Health Care Innovation for Low-Resource Settings: The Value of Local Immersion and Partnership

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Health Care Innovation is the creation, development, and translation of new and better solutions to health care challenges. At its core, this endeavor does not require extending the frontiers of science or the creation of new fundamental technologies. Rather, it is primarily focused on the use of existing science and established technologies in the design of new solutions to problems in health care. Successfully innovating for low- and middle-income countries (LMICs) requires a needs and stakeholder-driven approach to enable development and adoption of available, accessible, and acceptable solutions tailored to the specific need and context of care.

As such, it is important for projects in this field to start with the identification, validation, and detailed specification of a significant, unmet health care need—a need that calls out for a better solution than what exists and, thus, demands creative thinking. Once a need is validated through ethnographic and market research with relevant stakeholders and understood to some extent, the project team is ideally free to explore a wide range of possible technology domains from which a solution could emerge. This is in comparison to traditional academic research projects where the exploration of solutions is often limited to the expertise of a specific lab or principal investigator (PI). Projects true to the principles of health care innovation explore a wide range of potential technical solutions [1]. Once the team has developed outlines of many solution concepts, these are assessed against criteria emerging from clinical, technical, business, and organizational/team considerations. Some concepts may be exciting from a technical perspective but impractical from business or clinical perspectives. Successful innovation demands that the team maintain a keen eye on the goal, improving human health, and thus they should select the concept with the highest probability of full development into a product and delivering real-world impact. After that choice is made, the next steps follow an iterative product design and development process [2], one in which the team should routinely stop and assess their path from clinical, technical, business, and organizational/team perspectives.

Global health innovation at the Center for Bioengineering Innovation and Design

Health care innovation differs in mission, culture, funding, and personnel from traditional academic engineering programs and benefits from separate, focused program leadership. To this end, in 2009,

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the Johns Hopkins University (JHU) Department of BME launched the Center for Bioengineering Innovation and Design (CBID) with a dual mission of: 1) the education and professional development of the next generation of leaders in health care innovation and 2) the creation and early-stage development of health care solutions that have the potential for high impact. The graduate program launched with this intent was originally focused on creating solutions tailored to well-resourced health care systems typical of high-income countries (HIC), exemplified by institutions like The Johns Hopkins Hospital.

Following a successful inaugural year, collective interest from faculty, students, and partners led to incorporation of global health innovation (GHI) into CBID's core curriculum. An added focus on health care innovation for LMICs provided students with a unique learning experience through support of a developing health care system. This new focus area was supported by two main external partners with vastly different missions and motivations: CBID's corporate medtech partners and CBID's Global Health-focused not-for-profit partners.

Adding a global health focus to CBID's curriculum and projects served several strategic goals for CBID's corporate partners. First, higher annual growth in health care spending is mainly concentrated in LMICs. According to the World Health Organization, health care expenses are growing 6% per year on average in LMICs, compared to 4% per year in HIC [3]. Research shows that LMICs make up nearly 40% of worldwide total health expenditure [4]. For an established medtech company focused on high-income markets, to achieve double-digit growth, the company will need to also succeed in emerging LMIC markets. This will require companies to do more than simply market their existing products in LMICs. Instead, they will need to design and develop products tailored to the needs and constraints of those markets, including cost, usability, maintenance, performance, and acceptability. For example, in India, per capita health care expenditures are increasing at a CAGR of 15% and chronic diseases will account for 89% of 90 million deaths by 2050 [5], [6]. Diabetes, a leading cause of morbidity and mortality in LMICs ideally requires daily blood glucose monitoring (BGM) for proper management. Medtech companies, such as Johnson & Johnson, have successful BGM technologies designed for the USA, but in the 2000s, it became clear that these products were too complex and costly for the largest segments of the Indian market. Their success with a BGM design for India did not rely on new science or technology, but rather a different product design approach.

Talented health care innovators capable of blending best practices from HIC product design with the insights and mindset suitable for LMICs are a rare breed. One major challenge lies in the need of product designers focused on LMICs to have a clear understanding of the stakeholder landscape and their specific needs. Furthermore, engineers and other technical and clinical experts on these teams, if exclusively trained in a HIC system, struggle with what is affectionately referred to as "frugal innovation" or, in India, "Jugaad innovation" [7]. This mindset prioritizes sustainability, ease of use and maintenance, and cultural sensitivity, while delivering on the core value proposition of the original product. Importantly, corporate leaders forecast that such products will eventually be essential for success in HICs where there is growing need for lower cost, high performing solutions. Thus, CBID's corporate partners are eager to support this type of talent development with practical hands-on experience in developing effective and cost-effective solutions tailored for LMICs.

For CBID's not-for-profit partners, such as the U.S. Agency for International Development (USAID) and Jhpiego, the value differs. These organizations have witnessed many well-intentioned but ultimately unsuccessful attempts to deploy products originally designed for HICs into LMICs. For example, many hospitals in LMICs have "graveyards" of expensive donated medical equipment, such as newborn incubators, that were usable for only brief periods before failing. The reasons for these failures are multifaceted, but often stem from the design of these products for a vastly different part of the world. Conversely, many products designed specifically for LMICs, and funded by donors, failed to translate promising initial designs into tangible impact in the field. What is needed is the combination of two critical elements: a clear understanding of and partnership with local stakeholders, coupled with the rigorous medical device design and development practices which have been proven successful in HIC markets.

Student interest in contributing to health care innovation for LMICs was a major driver for its inclusion in the CBID graduate program. Many students desire an opportunity to develop skills, mindsets, and experiences that break the mold and constraints of their peers who have primarily trained for traditional, HIC-focused medtech innovation. They view LMIC-focused innovation as a greater intellectual and creative challenge, given the heightened challenge of creating an effective solution for complex presentations of diseases at a much lower cost and for underfunded health systems that are oftentimes dysfunctional in several aspects.

Designing technology for LMICs allows students to distill their engineering education to its fundamental principles, honing their skills to meet the specific needs of their end users. This also serves as a crucial lesson in the art of avoiding overengineering solutions, instilling in them the vital skill of creating resource-appropriate interventions. Students who excel in this sort of challenge develop a keen understanding of efficiency, adaptability, and real-world impact. Through this experience, they emerge as potential leaders with a deep sense of empathy and commitment to addressing global health disparities. Additionally, students feel that such projects offer them an opportunity to channel their skills and energy toward endeavors with potential for more substantial impact on human health compared to traditional HIC-focused projects, aligning with the overarching goal of advancing health care equity and accessibility.

Since 2010, when GHI was incorporated into the CBID program, ~50% of projects have been focused on LMICs. Teams are based at JHU and collaborate closely with advisors and health care implementation partners in the target region. Projects have spanned a diverse array of locations and three continents, including China (both coastal and western regions), India (from "clinics" in the Sundarbans to state-of-the-art facilities like the All-India Institute of Medical Sciences Hospital in New Delhi), Kenya, Uganda, Tanzania, Ethiopia, Rwanda, Ghana, Zambia, the Republic of South Africa, Guinea, Brazil, Indonesia, Nepal, and Bangladesh. These projects encompass a broad spectrum of clinical and global public health themes and technology, from digital health solutions addressing malaria control and breast cancer diagnosis to handheld devices that treat cervical cancer or screen for hemoglobin levels. These projects are all united and enabled by a fusion of local partnerships and immersion with best practice innovation and design principles and tools utilized by leading medtech companies and design firms.

Local partnerships and immersion for global health innovation

The foundation of CBID's global health projects is a deep and comprehensive understanding of an unmet need, including the underlying pathophysiology, key stakeholders (e.g., patients, caregivers, and care providers), financial system (e.g., self-pay, insurance, and foundation), infrastructure (e.g., equipment, instruments, medical devices, and therapies) and other elements of the overall context of care. While landscape analysis lays the foundation for this understanding, there is no substitute for field immersion, a core element of the CBID global health curriculum. Field immersion is only successful with the close support of local partners, involved in all aspects and stages of a health care innovation project, from needs identification and selection to solution concept development and evaluation. For health care innovation professionals who have predominantly lived and trained in HICs, such immersions, even if only a few weeks, serve to broaden perspectives and dispel assumptions and preconceived notions. During field visits, the level of creativity, frugal problem-solving, and dedication to social benefit is often much higher than at home. Assumptions about the reliability of electricity, water, clean air, safe transportation, and efficient management—factors that drastically impact the design of practical health care solutions—are rigorously challenged in LMIC settings, fostering a more holistic approach to innovation and simultaneously breaking stereotypes. Concurrently, students typically develop a deep respect for the "bright spots" in under resourced health systems, including the doctors, nurses, staff, community health workers, and how they accomplish so much for those they serve, despite systemic challenges. Students interact with policymakers and ministries of health to appreciate the vision and desire for change and impact, and what it would take to drive that change. This contextual immersion forms the foundation of any new innovation journey for CBID teams. Students return not merely with a list of needs and user requirements, but with empathy, respect, context, and motivation. Without this foundation, seldom are impactful innovations possible.

Of course, the need for direct and personal first-hand observation is not unique to LMIC health care innovation. For example, at Toyota, it is a core element of design thinking, referred to as "*genchi genbutsu*," or going to the actual location to observe and understand [8]. It calls for problem-solvers to immerse themselves in the context of the issue at hand, encouraging them to "go and see" for themselves. The designer of a new Toyota minivan for the U.S. market reportedly spent many weeks traveling across the country in a minivan with various American families. Immersive design practices offer unparalleled insights and inspiration for new solutions that may be missed otherwise. Similarly, a CBID student team lived with rural community health workers in their huts for several weeks to understand and appreciate rural health care delivery from the viewpoint of the health workers and patients in those communities. These students eventually went on to establish a telemedicine nonprofit startup, Intelehealth, that has now served over 25 million patients in LMICs. CBID invests heavily in this type of travel, immersion, and partnership, as a core part of its graduate program in health care innovation. Outcomes of this program include hundreds of talented medtech innovators with both HIC and LMIC design experience, as well as several life-saving products and organizations, such as CryoPop, HemoGlobe, VectorCam, Visilant, and Intelehealth [9], [10], [11], [12], [13].

During field immersion, CBID student teams, with the support of their in-country partners, spend time in clinics, operating rooms, and villages interacting with patients, families, community health workers, doctors, and even government officials (Figure 1). Armed with their background landscape research and a curiosity for new information, students perform rigorous ethnographic research through direct observation and interviews that they synthesize through mind-mapping and root cause analysis. Teams pay attention to unarticulated needs or Jugaad-like innovations that could be further refined and broadly disseminated. Given the resource constraints in LMICs, it is especially important to identify practice- and budget-based value signposts, including opportunities to improve practice efficiency and bottom-line (e.g., procedure time, inpatient stay, number and type of personnel required, technology costs, intervention cost-effectiveness) [14].

Students identify hundreds of unmet clinical needs that are validated and prioritized in collaboration with local stakeholders and partners prior to leaving the country. Creating strong relationships and communication channels while in-country is crucial for innovators as their understanding of the need evolves during solution development, and solution concepts must undergo validation with end-users to prove feasibility and sustainability.

Figure 1. Graduate students from the Johns Hopkins Center for Bioengineering Innovation and Design (CBID) listening to a midwife in a maternity clinic in Nepal. Effective global health innovation requires significant immersion and partnerships in the region. (Photo courtesy of Center for Bioengineering Innovation & Design.)

Our experience at CBID and informal surveys of global health innovators have emphasized the importance of local partnerships, both for development and translation of impactful solutions. Partners may include specific health care systems, medtech companies, foundations, universities, governments, and/or individual experts. GHI programs, at minimum, require strong partnerships that provide access to direct observation and interviews of key stakeholders to identify important insights and unmet needs. These partnerships can be further enhanced via inclusion of funding support/opportunities, usability and clinical testing, and commercialization support, all of which may vary significantly from HIC settings. In particular, identifying funding or commercial partners early on can significantly advance GHI projects and inform manufacturing, distribution, and regulatory pathway considerations. These partners can also identify potential product design pitfalls early on, and also help ensure a viable path to market beyond product development and technical de-risking.

In any partnership with a local health care provider, it is important to establish trust and bring real value to their objectives, regardless of the possibility of development and deployment of a potential solution. The time commitment and dedication on the part of a host site and its personnel is not trivial. Thus, it is important to have alignment on key themes and areas of interest with both short-term and long-term expectations. The needs identification process itself is often of great utility for partners, as it offers them the opportunity to systematically analyze and identify opportunities for improvement across operations, including provider training, patient screening and diagnosis, clinical outcomes, postoperative care, and time- and cost-efficiency. Results from ethnographic research have resulted in immediate impact via purchase of new tools/equipment, initiation of clinical trials to better understand a clinical need, and improvement in training programs. Teams can also add value by sharing learnings and existing practices from HIC settings, making connections to other partners or care providers around the world, and sharing research, innovation practices, and expertise that can become embedded within the partner site over time.

Ideally, teams and partners will identify and align on needs with significant impact potential, high technical and commercial feasibility, and a potential to draw in the resources required to translate and implement their solution at scale. It is useful to maintain a highly collaborative approach throughout the design and development process, including needs selection, design requirements, product specifications, solution concept selection, experimental strategy, design of usability/clinical trials, and during development of an implementation plan. This approach creates learnings for all stakeholders, builds trust and institutional investment in the solution, ensures that the correct endpoints are designed for and met, and increases the overall likelihood of successful technology development and deployment. ■

References

[1] J. P. Roberts et al., "A design thinking framework for healthcare management and innovation," *Healthcare*, vol. 4, no. 1, pp. 11–14, Mar. 2016.

[2] Y. Yazdi and S. Acharya, "A new model for graduate education and innovation in medical technology," *Ann. Biomed. Eng.*, vol. 41, no. 9, pp. 1822–1833, Sep. 2013.

[3] A. Soucat et al., *Tracking Universal Health Coverage: 2017 Global Monitoring Report*, World Health Org., Int. Bank Reconstruction, Develop./The World Bank, 2017.

[4] M. Jakovljevic and T. E. Getzen, "Growth of global health spending share in low and middle income countries," *Frontiers Pharmacol.*, vol. 7, p. 21, Feb. 2016.

[5] A. Ghosh et al., "India's per capita healthcare expenditure," *Econ. Political Weekly*, vol. 56, no. 8, pp. 42–49, Feb. 2021.

[6] United Nations News. (May 2023). *Chronic Diseases to Account for 86% of Deaths by 2050*. [Online]. Available: https://news.un.org/en/story/2023/05/1136832

[7] J. Prabhu and S. Jain, "Innovation and entrepreneurship in India: Understanding Jugaad," *Asia Pacific J. Manage.*, vol. 32, no. 4, pp. 843–868, Dec. 2015.

[8] F. Badurdeen, K. Wijekoon, and P. Marksberry, "An analytical hierarchy process-based tool to evaluate value systems for lean transformations," *J. Manuf. Technol. Manag.*, vol. 22, no. 1, pp. 46–65, 2011, doi: 10.1108/17410381111099806.

[9] S. Yogeshkumar et al., "Safety and efficacy of the new CryoPop® cryotherapy device for cervical dysplasia in low- and middle-income countries: Study protocol for a multicenter open-label non-inferiority clinical trial with historical controls," *Trials*, vol. 22, no. 1, 2021, Art. no. 915.

[10] S. Acharya et al., "Non-Invasive estimation of hemoglobin using a multi-model stacking regressor," *IEEE J. Biomed. Health Inform.*, vol 24, no. 6, pp. 1717-1726, Jun. 2020.

[11] A. Goodwin et al., "Mosquito species identification using convolutional neural networks with a multitiered ensemble model for novel species detection," *Sci. Rep.*, vol. 11, Jul.~2021, Art. no. 13656.

[12] Visilant. *Enabling Access to Eye Care Through Technology to Eliminate Avoidable Blindness*. Accessed: Feb. 2024. [Online]. Available: https://www.visilant.org/

[13] N. Verma et al., "Diagnostic cncordance of telemedicine as compared with face-to-face care in primary health care clinics in rural India: Randomized crossover trial," *JMIR Form Res.*, vol. 7, Jun. 2023, Art. no. e42775.

[14] S. Zenios et al., *Biodesign: The Process of Innovating Medical Technologies*. Cambridge, U.K.: Cambridge Univ. Press, 2009.

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