




# Cost-effectiveness analysis of human-centred design for global health interventions: a quantitative framework

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## ABSTRACT

**Introduction** Human-centred design (HCD) is a problem-solving approach that is increasingly used to develop new global health interventions. However, there is often a large initial cost associated with HCD, and global health decision-makers would benefit from an improved understanding of the cost-effectiveness of HCD, particularly the trade-offs between the up-front costs of design and the long-term costs of delivering health interventions.

**Methods** We developed a quantitative framework from a health systems perspective to illustrate the conditions under which HCD-informed interventions are likely to be cost-effective, taking into consideration five elements: cost of HCD, per-client intervention cost, anticipated number of clients reached, anticipated incremental per-client health benefit (ie, disability-adjusted life years (DALYs) averted) and willingness-to-pay. We evaluated several combinations of fixed and implementation cost scenarios based on the estimated costs of an HCD-informed approach to tuberculosis (TB) contact investigation in Uganda over a 2-year period to illustrate the use of this framework.

**Results** The cost-effectiveness of HCD-informed TB contact investigation in Uganda was estimated to vary from US\$8400 (2400 clients reached, lower HCD cost estimate) to US\$306 000 per DALY averted (120 clients reached, baseline HCD cost estimate). In our model, cost-effectiveness was improved further when the interventions were expected to have wider reach or higher per-client health benefits.

**Conclusion** HCD can be cost-effective when used to inform interventions that are anticipated to reach a large number of clients, or in which the cost of HCD is smaller relative to the cost of delivering the intervention itself.

## INTRODUCTION

The past two decades have seen unprecedented investment in research and development of new health innovations for low and middle-income countries (LMICs). However, very little of this investment has been directed towards design and delivery innovations.<sup>1</sup> One example of this discrepancy is in the field of tuberculosis (TB) research, where less

## WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ An increasing number of global health interventions involve human-centred design (HCD), a creative process that often involves large initial costs for technical experts.
- ⇒ The cost-effectiveness of HCD-informed global health interventions is largely unknown.

## WHAT THIS STUDY ADDS

- ⇒ The authors developed a quantitative framework to illustrate the conditions under which HCD interventions would likely be cost-effective.
- ⇒ This framework was applied to an HCD-informed tuberculosis contact investigation intervention in Kampala, Uganda.
- ⇒ The cost-effectiveness of HCD-informed interventions is optimised by minimising up-front costs of HCD, increasing the number of clients reached, and increasing the per-client health benefit.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE AND/OR POLICY

- ⇒ HCD-informed global health interventions can be cost-effective if they reach enough clients and provide enough benefit to offset the up-front costs.
- ⇒ Decision-makers can use this simple framework to obtain initial estimates of cost-effectiveness when considering whether to employ an HCD-informed approach to a global health intervention.

than 13% of TB research funding is allocated to operational research (or epidemiology).<sup>2</sup> The predominant biomedical research model often implicitly assumes that interventions proven to work in certain settings will be transportable to others. Unfortunately, this assumption often does not hold—and for a given intervention to be effective in a new setting, it must be tailored to the specific context.<sup>3</sup> One potential approach to this problem is human-centred design (HCD), a creative process aimed at improving efficiency and facilitating innovation of a product or intervention by putting people at



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the centre of the design focus.<sup>4</sup> HCD allows one to gain insight into the needs of the beneficiaries, create innovative approaches to meet these needs and deliver solutions tailored to specific socioeconomic contexts.<sup>5</sup> Early definitions of HCD “presumed an intended and predetermined use for each item/service as well as a static ‘user’ envisioned by the designer/engineer”.<sup>6</sup> This definition has evolved to emphasise the ‘understanding of needs, desires and experiences’ of users and the techniques needed to reach this understanding through communication, interaction, empathy, and stimulation.<sup>7</sup>

While HCD was first implemented in industrial design and engineering, it has been increasingly used in the global health context, especially given the strong focus of HCD on people and their communities and its emphasis on human interactions from design to implementation.<sup>7,8</sup> Examples of HCD-informed contributions to global health range from smaller ‘incremental’ innovations to bolster existing interventions, such as the development of a marketing strategy for Nigerian health insurance,<sup>9</sup> to larger ‘disruptive’ innovations that result in completely new interventions such as the design of new services in Zambia to decrease unplanned pregnancy among girls aged 15 to 19.<sup>10</sup>

As the role of HCD in global health expands, a major consideration is whether HCD can be cost-effective in resource-limited contexts. Alternatives to HCD exist, including implementing without a specific strategy (which entails no additional costs) and tailoring interventions to address determinants of practice based on behavioural theory (which may be less expensive but more time-consuming than HCD).<sup>11,12</sup> Until local capacity can be more broadly built, HCD often involves sourcing technical guidance and expertise through partnerships with design firms based in high-income countries, resulting in large up-front costs. The return on this investment (in terms of health benefit) varies, so decision-makers must generally assess whether an HCD-informed intervention would be cost-effective before initiating the HCD process. We, therefore, sought to develop a quantitative framework to help answer the question, ‘What level of anticipated incremental health benefit is needed to justify investment in an HCD-based global health intervention?’

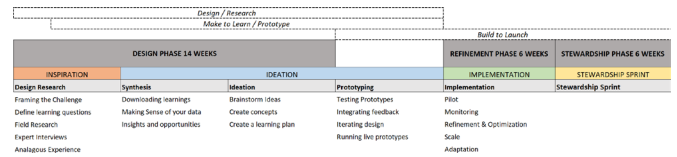
**METHODS**

**Patient involvement**

As part of the HCD process, the parent study engaged patients with TB, community members, healthcare workers, and implementing partners in the development and refinement of the proposed TB contact investigation implementation strategy.

**Overview**

Our primary objective was to identify the conditions under which HCD can be cost-effective, when applied to health interventions in LMICs. To accomplish this objective, we first defined a range of reasonable HCD costs



**Figure 1** Overview of HCD-informed design process for TB contact investigation. The process of creating the HCD-informed solution for TB contact investigation in Kampala, Uganda, took place over 20 weeks. During these 20 weeks, the designers and healthcare professionals completed all three phases of HCD from inspiration through ideation and implementation, with the aim to build empathy with the target community and then to propose, create, test and refine solutions rooted in people’s actual needs (8). Activities within each phase are listed at the bottom of the figure. After 20 weeks of creating, testing, and iterating, the HCD-informed intervention was ready for implementation. Figure courtesy of IDEO.org. HCD, human-centred design; TB, tuberculosis.

in consultation with the non-profit design studio IDEO.org. The costs included fixed costs from the design phase and variable implementation costs that comprised of personnel, travel, and equipment costs. Using these costs, we then estimated the incremental cost-effectiveness of a hypothetical HCD-informed intervention using an analytical framework with five elements: (1) cost of HCD, (2) incremental per-client intervention cost (HCD-informed minus non-HCD-informed), (3) anticipated number of clients reached, (4) anticipated incremental per-client health benefit (ie, DALYs averted) and (5) willingness-to-pay.<sup>13</sup>

**Motivating example**

To provide a benchmark example, we projected the potential cost-effectiveness of an HCD-informed intervention for TB contact investigation in Kampala, Uganda.<sup>14</sup> This intervention targeted urban and peri-urban communities surrounding the health facilities previously identified based on their geographic proximity to the Uganda-based implementing partner, Uganda Tuberculosis Implementation Research Consortium (U-TIRC). The target population included household and non-household contacts of people newly diagnosed with pulmonary TB in these clinics.

As envisioned by the design partner IDEO.org, the HCD process consists of three phases: inspiration, ideation and implementation (figure 1). For this intervention, the inspiration phase involved understanding community beliefs and priorities through interviews and focus group discussions. The ideation phase involved generating new ideas through brainstorming sessions, rough prototyping and the testing and refining of these prototypes through participant feedback. The inspiration and ideation phases of the HCD process resulted in development of the ‘Tuli Wamu Nawe’ (Luganda for ‘We are with you’) strategy. This strategy emphasises a team-based approach, in which community health workers are supported by ‘health riders’, who transport health workers to patient homes and sputum specimens to

clinics. This strategy also includes printed informational materials to help community health workers to educate patients diagnosed with TB and to help patients educate their household and close contacts. The *Tuli Wamu Nawe* strategy is now in the implementation phase and undergoing evaluation in a stepped wedge cluster randomised trial. Both implementation and effectiveness outcomes are under evaluation, including the incremental proportion of contacts completing screening and testing, and the incremental number of contacts diagnosed with microbiologically confirmed TB.

### Cost-effectiveness of HCD-informed TB contact investigation

In deciding whether to pursue HCD, expenditure data on the (future) intervention are rarely available. Thus, to better replicate the decision-making process, we assume availability of budget estimates (rather than expenditure data) and take a health systems perspective. To estimate costs in our motivating example, we sourced itemised budgets from both IDEO.org and U-TIRC. In doing so, we assumed that the incremental cost of the HCD-informed intervention (relative to the standard of care) includes both an up-front cost associated with the inspiration and ideation phases (ie, costs that must be incurred before any clients benefit from the potential intervention) and an ongoing cost associated with the implementation phase (ie, personnel, travel, and equipment costs). For purposes of providing a transparent decision-making framework, we assumed that the inspiration/ideation phase cost (ie, cost of design) is fixed, whereas the implementation phase cost scales linearly with the number of clients reached.

We compared the budgets from this project to actual expenditures for other HCD-informed interventions and for prior contact investigation activities in Uganda to confirm that cost estimates were reasonable. All costs were converted and inflated to 2020 US dollars using the World Bank gross domestic product (GDP) deflator for the USA at 3600 Ugandan shillings to 1 US dollar.<sup>15</sup> Future costs were discounted at 3% per year, as recommended by the US Panel on Cost-Effectiveness in Health and Medicine.<sup>16</sup>

To estimate corresponding effectiveness (ie, health benefit), we first estimated the number of TB cases that might be identified through contact investigation, using data from a meta-analysis of household contact investigation.<sup>17 18</sup> Given that contact investigation may still occur without the HCD process, we considered two scenarios: one in which the HCD-informed intervention was ‘incremental’ (ie, without HCD, contact investigation would still be performed, but less efficiently—defined here as diagnosing 40% of all household cases), and one in which this intervention was ‘disruptive’ (ie, without HCD, no contact investigation would be performed). Based on projections from the ongoing trial, we assumed that this ‘disruptive’ intervention could reach 720 household contacts—regardless of underlying TB status—if implemented across six clinics for 2 years. We then used a

published transmission model calibrated to South Africa to estimate the corresponding cost per disability-adjusted life year (DALY) averted based on the cost per case detected, over a 2-year time horizon.<sup>19</sup> We also explored potential economies of scale from reaching larger client volumes.

### Generalisable framework for estimating cost-effectiveness of HCD

Using our estimates above as a benchmark, we used sensitivity analyses to create a more general framework to estimate the incremental cost-effectiveness of a generic HCD-informed intervention. We considered three scenarios for the up-front cost of the HCD process: equal to the projected cost of HCD in the TB contact investigation intervention above, 50% lower and 50% higher. We also considered three scenarios for the incremental per-client cost of implementing the HCD-informed component of the intervention (US\$0.10, US\$1 and US\$100), to illustrate the wide range of potential costs that might be anticipated across different types of global health interventions. Using these estimates of incremental HCD cost, we then plotted the projected incremental cost-effectiveness of HCD (cost per DALY averted) according to the number of clients projected to be reached and the incremental number of DALYs averted per client (ie, DALYs averted with HCD minus DALYs averted without HCD). These estimates are then compared with different willingness-to-pay thresholds to provide decision-makers with an initial estimate of whether undertaking an HCD process would likely be considered cost-effective under prevailing cost-effectiveness thresholds. In making this comparison, we assumed that cost-effectiveness could be evaluated based on society’s willingness-to-pay for health utility (ie, DALYs averted), and that incremental cost-effectiveness thresholds could be used as a proxy for willingness-to-pay thresholds.

## RESULTS

Based on detailed budgetary review, we estimated the up-front cost of the HCD process for TB contact investigation as US\$356 000, including design, creation, and testing of contact investigation over a 20-week period from inspiration to implementation. We estimated the corresponding incremental cost of implementing the HCD-informed component of the intervention (eg, printing materials, supporting ‘health riders’) as US\$0.41 per client (household contact) reached. Assuming a baseline prevalence of 3.1% of active TB in household contacts,<sup>17</sup> we estimated that HCD-informed household contact investigation could detect 22.3 cases of active TB across six clinics over 2 years (table 1).

Assuming a low (2.2%) and high (4.4%) prevalence of active TB in household contacts resulted in detecting 15.8 and 32.7 cases, respectively. Assuming that, without HCD, contact investigation would not occur (ie, HCD as ‘disruptive’), we estimated the incremental cost-effectiveness

**Table 1** Estimated number of active TB cases detected and cost per DALY averted for HCD-informed TB contact investigation in Uganda

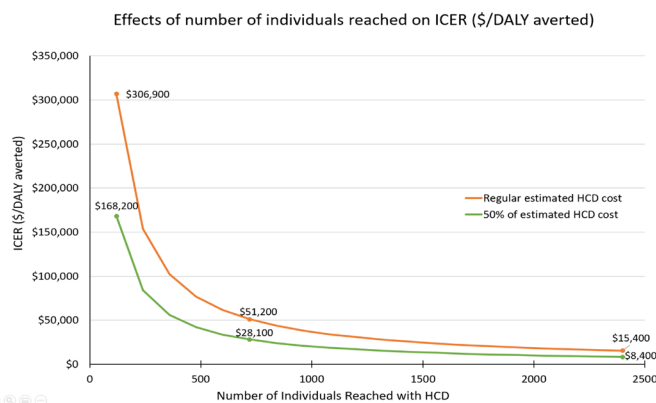
Design	Bound	Active TB prevalence (cases/100 people)	Incremental contacts reached	Incremental cases detected	Incremental cost of HCD	Cost per case detected	DALYs averted per case detected	Cost per DALY averted
HCD as 'disruptive': no activity without HCD	Low	2.2	720	15.8	US\$356 000 + US\$0.41/contact	US\$24 900	0.345	US\$72 100
	Mid	3.1		22.3		US\$17 700		US\$51 200
	High	4.4		31.7		US\$12 400		US\$36 100
HCD as 'incremental': 40% efficiency without HCD	Low	2.2	432	9.5	US\$356 000 + US\$0.41/contact	US\$41 500	0.345	US\$120 200
	Mid	3.1		13.4		US\$29 400		US\$85 300
	High	4.4		19.0		US\$20 700		US\$60 100

DALY, disability-adjusted life year; HCD, human-centred design; TB, tuberculosis.

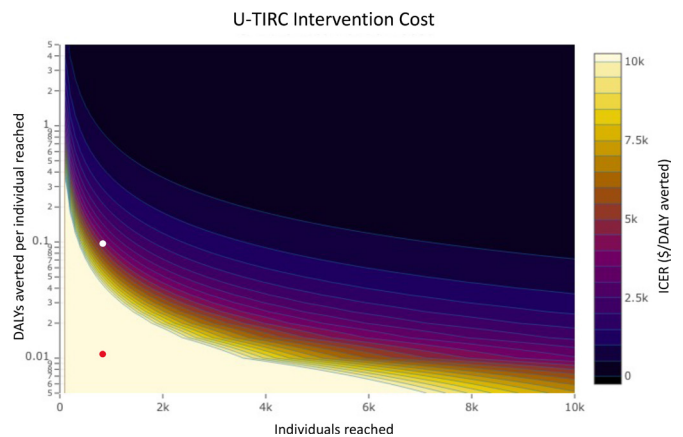
of the HCD-informed intervention as US\$17700 per case detected, or US\$51200 per DALY averted with the baseline prevalence of active TB. The incremental cost-effectiveness in low and high prevalence settings was estimated as US\$24900 and US\$12400 per case detected or US\$72100 and US\$36100 per DALY averted, respectively. Cost-effectiveness estimates were less favourable if we assume that contact investigation would still occur in the absence of HCD, with similar costs but lower efficiency (ie, HCD as 'incremental').

The incremental cost-effectiveness of an HCD-informed intervention improves as the number of people reached by the intervention increases and the cost of the HCD process decreases (figure 2). For example, in the case of

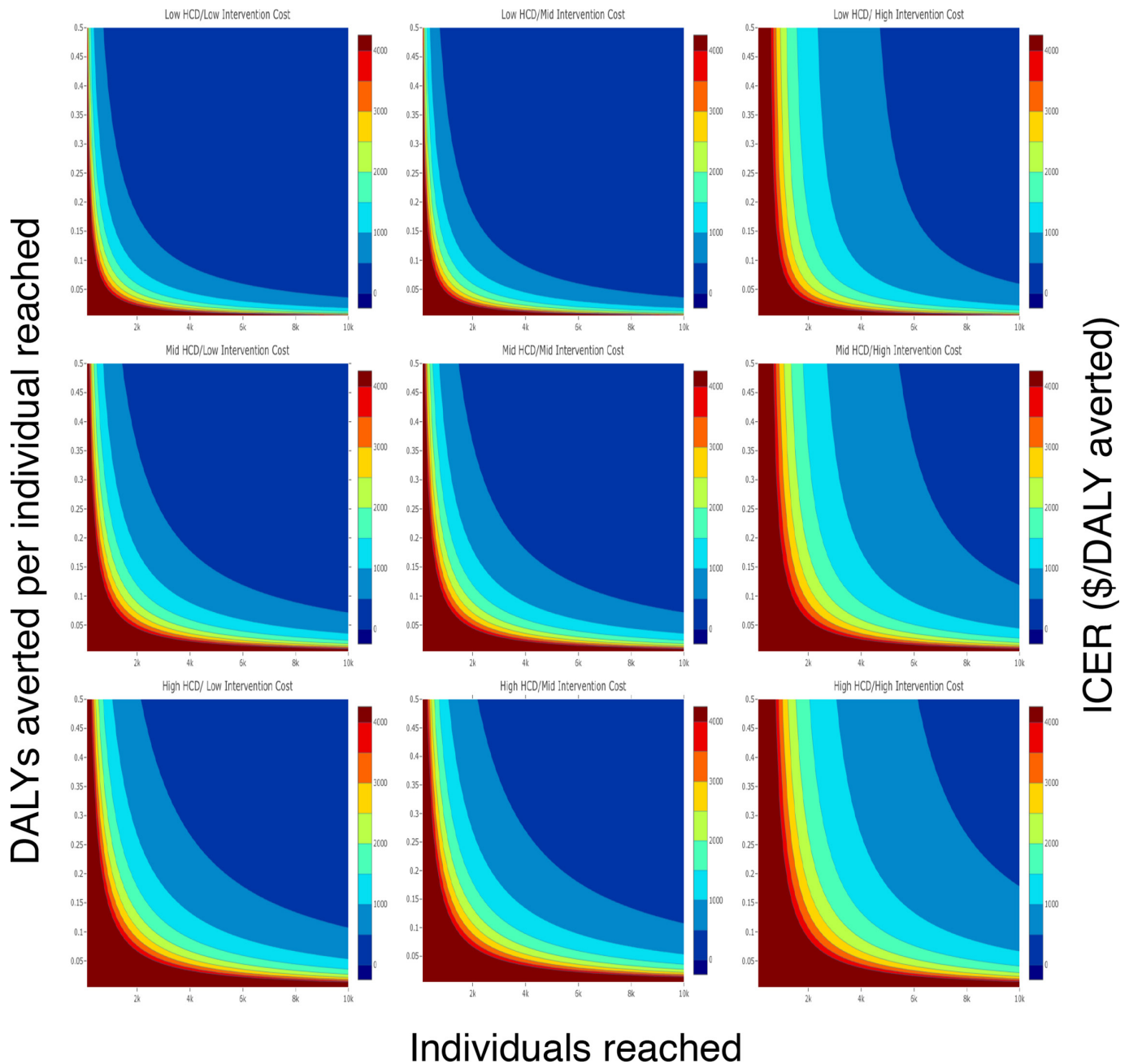
HCD-informed TB contact investigation in Uganda, the incremental cost-effectiveness of the intervention was estimated at US\$306900 per DALY averted if only 120 contacts could be reached, but it improved to US\$8400 per DALY averted if 2400 contacts were reached and the up-front costs of the HCD process were cut in half. Similarly, if more DALYs could be averted per client reached, the estimated cost-effectiveness of the HCD process was projected to improve (figure 3). For example, in the primary scenario for HCD-informed TB contact investigation, we estimated that 0.011 DALYs would be averted per contact reached. For an intervention with similar



**Figure 2** Incremental cost-effectiveness of a human-centred design (HCD)-informed tuberculosis contact investigation intervention, according to number of clients reached. The x-axis shows variation in the incremental number of clients reached as a result of implementing the strategy that emerged from the HCD process. The y-axis shows the estimated incremental cost-effectiveness ratio (ICER, measured in cost per disability-adjusted life year (DALY) averted), assuming an up-front HCD cost of US\$356000 (orange line, as estimated in the project itself) or US\$178000 (green line, 50% HCD cost), plus US\$0.41 per contact reached. Labels indicate ICER estimates for 120, 720 (point estimate), and 2400 incremental contacts reached. As the number of clients reached increases, cost-effectiveness estimates become more favourable.



**Figure 3** Incremental cost-effectiveness of a human-centred design (HCD)-informed tuberculosis contact investigation intervention, according to number of clients reached and disability-adjusted life years (DALYs) averted per contact reached. Contours show thresholds of the incremental cost-effectiveness ratio (ICER, measured as cost per (DALY) averted) of an HCD-informed intervention costing US\$358000 up-front and US\$0.41 per client reached, as a function of number of clients reached (x-axis) and DALYs averted per client reached (y-axis). The primary estimates corresponding to estimates in table 1 and figure 2 (720 contacts reached, 0.011 DALYs averted per contact reached) are shown by the red dot in the lower left. The white dot illustrates the incremental cost-effectiveness (US\$5630/DALY) of a similar intervention that could avert 0.1 DALYs per client reached.



**Figure 4** Estimated cost-effectiveness of human-centred design (HCD)-informed global health interventions. Contours represent the estimated incremental cost-effectiveness of an HCD-informed health intervention, according to the number of clients reached (x-axis, in thousands) and disability-adjusted life years (DALYs) averted per client reached (y-axis). The first row ('Low HCD Cost') assumes an up-front HCD cost of US\$178 000 (in 2020 US dollars); the second ('Mid HCD Cost') assumes US\$356,000; and the third ('High HCD Cost') assumes US\$534 000. The first column ('Low Intervention Cost') assumes an incremental HCD cost of US\$0.10 per client reached; the second ('Mid Intervention Cost') assumes US\$1; and the third ('High Intervention Cost') assumes US\$100.

cost that was instead able to avert 0.1 DALYs per client reached, incremental cost-effectiveness would fall from US\$51 200 to US\$5630 per DALY averted (figure 3, red dot to white dot).

Figure 4 presents estimates of incremental cost-effectiveness of HCD at three different estimates of up-front HCD costs (US\$178,000; US\$356,000 and US\$534,000) and incremental HCD costs per client reached (US\$0.10, US\$1, US\$20, and US\$100), under

different assumptions regarding the number of clients reached and the incremental number of DALYs averted per client reached. For example, assuming an HCD-informed intervention for which an incremental 2000 clients were estimated to be reached and an incremental 0.05 DALYs were estimated to be averted per client reached, estimated cost-effectiveness of the HCD process was US\$1800 per DALY averted assuming US\$178 000 up-front and US\$1 per client reached, versus US\$3562

per DALY averted assuming US\$356 000 up-front and US\$0.10 per client reached (table 2). For this specific scenario, table 2 presents estimates of the size of the programme and/or DALYs averted per client that would need to be achieved to achieve cost-effectiveness at thresholds of US\$500 or US\$1000 per DALY averted.

### DISCUSSION

In this study, we developed a framework to assess the cost-effectiveness of HCD-informed health interventions in high-burden countries. This framework illustrates the importance of considering the up-front cost of the HCD process in the context of the overall intended scope of the programme (number of clients reached), magnitude of health benefits (DALYs averted per client), ongoing incremental cost of the HCD-informed intervention per client reached, and willingness-to-pay. We illustrate the application of this framework to an HCD-informed intervention for TB contact investigation in Uganda, demonstrating that increasing the volume of clients reached and decreasing the up-front cost of HCD can improve cost-effectiveness estimates by a factor of more than 10. This framework can be useful to decision-makers in LMICs who must consider whether the anticipated benefits of HCD can justify the often large up-front costs.

To date, most cost-effectiveness analyses of global health interventions have tended to ignore the substantial up-front costs that are often required to design interventions in a manner that is responsive to local priorities. When such design is not required (eg, a standardised intervention already exists), cost-effectiveness thresholds may be easier to meet. For example, a trial of universal HIV testing and treatment in Zambia estimated that the intervention would need to avert 0.019 DALY per person reached to be cost-effective.<sup>20</sup> By contrast, our framework suggests that, if such an intervention would require a design process costing US\$178 000 up-front plus US\$0.10 per client, nearly 8000 clients would need to be reached in order for an intervention of similar effectiveness to be cost-effective at a threshold of US\$1000 per DALY averted (figure 4, upper left). Thus, ignoring the importance of the design process can result in interventions that do not achieve the intended health impacts, but ignoring the cost of the design process can result in overly optimistic estimates of cost-effectiveness. Future economic evaluations of global health interventions should consider the degree to which HCD (or similar design processes) would be required to make the intervention effective in the context of local priorities—and if so, should formally consider the cost of the design process as part of the intervention’s cost-effectiveness.

An important finding from this analysis was that, in estimating the cost-effectiveness of the HCD process, the up-front cost of HCD tended to be a more important consideration than the incremental per-client cost. For example, in table 2, there was minimal difference between interventions for which the incremental cost

**Table 2** Estimated incremental cost-effectiveness of a representative HCD-informed intervention

Per client cost	Low HCD up-front cost (US\$178 000)			Mid HCD up-front cost (US\$356 000)			High HCD up-front cost (US\$534 000)		
	US\$0.10	US\$1	US\$20	US\$100	US\$20	US\$100	US\$1	US\$20	US\$100
Incremental cost-effectiveness (2000 clients reached, 0.05 DALYs averted per client)									
Incremental cost per DALY averted	US\$1782	US\$1800	US\$2180	US\$3780	US\$3580	US\$5560	US\$5342	US\$5360	US\$7340
<b>Number of clients that must be reached to achieve cost-effectiveness (0.05 DALYs averted per client)</b>									
US\$1000/DALY threshold	3570	3630	5930	*	7130	7270	10700	10900	17800
US\$500/DALY threshold	7150	7420	35600	*	14300	14800	21400	22300	106800
<b>Number of DALYs that must be averted per client reached to achieve cost-effectiveness (2000 clients reached)</b>									
US\$1000/DALY threshold	0.089	0.09	0.109	0.19	0.178	0.179	0.267	0.268	0.37
US\$500/DALY threshold	0.178	0.18	0.218	0.38	0.358	0.356	0.534	0.536	0.74

\*Cannot achieve cost-effectiveness because US\$100 per client (at 0.05 DALYs averted per client) would exceed the threshold. DALY, disability-adjusted life year; HCD, human-centred design.

of HCD per client was estimated to be US\$0.10 versus US\$1.00, but substantial differences existed when varying the up-front cost by  $\pm 50\%$ . In general, as seen in figure 4, an HCD process costing US\$178 000 up-front could be justified at a cost-effectiveness threshold of US\$1000 per DALY averted if a sufficient number of clients could be reached—whereas a process costing US\$534 000 could rarely, if ever, be justified at this threshold. These findings argue for the importance of innovations to reduce the up-front cost of HCD for global health interventions, while retaining their quality.

Another important consideration when evaluating the cost-effectiveness of HCD-informed global health interventions is the local willingness-to-pay for health. This threshold may vary widely across contexts and perspectives, whereas GDP per capita was traditionally used as a standard threshold for willingness-to-pay for one DALY averted,<sup>21</sup> it has been more recently argued that decision-makers should consider either higher thresholds, based on individuals' valuation of a year of statistical life,<sup>22</sup> or lower thresholds based on revealed willingness-to-pay.<sup>21</sup> The sensitivity of the willingness-to-pay threshold to the assessment of HCD cost-effectiveness speaks to the importance of defining this threshold in each local decision-making context.

Fuge *et al* highlighted the diversity in HCD methods in a pattern analysis that spanned 809 HCD case studies. These authors found that 87% of interventions used 'hear methods' (inspiration phase) compared with 'create and deliver methods' (ideation and implementation phases).<sup>23</sup> These authors also compared projects involving industrial designers or engineers within IDEO.org and projects using non-IDEO.org designers.<sup>23</sup> They found that IDEO.org designers tend to have much higher usage in the initial 'hear stage' (inspiration phase), with greater preference for methods that involve end users at an early stage of the design process. Future cost-effectiveness analysis could consider comparing HCD-informed interventions applied by laypeople versus professional design teams.

Our streamlined analytical framework makes a number of simplifying assumptions. First, we assume that the up-front and per-client costs of HCD (as well as the number of clients reached and DALYs averted per client) can be estimated separately and also in incremental fashion relative to a non-HCD standard of care. This challenge was also noted in another HCD intervention carried out in Nigeria, Ethiopia and Tanzania, where researchers and designers faced challenges in measuring the total design cost and isolating the cost of HCD.<sup>24</sup> In such cases, this framework may still be useful to decision-makers in highlighting the costs for which assumptions must be made in order to estimate the incremental cost-effectiveness of HCD. Our primary analysis is also anchored on a single emblematic intervention and thus cannot account for the full spectrum of on-the-ground realities of HCD implementation. We intend to validate this framework using data from an ongoing trial of the intervention in

our motivating example; future refinement could also explore alternative HCD methodologies as well as applications of HCD to other interventions, comparing those interventions to the framework presented here. Finally, this framework simplifies a wide array of ongoing costs. Quality control, refresher training, monitoring and evaluation are considered as 'per-client' implementation costs when, in reality, many of these costs scale non-linearly with the number of clients served. As such, this simplified framework should only be used for initial planning and should not be interpreted as a full cost-effectiveness analysis of any specific HCD-informed intervention.

In summary, even though global health is a common focus area in HCD research,<sup>25</sup> a framework for estimating the cost-effectiveness of HCD-informed interventions in global health has been lacking. This research provides a transparent, quantitative framework, whereby global health decision-makers can obtain 'first-pass' estimates as to whether an HCD process is likely to be cost-effective, based on a small number of inputs. This framework illustrates the importance of considering the up-front cost of HCD in any economic evaluation of an HCD-informed intervention, and also of future work to make HCD available at lower cost (yet high fidelity) in the global health context.

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**Contributors** CLi and DD conceived and developed the framework. CLi and JHL carried out the analysis. CLi, JHL, and DD took the lead in writing the manuscript. JLD, PT, AG, AT, and AK implemented the motivating example research project this evaluation is based on. CLa was in charge of the HCD process and provided insight on HCD for the manuscript. DD takes responsibility for the overall content as the guarantor. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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**Competing interests** Chris Larkin is an employee of IDEO.org, a human-centered design firm. Neither IDEO.org nor the National Institutes of Health had any input as to the analysis or the decision to publish.

**Patient and public involvement** Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

**Patient consent for publication** Not applicable.

**Ethics approval** This study does not involve human participants.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data are available in a public, open access repository. The full dataset and statistical code are available in a public Github repository. DOI: 10.5281/zenodo.5854794.

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## REFERENCES

- 1 Woolf SH. The meaning of translational research and why it matters. *JAMA* 2008;299:211–3.
- 2 Treat. Action Group. Report on TB research funding trends, 2020. Available: <https://www.treatmentactiongroup.org/resources/tbrd-report/tbrd-report-2020/> [Accessed 25 Oct 2021].
- 3 Odeny TA, Padian N, Doherty MC, et al. Definitions of implementation science in HIV/AIDS. *Lancet HIV* 2015;2:e178–80.
- 4 Szczepanska J. Design thinking origin story plus some of the people who made it all happen. *medium*, 2019. Available: <https://szczpanks.medium.com/design-thinking-where-it-came-from-and-the-type-of-people-who-made-it-all-happen-dc3a05411e53> [Accessed 20 Sep 2021].
- 5 Design kit: the Human-Centered design toolkit. Available: <https://www.ideo.com/post/design-kit> [Accessed 20 Sep 2021].
- 6 Bazzano AN, Martin J, Hicks E, et al. Human-centred design in global health: a scoping review of applications and contexts. *PLoS One* 2017;12:e0186744.
- 7 Giacomini J. What is human centred design? *The Design Journal* 2014;17:606–23.
- 8 Labrique A, Vega C, Khan F. Innovaton and Human-Centered design: Unlocng public health and food science for the 21S Centry. *Sight Life* 2018;32:72–7.
- 9 IDEO U. The field guide to Human-Centered design. Available: <https://www.ideo.com/blogs/inspiration/the-field-guide-to-human-centered-design> [Accessed 20 Sep 2021].
- 10 IDEO.org. Projects to programs. Available: <https://www.ideo.org/perspective/projects-to-programs> [Accessed 20 Sep 2021].
- 11 Powell BJ, Fernandez ME, Williams NJ, et al. Enhancing the impact of implementation strategies in healthcare: a research agenda. *Front Public Health* 2019;7:3.
- 12 Baker R, Camosso-Stefinovic J, Gillies C, et al. Tailored interventions to address determinants of practice. *Cochrane Database Syst Rev* 2015;2015:CD005470.
- 13 Lee JH. HCD cost-effectiveness data. *Zenodo* 2022.
- 14 Davis JL, Turimumahoro P, Meyer AJ, et al. Home-Based tuberculosis contact investigation in Uganda: a household randomised trial. *ERJ Open Res* 2019;5:00112-2019–2019.
- 15 GDP deflator (base year varies by country) - Uganda, United States Data. Available: <https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS?end=2020&locations=UG-US&start=1982&view=chart> [Accessed 20 Sep 2021].
- 16 Neumann PJ, Ganiats TG, Russell LB, eds. *Cost-Effectiveness in Health and Medicine*. 2 ed. New York: Oxford University Press, 2016.
- 17 Fox GJ, Barry SE, Britton WJ, et al. Contact investigation for tuberculosis: a systematic review and meta-analysis. *Eur Respir J* 2013;41:140–56.
- 18 Velen K, Shingde RV, Ho J, et al. The effectiveness of contact investigation among contacts of tuberculosis patients: a systematic review and meta-analysis. *Eur Respir J* 2021;58. doi:10.1183/13993003.00266-2021. [Epub ahead of print: 09 12 2021].
- 19 Azman AS, Golub JE, Dowdy DW. How much is tuberculosis screening worth? estimating the value of active case finding for tuberculosis in South Africa, China, and India. *BMC Med* 2014;12:216.
- 20 Thomas R, Probert WJM, Sauter R, et al. Cost and cost-effectiveness of a universal HIV testing and treatment intervention in Zambia and South Africa: evidence and projections from the HPTN 071 (PopART) trial. *Lancet Glob Health* 2021;9:e668–80.
- 21 Marseille E, Larson B, Kazi DS, et al. Thresholds for the cost-effectiveness of interventions: alternative approaches. *Bull World Health Organ* 2015;93:118–24.
- 22 Patenaude BN, Semali I, Killewo J, et al. The value of a statistical Life-Year in sub-Saharan Africa: evidence from a large population-based survey in Tanzania. *Value Health Reg Issues* 2019;19:151–6.
- 23 Fuge M, Agogino A. Pattern analysis of IDEO's human-centered design methods in developing regions. *J Mech Des N Y* 2015;137:071405.
- 24 Doyle AM, Mulhern E, Rosen J, et al. Challenges and opportunities in evaluating programmes incorporating human-centred design: lessons learnt from the evaluation of adolescents 360. *Gates Open Res* 2019;3:1472.
- 25 Gordon P, Kramer J, Moore G. A systematic review of Human-Centered design for development in academic research, 2017. Available: [http://best.berkeley.edu/wpcontent/uploads/2015/07/8-26-2017-HCDDSystematicCharacterization\\_Working-Paper.pdf](http://best.berkeley.edu/wpcontent/uploads/2015/07/8-26-2017-HCDDSystematicCharacterization_Working-Paper.pdf)