–client into a one-to-one collaboration. Each project in the MGH GHI and IIH portfolio is measured for success based on its level of cocreation.

Challenges in Medical Device Development

There are currently 6.9 billion people in the world, and almost half of them live on less than US$2.50 per day [5]. Within these statistics, the disparity between access to health care is glaring. For example, the location of where one is born, developed or not, drastically alters the chances of survival for both the newborn and mother. Mothers in developing countries are 300 times more likely to die, and newborns are ten times more likely to die than mothers and newborns in the developed countries [6]. Even more alarming is that many of these deaths are preventable with simple solutions and interventions. Technological innovations are part of the solution.

Unfortunately, the current state of medical technological transfer is one of hand-me-down devices from developed countries to developing countries. Without designs that are aimed at operating within the rigors of developing countries' medicine, these transfers often fail. Estimates cite that 95% percent of medical devices in LMICs is donated and 70–80% of these devices is nonfunctional within five years [2], [7]. Estimates of the dysfunction in these settings vary; recent analysis found 38.3% pieces of equipment out of service [8]. In an effort to rectify this gap in access, many global manufacturers retrofit or strip down their products to make simplified, cheaper versions. This can only take you so far. When one encounters challenges that have no analog in the developed markets, the model fails. A fundamental requirement is to use bottom-up design principles and take advantage of indigenous technology innovations.

Appropriate technology can often lead to trickle-up innovations. These can be unintended spin offs from a developing world application into a developed world application. Examples of this include GE's Vscan Ultrasound systems originally designed for LMICs and later commercialized as low-cost alternatives for emergency medical technicians and emergency rooms in industrialized countries [9], [10]. It is critically important to recognize that trickle-up innovations occur when a designer can focus and adapt the parameters for design toward LMICs. The temptation is often to assume that one can create a dual-use solution for low- and high-income markets. While this may be possible, our experience has shown that this approach leads to contextually irrelevant performance demands from the high-income market. This, in turn, rapidly dilutes the design parameters that make the same technology shine in LMICs. In essence, it renders this dual-use approach into a game of chances. Good design can improve on this process. One of the values of Global Health Technology 2.0 is shifting the established design paradigms to solve problems in the face of elegantly identified design challenges. This process is expected to impact health in LMICs and in the developed countries alike.

Global Health Technology 2.0

Using a few examples, we outline key insights into creating a center of excellence with our evolving model of collaborative research and development.

Training 2.0

Using devices as a hallmark of professionalism can catalyze the uptake of new protocols and continuing medical education for personnel. In Aceh, Indonesia, after the 2004 Tsunami, CIMIT GHI and MGH helped design a novel community-based midwife training program focused on peribirth emergencies as one of the first steps in rehabilitating the primary care services. The training was concise, on-site, and the women trained received an Indonesian-manufactured newborn resuscitation device. Unexpectedly, the midwives began to hold up these tube-and-mask devices and say, "I've been trained." This became a symbol of medical sophistication and a driver both for untrained midwives to seek training and for expectant mothers to seek the care of trained midwives.

In parallel, IIH created a series of prototyping kits called the *MEDIKit* aimed at health-care workers eager to create their own solutions (Figure 2). MEDIKits is a platform technology for

JOSE GOMEZ MARQUEZ.

FIGURE 2 Training 2.0–Nurses and doctors in Ocotal, Nicaragua, using MEDIKit in the hospital.

device prototyping and fabrication. Modular components allow medical professionals to design their own appropriate solutions. For implementation, the kits are coupled with an eight-week training course, taught by IIH researchers. Given the appropriate tools and the right context set by the course, MEDIKit participants are immediately empowered to innovate in their work environment, addressing the challenges in health care that hinder development.

Rapid Prototyping

Experiencing a solution through a prototype offers a substantially different experience than a concept on the paper. By forming rapid design and prototyping teams, IIH creates affordable prototypes for user testing in a matter of days and deploys them into the field soon after. Prof. Catherine Klapperich of Boston University created the system for nucleic acid preparation (SNAP) portable DNA isolation system (Figure 3). Dr. Klapperich visited the IIH laboratories with a challenge to turn her desktop version of a microfluidic manifold for isolating DNA into a portable machine aimed at developing countries. Employing a combination of energetic students and knowledgeable design directors armed with automated rapid prototyping technologies, Dr. Klapperich received a final prototype within a few weeks. The SNAP system introduces a self-contained microfluidic system capable of extracting nucleic acids from a blood sample at the point of care, without the need for electricity, cold chain, or specialized training. With the device, she was able to continue her research, attract grant funding from CIMIT's annual innovation grants, and produce field data that are driving the device closer to a product.

JOSE GOMEZ MARQUEZ.

FIGURE 3 Rapid prototyping–SNAP-portable DNA isolation system.

Lean, Collaborative R&D Structures

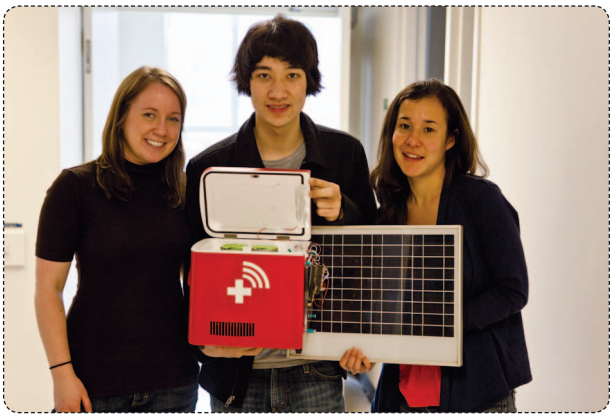
In response to a constrained funding environment for health technologies, we have instilled a model of collaborative resource sharing. Going beyond the bilateral partnerships formed between coprincipal investigators' once funding materializes, we have formed an ecosystem where our resources are pooled in to a "commons" available to members of the network. Each researcher is subscribed to a model of paying it forward to advance an agenda of invention and prototyping among colleagues.

Field Innovation Network

The ability to take a device from the laboratory to a field site 4,000 mi away within 48 h allows innovation teams to get real-time valuable feedback. At the onset, our institutions affiliated a network of international laboratory sites, health-care facilities, and research centers in Central and South America, Southeast Asia, East Africa, Pakistan, and Europe. Each site has the ability to produce high-quality user and field testing within days of receiving a device. Conventionally, designs are incubated in laboratories for months, deployed many months after, and then a design team regroups to analyze user feedback. In contrast, after 14 days of prototyping, an affiliate, Dr. Jonathan Spector, a neonatologist at MGH, saw his design for a neonatal rescue cot (NRC) shipped to three different sites in Nicaragua. User adoption studies were conducted for the NRC and then sent back to Boston for continued iteration a week later.

Another example is CoolComply, shown in Figure 4. CoolComply addresses two fundamental problems with multidrug resistant tuberculosis (MDR-TB)—the difficulty of monitoring patient adherence at the home given the long treatment time (18–24 months) and maintaining adequate temperatures (15 °C) for the medication [11]. In 2009, CIMIT GHI visited two novel treatment sites of the Global Health Committee/Cambodian Health Committee (GHC/CHC) in Cambodia and Ethiopia and noted the superior performance of home-based care approaches to MDR-TB [12]. However, despite a successful model for adherence, the GHC/CHC highlighted the rate-limiting factor of home-based cool-chain equipment and the consequent hindrance on scalability of this model in both countries. CIMIT GHI brought this challenge back to Boston and began working with IIH and the Center for Global Health at MGH to create an intelligent network of devices that can propel MDR-TB home-based care. Throughout the process, the team has worked with the GHC/CHC in Ethiopia, patients, and providers on design modifications, process, and implementation.

Having ongoing clinical care–research relationships in a number of LMIC settings is another strength of academic inclusion in the Global Health Technology 2.0 process. The Institutional Review Board's (IRB) review is the ethical assessment of the merits of performing any investigation on a given population of patients. It is imperative that IRB committees in resource-constrained settings have the capacity and opportunity to evaluate the risks and benefits of studies affecting their community. Although the initial connection with or de novo creation of local IRB committees may take time, pre-evaluation of subsequent evaluations are streamlined. This process has served



NATHAN COOKE

FIGURE 4 Field innovation network–CoolComply-patient support optimization and adherence monitoring for MDR-TB. From left: Anna Young, Stephan Boyer, and Aya Caldwell.

both to establish ethical merits and to engage the local scientific communities in Indonesia, Pakistan, Ethiopia, and Nicaragua.

Team Diversity

Our model goes beyond multidisciplinary teams and into discipline shifting. Cocreation discourages participants from being pigeonholed and specialized. The best ideas may come from individuals who have limited background in the subject area but are willing to explore ideas and prototyping. Our own process experience has repeatedly demonstrated the value of role flexing. A team may include a client, anthropologist, economist, physician, designer, and engineer. Traditional role "pigeonholing" leads to the division of processes along these disciplinary lines. However, in a generative process of cocreation, we see that the clients become not only a user but a designer, a physician, a policy advisory, an anthropologist, and an engineer. Role flexing has already yielded novel approaches and solutions in unforeseen ways, which is precisely what is needed to avoid pitfalls of decades past. This is the inception of cocreation.

Invention Still Matters

Finally, Global Health Technology 2.0 is not just about delivery. Through appropriate, tailored, affordable design, clinics around the world can gain access to devices and training that were not possible five or ten years ago. Barriers to care may become innovation opportunities and long-identified "stuck points" to providing necessary care surmounted. However, a creation space, including academia and partners, must be nurtured for this process to flourish. Global Health Technology 2.0 positions the adoption of effective health technologies as an independent determinant of health. Cocreation is essential as a source of these technologies. Herein, collaborations across the globe, disciplines, and cultures continuously exchange ideas throughout the entire product development process.

Team diversity, established clinical care and research platforms, rapid and iterative prototyping, and training the next generation of innovators are essential ingredients. Shifting the established design paradigms to solve problems in the face of previously insurmountable innovation challenges stands to impact health and health-care delivery.

Conclusions

Technological innovations have the potential to change the lives of millions of individuals living in resource-limited settings; yet, many of these technologies are unused and broken, and providers are disempowered [7]. The high failure rate is, in part, a result of devices not being designed for these settings. Technology product development should be based on cocreation with specific end users' adoptability and feedback. These should be incorporated to modify designs so that the effectiveness and durability in the intended clinical setting is optimized. There is a sizable need for technologies that are simple to use, meet required performance metrics, and ruggedized to operate under harsh-use conditions.

Collaborations and cocreation with end users allow for a unique group of individuals from various disciplines, institutions, and sectors to innovate for the challenges currently faced in global health and technology development. These, in turn, act as an impetus to develop specific solutions for the intended user to successfully translate their research. The successful implementation of technologies has the potential to augment health-care provider's impact and catalyze the improvement of patient care and outcomes not only in LMICs but developed countries alike as these concepts are relevant globally. This process of extending the novel languages of innovation is just the beginning of Global Health Technology 2.0.

Aya Caldwell (acaldwell1@partners.org) *and* ***Kristian R. Olson (krolson@partners.org)*** *are with the Center for Global Health at Massachusetts General Hospital (MGH), CIMIT's Global Health Initiative.* ***Anna Young (annakyoung@gmail.com)*** *and* ***Jose Gomez-Marquez (jose.gomez.marquez@gmail.com)*** *are with Massachusetts Institute of Technology (MIT) Innovations in International Health.*

References

[1] Institute for Health Metrics and Evaluation, *Financing Global Health 2010: Development Assistance and Country Spending in Economic Uncertainty.* Seattle, WA: IHME, 2010.

[2] World Health Organization, *Medical Devices: Managing the Mismatch: An Outcome of the Priority Medical Devices Project.* Geneva: World Health Organization, 2010.

[3] K. Olson and A. Caldwell, "Designing an early stage prototype using readily available material for a neonatal incubator for poor settings," in *Proc. Annu. Conf. IEEE Engineering in Medicine and Biology Society (EMBS)*, Sept. 2010, pp. 1100–1103.

[4] E. F. Schumacher, *Small is Beautiful*: *Economics As If People Mattered*. New York: Harper Perennial, 1973.

[5] World Bank, *World Development Indicators 2008*. Washington, DC: World Bank Publications, 2008.

[6] United Nations Children Fund (UNICEF), *The State of the World's Children Special Edition: Celebrating 20 Years of the Convention on the Rights of the Child*. New York, NY: UNICEF, 2009.

[7] R. A. Malkin, "Design of health care technologies for the developing world," *Annu. Rev. Biomed. Eng.*, vol. 9, no. 1, pp. 567–587, 2007.

[8] L. Perry and R. Malkin, "Effectiveness of medical equipment donations to improve health systems: How much medical equipment is broken in the development world?" *Med. Biol. Eng. Comput.*, *Online First*, vol. 49, no. 7, 2011. [Online]. Available: http://www.springerlink.com/content/p1088x8r73035463

[9] J. Immelt, V. Govindarajan, and C. Trimble, "How GE is disrupting itself," *Harv. Bus. Rev.*, vol. 87, no. 10, pp. 56–65, 2009.

[10] General Electric. (2011, Apr. 1). A closer look at GE's pocket size Vscan ultrasound [Online]. Available: http://www.gereports.com/a-closer-look-at-ges-pocket-sized-vscan-ultrasound

[11] World Health Organization, Multidrug and Extensively Drug-Resistant TB (M/XDR-TB): 2010 Global Report on Surveillance and Response. Geneva: World Health Organization, 2010.

[12] S. Thim, S. Sath, M. Sina, E. Y. Tsai, J. C. Delgado, A. E. Shapiro, C. E. Barry, III, P. Glaziou, and A. E. Goldfeld, "A community-based tuberculosis program in Cambodia," *J. Amer. Med. Assoc.*, vol. 292, no. 5, pp. 566–568, Aug. 2004.