Developing World Users as Lead Users: A Case Study in Engineering Reverse Innovation

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This paper examines the "reverse innovation" of the leveraged freedom chair (LFC), a high-performance, low-cost, off-road wheelchair originally designed for developing countries. A needs study of 71 developed world wheelchair users was conducted through three different data collection efforts. These data were contrasted with studies of 125 developing world wheelchair users, who were shown to be lead users for their developed world counterparts. The GRIT freedom chair (GFC), the developed world version of the LFC, was designed based on results of the study. By recognizing developing country users as lead users, designers can reveal latent needs and create globally disruptive innovations. [DOI: 10.1115/1.4030057]

1 Introduction

Innovation is linked to economic growth, competitiveness, and progress [1]. Innovative solutions are required to solve the most pressing social challenges facing humanity, and to tap into the rapid economic growth of developing markets. China and India are projected to have the first and third largest economies, respectively, by 2050 [2], and combined with Brazil and Russia are forecasted to grow from 18% of global market capital now to 41% in 2030 [3]. Products designed for developing markets may disrupt global markets by providing high value at a low cost compared to their developed world equivalents. The process of reverse innovation, where products are first designed for poor countries and then adapted for wealthier countries, is predicted to become more relevant as companies focus their attention on developing markets [4]. For example, General Electric has already seen global success through reverse innovation by creating ultrasound machines for China, which deliver 50% the performance for 15% the price of their U.S. equivalents, opening up new markets in developed countries, such as rural healthcare clinics and ambulances [5].

Reverse innovations may catalyze global product innovation because the challenges faced by developing markets are compelling and remain unsolved. Engineers must understand how to link actionable design processes to appropriate innovations for developing and developed markets alike. An innovative product or system changes or has the potential to change the nature of the marketplace by satisfying a new (or latent) user need or by satisfying user needs in a new way [6]. Therefore, the keystone of an innovative product development process is user need identification, but often these methods only produce incremental innovation [7–11]. While they can confirm needs are relevant once identified, typical users are unable to articulate facets of a product that would delight them since latent needs are unexpected and users are generally limited in perspective to expressing needs with which they are familiar and giving very little basis for the creation of truly innovative solutions [12,13]. Also, it is difficult for typical users of existing products to imagine what they might want in the future under different conditions in their life [14].

Lead users, however, are an exception and can be engaged to elucidate latent needs. Von Hippel defines lead users as individuals or firms that display both of the following characteristics [15,16]:

(1) Lead users expect to benefit significantly by finding a solution to their needs. As a result, they often develop new products or services themselves because they cannot or do not want to wait for them to become available commercially.
(2) Lead users have new product or service needs that will be general in a marketplace, but they face them months or years before the bulk of the market encounters them.

While the concept and efficacy of lead users are established for developing products and systems, lead users are difficult to pinpoint in mass and may only highlight innovative concepts for niche or high-end products [17]. This may be due to lead users being associated with the obvious case of high performance relative to normal users, such as of marathon runners versus casual joggers [11,18]. The definition of lead users has been expanded to include extraordinary users who perform tasks in a more limited capacity than the mainstream, such as people with disabilities [19], the elderly [20], and certain cultural groups such as specific religious designations (old order mennonites) [21]. Additionally, there are instances where mainstream users are situationally or temporarily impaired and perform as extraordinary lead users, such as navigating in the dark [22]. The needs of extraordinary lead users can be replicated by more ordinary users who are put in extraordinary situations [17,23].

People in developing countries may be another category of users who could be classified as lead users. These people may experience needs more acutely than their counterparts in developed countries. Eighty percent of the global population lives on less than $10 a day [24]. Many of these people experience compromised health, education, nutrition, water, and economic opportunities, and also have unique cultural preferences compared to users in the West [25,26]. Although they face harsh economic and environmental constraints, people in developing and emerging markets still have aspirations for improved living conditions and opportunities for their family—quality of life values that are likely to be shared by people around the world. Literature exists that discusses the unique aspects, principles, and opportunities of creating products for developing countries [27], and well-engineered examples exist of developing world innovations [28]. However,

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these examples do not provide actionable steps for how to derive engineering requirements from developing world users. By understanding *how* to engineer reverse innovation, designers can concurrently address unmet needs in developing countries and create high-value, low-cost product platforms that positively impact rich and poor consumers alike.

2 Research Questions and Motivation

In this paper, we explore three principles behind engineering reverse innovation:

(1) Collectively, people in developing countries can be lead users, who elucidate latent needs for global products.
(2) Testing developing world innovations with developed world customers can show how a product platform must be modified between global markets in order to become a reverse innovation.
(3) Products initially motivated by needs in developing markets can become innovative products in developed markets.

This paper is built on a case study of the LFC (Fig. 1), which is a low-cost, lever-propelled, all-terrain wheelchair originally designed for the 40×10^6 people in developing countries who need a wheelchair but do not have access to one [29,30]. Most of these people live in rural areas of developing countries and often have to travel far on rough roads for employment and education. Other mobility aids available in developing countries cannot fulfill both the mobility needs of these users; pushrim-propelled wheelchairs (WC) are inefficient to propel for long distances on rough roads, and hand-powered tricycles are difficult to maneuver on soft ground and up steep hills, and too large to use inside. All-terrain WC are available in developed countries [31,32], but cost $4500–$7500—too expensive for wheelchair provision organizations in developing countries and also for many in the developed world. The LFC costs $250 in quantity, within the same price range of the most commonly distributed WC in developing countries [33–35]. Every moving part on the LFC is made from a bicycle component, which makes the chair repairable.

Fig. 1 The LFC. (*a*) Profile view of the LFC. (*b*) LFC user in India.

As a developing world technology, the LFC has proven to be innovative. In field trials with wheelchair users in Guatemala and India, it tested 76% faster, 41% more efficient, and could produce 51% more torque than conventional WC [30]. The LFC was a winner of a 2010 R&D 100 award and was named one of the Wall Street Journal's top innovations in 2011. Over 1200 LFCs have been sold in 2014, the first year of fullscale production.

The motivation to reverse innovate the LFC for developed markets came from many wheelchair users in the U.S. and Europe contacting our team and requesting to buy the chair. The interview data upon which this paper is based were collected to inform our team how the LFC must be modified to meet the specific needs of wheelchair users in developed countries. From these data, we show that developing world wheelchair users were lead users for potential customers of the LFC in developed markets. The resulting reverse innovation, sold by Global Research Innovation and Technology (GRIT) and called the GFC, has a number of features to improve its functionality and portability for developed world users, which we show or make it an innovative product according to the innovation characteristics described by Saunders et al. [6].

3 Data Collection

To explore if developing world wheelchair users were lead users, we compared their needs to those of new potential users in developed countries. Needs of the new users were ascertained through surveys and interviews and then compared to legacy customer need data from the LFC project. Multiple data collection methods were employed, which are summarized in Table 1 and described in Secs. 3.1–3.4. The surveys and interviews were all structured to progressively become more specific to elicit responses that would directly inform the development of the GFC, yet not bias respondents prematurely. Each component of the study was approved by relevant Institutional Review Boards at the Singapore University of Technology and Design and the Massachusetts Institute of Technology.

3.1 Assistive Technology Exposition. A pilot study was conducted at the Singapore Abilities Expo, an assistive technology exposition. This study was used to discover if there were differences in the needs of original developing world users of the LFC versus typical Singaporean mobility aid users. It was also used to test our questionnaire and determine if the study should be improved before engaging larger groups of users. We solicited participants in the study by setting up a booth for the LFC and providing pamphlets about the product, as well as having an LFC on hand for demonstrations. Part I of the survey pertained to multiple choice demographic information. Part II included multiple response questions relating to current mobility aid use and preferences, including like/dislike questions [7] relating to users' favorite aspects and if they would change anything about their mobility aid—prompts that could be compared to future data collection efforts. Part III was free response, where comments that were informally made about the LFC during conversation could be recorded. We transcribed responses from users who were unable to write or who preferred to dictate.

3.2 Web-Based Survey. The purpose of the web survey was to collect broad-based quantitative and qualitative user need data from a large sample. The survey was administered using the web-based Survey Monkey client. One hundred and seventy-four letters of invitation were sent to potential subjects who had reached out to our team inquiring or commenting about the LFC project. The scope of the survey questions included demographic information, like/dislike style questioning about users' own mobility

Table 1 Overview of data collection efforts

Name	What	Where	Who	How	Why
Assistive Technology Expo	Pilot study	Abilities Expo, Singapore	14 users, 5 medical professionals	Booth and LFC demo at expo	Discover and scope for future methods
Web-Based Survey	Survey	Internet	24 users, 7 family/friends of user, 3 medical pros, 3 advocates (1 unknown)	174 invitations sent for Survey Monkey	Broad-based quantitative–qualitative user needs
Recreational Therapy Program	Contextual interviews	Northeast Passage, United States	9 recreational wheelchair users, 5 rehabilitative professionals	Rural user LFC trials	In-depth qualitative user needs data based on actual usage
Legacy LFC Data	Re-analysis of past data	Tanzania, Kenya, Uganda, Guatemala, India	125 developing world stakeholders	Legacy questionnaires analyzed for user needs	Make legacy data compatible with current study

products, situations that illustrate when the performance of the LFC would be useful, issues with adopting mobility products currently available on the market, and features that would convince the respondent to purchase an LFC over existing products. In addition to measuring the frequency of responses, the web-based survey questions were structured such that respondents explicitly ranked the importance of answers or quantified their agreement with statements using a Likert scale.

3.3 Recreational Therapy Program. Contextual interviews were conducted on two separate days at Northeast Passage, a Recreational Therapy Program in Durham, NH. The purpose of these interviews was to gather in-depth qualitative user needs based on actual LFC usage with advanced users, who already use adaptive mobility equipment for recreation. Hour-long tests of the LFC and concurrent interviews were conducted in a rural setting. During the trial, each subject was encouraged to ride the LFC as much as possible to minimize the effect of learning curves, although no mandatory usage was imposed. Interview questions were broken down into situational performance, LFC design review, LFC future development, and free response.

3.4 Legacy LFC Data. Data collected during the LFCs development was re-examined to compare the needs of developing world wheelchair users to those in this study. The legacy data included results from field trials with 26 subjects conducted in 2009 in East Africa (including Kenya, Tanzania, and Uganda), in 2010 in Guatemala, and in 2011 in India and are documented in earlier literature [29]. The legacy data also included an assessment of mobility aid technology conducted in Tanzania in 2005, which included 99 interviews of mobility aid users, manufacturers, and disability groups [36]. Although these trials primarily focused on measuring biomechanical performance of the LFC, they also included user surveys, from which needs data were extracted. In particular, like/dislike questioning data were collected that could be compared to results from the present study.

4 Analysis

In this section, we will first review the user demographics, followed by exploration of the research questions.

4.1 Demographics of the Sample Set. The demographics of the sample set are made based on the following data collection efforts: an assistive technology exposition, a web-based survey, and a recreational therapy program.

4.1.1 Assistive Technology Exposition. Every respondent was Singaporean. Fourteen were users of assistive technology, of which 85% used a wheelchair at least some of the time, in addition to other aids (walkers, calipers, crutches, etc.). All of the users were male. Over 60% of the user respondents were over age 40. Fifty percent of the users were impaired due to polio, while the rest were a mix of other impairments that cause lower body disability. It was observed that most users used manual depot chairs (low-cost chairs commonly found in hospitals or airports). The users typically traveled locally (within neighborhood, a few kilometers) to church, hospitals, shopping centers, and some work. Travel was generally a short distance to the bus stop or subway. There were a variety of options of travel (taxi, personal car, and subway). Additionally, five medical professionals were surveyed. Of this group of Singaporean professionals, all were female, four were 21–30 yr of age and one was between 31 and 40 yr of age. The medical professionals worked with a mix of users with impairments such as stroke, spinal cord injury (SCI), and amputations.

4.1.2 Web-Based Survey. Of the 36 people who participated in the survey, 67% lived in the United States. Thirty-two of the respondents lived in countries classified as advanced economies by the International Monetary Fund (IMF), with the remainder from Colombia (two respondents), Indonesia (one respondent), and Uruguay (one respondent). However, the demographic information, access to technology, and needs of these four respondents were similar to the IMF set. Of the 36 respondents, 65% were wheelchair users, while the remaining 35% were family, friends, advocates, or medical professionals responding on behalf of a user. Twenty-five of the respondents described themselves as male, while only 12 or 32% were female. Sixty percent were over the age of 40. Respondents reported their population density as 42% Suburban, 29% Urban, and 26% Rural. The breakdown of reported user impairments was: 39% SCI; 29% other; 13% spina bifida; and 11% for amputee and multiple sclerosis. The types of mobility aids used for independent mobility were: 43% ultralight WC; 41% canes, walkers, or crutches; 32% standard manual chairs; and 32% road vehicles. When asked to select only one device as their primary device, 47% responded ultralight wheelchair. No respondent selected power-assisted wheelchair, handcycle, or road vehicle as their primary device. Respondents were permitted to select multiple answers for this question. Sixty-three percent of the respondents were working or were a student, 13% were retired, and 21% were not working (reported unable to work or out of work). The U.S. unemployment rate was (at the time of writing) 6.3% [37]; in contrast, 21% of respondents of the web-based survey were not working. The median U.S. household income was $52,000 [38]. Using $60,000 as a conservative cutoff, 51% of the respondents of the web survey were below the median income in the U.S., while 35% were above. Thirty-two percent of the web-based survey respondents were in a household earning below $30,000/year, which is approximately the poverty level for a five-person household in the U.S. [39]. Twenty-four percent of respondents lived on less than $20,000/year/household. In contrast, only 14% of the entire U.S. population lives below the poverty line [40]. This confirms that our sampled set has a similar

demographic profile as typical wheelchair users, indicating validity of the data.

4.1.3 Recreational Therapy Program. All interviewees were U.S. citizens local to the New England region. Of the 14 respondents, 9 were wheelchair users. The remaining five were either rehabilitation professionals or advocates helping out at the event. Six of the users were male, and three were female. While each user's age was not specifically recorded, a best estimate by the interviewer would be a range of 25–50. The terrain was rural. Specific impairment was not an interview question, but paraplegia due to SCI or spina bifida would be presumed the predominant reason for mobility aid use based on observation and the high functionality of users (C7 and C8 quads). All users had rigid ultralight WC, most of which were high end. Most were longtime mobility aid users, with much experience with adaptive recreational equipment. Data on income, employment, and activities of daily life were not recorded in the interviews, but the interviewees were encouraged to take the complementary web-based survey.

4.2 Demonstrating Developing World Wheelchair Users as Lead Users. The definition of a lead user has two components: (1) since lead users benefit significantly from a solution, they may have created one for themselves already and (2) lead users experience the same needs as the main population but earlier [15,16]. Sections 4.2.1–4.2.2 describe each of these facets of lead users in the context of this study.

4.2.1 Significant Benefit to Lead Users. It is likely that people in the developing world will significantly benefit from innovation because many of their fundamental needs remain unmet. By being positioned to benefit significantly from a solution, developing world users align with Von Hippel's criteria of lead users. People with disabilities worldwide have poorer health and socioeconomic outcomes: lower educational achievements, less economic participation, and higher rates of poverty than people without disabilities; these issues are further magnified in the developing world, where there are higher rates of disability and poverty [41]. For many people with disabilities, an appropriate, robust, and well-fitted wheelchair not only enhances mobility, but also facilitates inclusion in the community, education, work, and living with dignity [42].

In addition to benefiting from a solution, a lead user (per von Hippel) should have developed a solution to their problem. Such solutions are ubiquitous throughout the developing world, ranging from hand-powered tricycles, which are primarily locally innovated products, to platform dollies (like those used for moving furniture), on which a person kneels and propels themselves by pushing on the ground with their hands. Mobility is a fundamental human need—if people can find a way to achieve it, they will, but not everyone has the skills and resources available to make a solution.

4.2.2 Needs Will be the Same but Are Expressed Earlier by Lead Users. For developing world wheelchair users to be considered lead users, they must express the same needs as developed world users but earlier. We compared the demographics of the two groups and then analyzed the similarity of their needs. This included investigating whether developing world wheelchair users stated latent needs that were not expressed by developed world users.

Relative to their able-bodied counterparts, people with disabilities in both developing and developed counties are more likely to live in poverty. In the developing world, people with disabilities have a lower educational attainment and higher unemployment rates than people who are not disabled [43]. These demographic results align with other studies on disability and poverty, which state that people with disabilities, no matter the development level of their country, have worse socioeconomic outcomes than people without disabilities [41].

Our study showed differences in the types of WC people use, and how they gain mobility in different parts of the world. The majority of U.S. users owned custom-fit, ultralight WC. Users in developing countries tended to have either low-cost donated WC or locally made tricycles for their daily use. The 36 respondents of the web survey reported using 89 different mobility aids, with 32% regularly using automobiles, and many more using accessible transportation services. In contrast, people with disabilities in developing countries typically had one donated wheelchair and only occasional access to automobiles or public transportation.

Before developed world participants in our study were prompted about aspects of the LFC, they were asked general questions about mobility aids. These included: "what are your/their favorite aspects of a mobility aid?" and "if you/they could change anything about a mobility aid, what would it be?" The raw responses to the like/dislike questions were coded by grouping into unique need categories per the affinity diagram method [7]. Specifically, every reported need was placed on a Post-It® note and grouped with similar responses. Each group of raw needs was given a unique category title, such as "affordable" or "intuitive." These unique need categories were then compared to the legacy needs expressed by developing world wheelchair users, which were analyzed with the same method. The categorization was further refined and discussed among the research team. These data were then grouped into a Venn diagram (Fig. 2, top), following the approach by Vaughan et al. [23]. In this analysis, we found that the developing world users articulated 13 of the 14 needs expressed by developed world users, in addition to nine potential latent needs which were not expressed by developed world users.

For a need to be latent, users must recognize its importance when exposed to it. Developed world users were exposed to the nine potential latent needs (Fig. 2, top) by asking them questions about features and performance associated with the LFC. This was done by asking them about various scenarios in which they may need enhanced performance and the frequency with which the scenario may occur. Responses were given on a five-point Likert scale, with "1" correlating to very rarely and "5" to very frequently. The importance of each performance need was judged by its average Likert score, along with ± 1 standard error (Fig. 3). All situations presented reflected strengths of the developing world LFC. The most frequently encountered scenario for developed world users was the desire to roll over rough ground without getting stuck; this was a surprising result because the Americans with Disabilities Act (ADA) mandates accessible infrastructure. Users also desired reduced effort to go up an incline and propelling for a

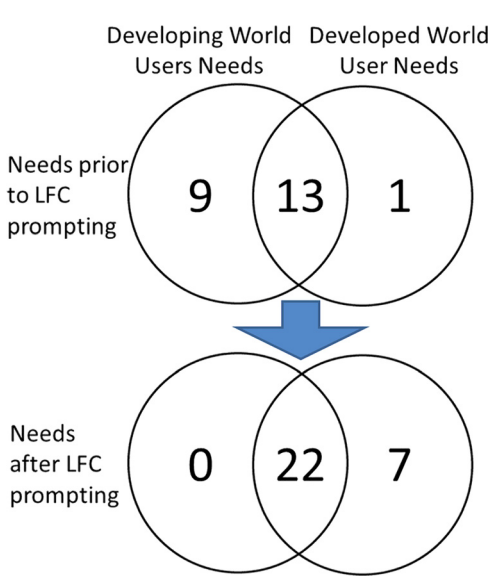

Fig. 2 Venn diagram of developing world user needs versus developed world user needs prior to and after prompting of LFC features, illustrating not only shared needs, but also latent needs

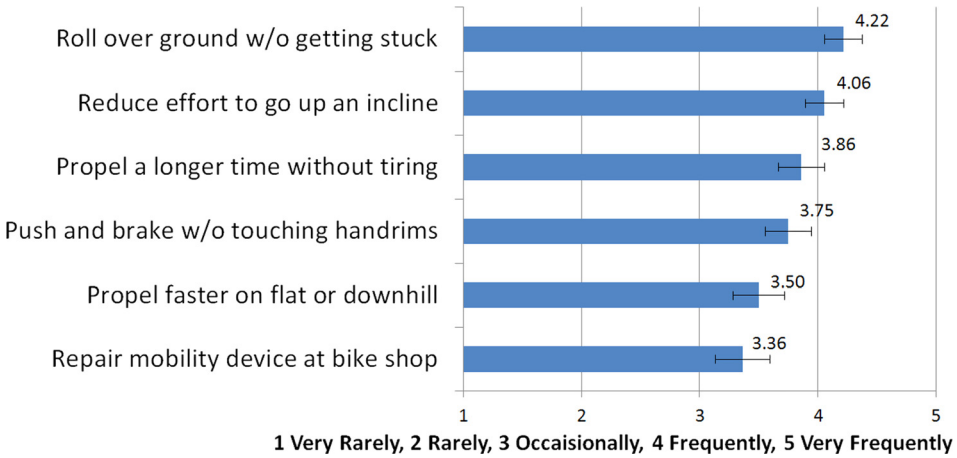

Fig. 3 Means of Likert scale values and ±1 standard error bars, corresponding to the frequency with which developed world users experienced different performance scenarios ("1" = very rarely and "5" = very frequently)

longer time without tiring. The desire to repair a mobility device at a bike shop was the least frequently occurring scenario (although still above the Likert scale rating of indifference). While repairability in a bike shop may not have been a prioritized need that developed world users were able to articulate, there is a possibility that this feature would be a latent need that the GFC could meet. Many assistive devices in developed countries cannot be easily serviced in bicycle shops. Local repairability of the LFC has been one of its main strengths in developing countries.

In addition to asking about the situations that users may encounter, we also specifically asked about features of the LFC. This was done because survey data would be used for the research presented here, as well as determining what features of the LFC would be transferred to the GFC and what new features would have to be designed. The questions were framed as comparisons between the LFC and existing products and asked as: "assuming you/they would purchase at least one device from the list of existing products, please select the features of the LFC that would convince you to purchase it over the existing device." The respondent was provided a series of options and asked to select only as many features as would convince them to choose the LFC over the another device. The number of responses for each option was tallied and ranked by frequency of mention (Fig. 4). Many of the core LFC features had a high frequency of mention, including out-of-pocket affordability, ease of repair, compatible with functional level, durability, and prioritization of functionality over esthetics.

There are core cultural differences and expectations between developing and developed world users. This is exemplified by the developed world users assuming that the LFC is easier to stow for transport, lighter to lift, and can be used as a primary device. These features are true when the LFC is compared to other developing world products, but may not be true when comparing the GFC to WC and other assistive devices found in developed countries, particularly ultralight WC. However, the results in Fig. 4 demonstrate users' aspirations and expectations for the GFC, which gave our design team insight into features that could be added to the chair to make it useful and innovative. The bottom part of Fig. 2 shows the overlap of needs between developing and developed world wheelchair users, after the developed world users had answered the prompted questions about features of the LFC. The explicit prompting resulted in a change of the Venn diagram, where all nine of the developing world needs that had not been mentioned before prompting were mentioned after. This confirmed that these nine needs were not obvious to the developed world users.

To further explore the latency of these nine needs, we analyzed their prioritization before and after prompting of the LFC characteristics. We asserted that a significant rise in the prioritization of a need after prompting was a sign of its latency. Accordingly, we

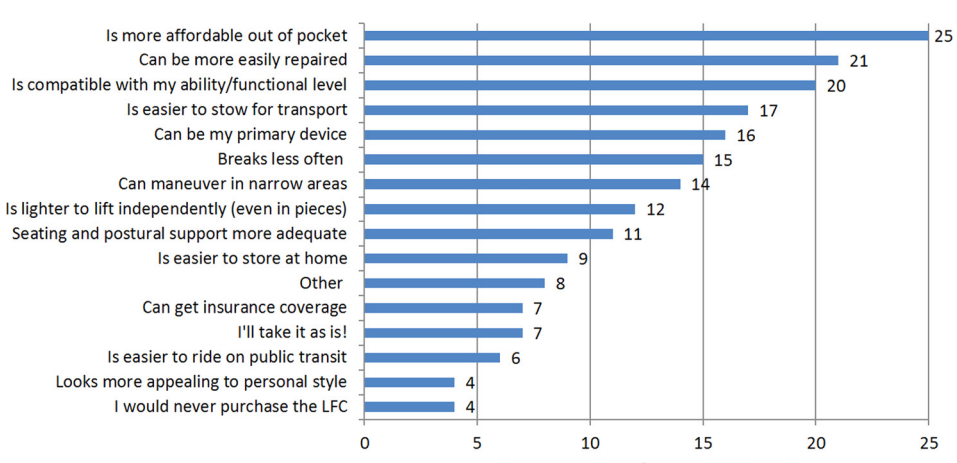

Fig. 4 Frequency of response of the most prevalent features to convince respondents to select the LFC over benchmarked products

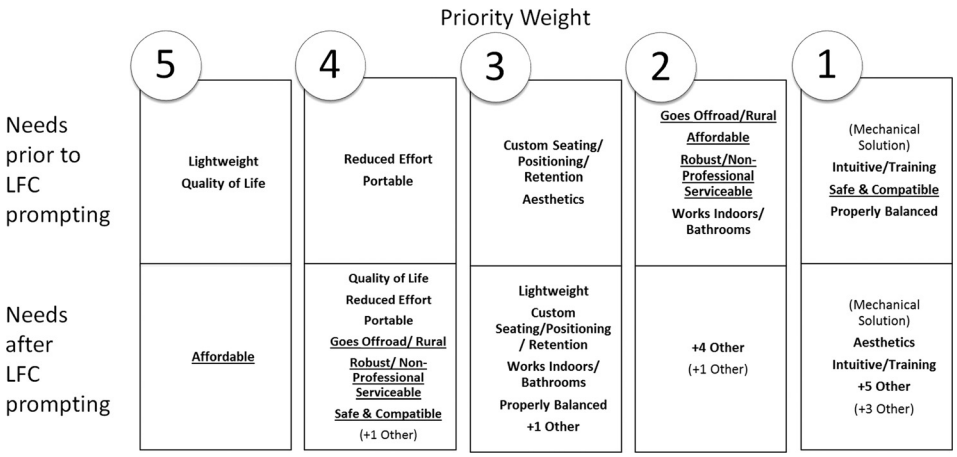

Fig. 5 Needs of developed world WC users, expressed before and after prompting about features of the LFC. Needs are weighted from 5 to 1, with 5 being the most important. All needs (except those in parentheses) were also elicited from developing world user needs. Needs underlined are likely latent because of their significant increase in priority when reported after prompting about LFC features. The "others" are generally related to specific use scenarios and were not included in the set of potential latent needs. The needs in this figure correspond to the total number of needs in the right-hand section of the Venn diagram in Fig. 2.

defined a need whose position changed significantly (by two or more positions in rank) after prompting about the LFC as a latent need. In order to do this, the unique affinitized needs before prompting about the LFC were given an importance ranking based on the interview data (correlated to frequency of mention) and mapped to a normalized weight between 1 and 5, with 5 being the most important and most frequently mentioned. For responses given after prompting about the LFC, the author synthesized the explicit prioritization data from the quantitative survey results with the frequency of mention of needs expressed through free responses in order to generate a full, ranked set of needs also on a 1–5 scale, with 5 being the most important and most frequently mentioned. Figure 5 shows the weighting of needs expressed by developed world users before and after they were explicitly prompted about the LFC. Needs underlined in Fig. 5 are likely latent because of their significant increase in priority when reported in the context of LFC features. These needs included going off road/rural, affordable, robust/nonprofessional serviceable, and safe and compatible with user ability. The needs labeled as "others" are related to specific use scenarios and not shown here or have to do with marketing, such as awareness of product. Prompting about features of the LFC could be considered leading, but this was necessary to understand how users' prioritization of needs changed when exposed to features of the chair.

4.3 Engineering a Reverse Innovation. The evaluation of an innovation is most often classified retroactively by market response. The LFC can be considered an innovation in developing and emerging markets because of the press, awards, and sales it has achieved, as well as its performance relative to other WC.

The data collected in this study gave our team insight into how the GFC could be designed to meet the specific needs of wheelchair users in developed countries. The needs of developed world users can be systematically linked to engineering functional requirements through the quality functional deployment (QFD) tool [44]. The QFD matrix highlights, through a technical importance rating, what product engineering requirements most strongly influence the fulfillment of the most highly prioritized user needs. Furthermore, the QFD establishes concrete targets for meeting these engineering requirements. Completing the QFD exercise for the design features that should be included in the GFC resulted in the following functional requirements, ranked by priority:

(1) minimize manufacturing cost
(2) minimize weight of largest part when disassembled
(3) support users' weight (max user weight 100 kg)
(4) minimize total weight (less than 20 kg)
(5) most frequent service parts repairable by person of moderate technical ability

By elucidating these functional requirements, our team was able to implement them into the design of the GFC (Fig. 6). The GFC, as opposed the original LFC, can be quickly broken down for transport in the trunk of a car and is made from U.S.-specification bicycle components that are available and serviceable in most any bicycle shop. The chair sells for $3300, which is significantly more expensive than the LFC, but is 67–40% the price of other

Fig. 6 The GFC. (*a*) GFC prototype in profile. (*b*) GFC prototype disassembled for transport in the trunk of a sedan. (*c*) Exploded view of the quick-release wheel mechanism, which enables the rear wheels to be removed using one hand. When the wheels are removed, the drivetrain remains attached to the frame of the chair. The moving parts, freewheel, and coupling utilize standard bicycle parts.

off-road WC and lever-propelled mobility aids on the market, and is comparable or less expensive than other recreational assistive devices such as handcycles. The price of the GFC has to include liability insurance, dealer markups, U.S. manufacturing costs, and a high level of material quality and fit and finish—attributes that are not part of the LFC. The GFCs low price compared to competitive products is accomplished by taking advantage of modern mass production techniques (such as CNC machining, stamping, and sheet metal bending), using off-the-shelf bicycle components for the drivetrain and minimizing part count and fabrication steps.

4.4 Demonstrating That Reverse Innovation can Produce an Innovative Product. To determine whether the GFC is innovative, we compared it to competitive assistive devices using a set of characteristics that are common to innovative mechanical products. This was done via the framework created by Saunders [6], who conducted an empirical study of nearly 200 award-winning products and identified 13 innovation characteristics that distinguish those products from the competition. These characteristics were grouped into five product-level subcategories including functionality, architecture, environmental interactions, user interactions, and cost. Saunders recognized that award winning products have multiple characteristics of innovation. Products that exhibited an average of three or more innovative characteristics than competitors at the time of launch, and two after multiple years in the market, were 77% successful (success was defined as continuing to sell, years after initial launch).

Since significant challenges are faced by entrepreneurial startups launching a first product, and multiple factors influence the creation of a successful product [45], we cannot guarantee the market success of the GFC. However, Table 2 demonstrates that the GFC can be considered innovative, per Saunder's method, by having more than three innovative characteristics compared to competing products. The competing products in Table 2 are: depot WC, which are the low-cost WC commonly found in hospitals and airports; ultralight WC, which are made from lightweight alloys such as titanium and aluminum and are the most common choice for active patients; handcycles, which are pedaled like a bicycle with the hands and are primarily used for recreation; and the MTNtrike, which is another off-road, lever-propelled wheelchair sold in developed countries [31]. Relative to depot or ultralight WC, the GFC offers an innovative user interaction via the levers, which have been shown through field trials of the LFC to produce more torque and higher speeds for less metabolic effort than pushrim-propelled WC [29]. The GFC also offers an expanded usage environment compared to all of the competitive products expect for the Mountain Trike [31]; pushrim chairs struggle on rough, off-road terrain and handcycles are too big to use indoors. The GFC and the Mountain Trike share a similar layout, however, the GFC can be disassembled to a portable size relative to handcycles and the MTNtrike. The purchase price of the GFC is comparable to ultralight WC and is less than half that of the Mountain Trike. Since the GFC uses bicycle components for its moving parts, which can be serviced at a bicycle shop, it should have lower maintenance costs than the WC and the Mountain Trike; handcycles also use bicycle components.

Table 2 Analyses of innovative product characteristics of the GFC compared to competitive products per Saunders [6]

Product Comparative product	GFC Depot WC	GFC Ultralight WC	GFC Handcycle	GFC MTNtrike
Function				
Add function				
Architecture				
Mod size			X	X
Mod physical layout	X	X	X	
Ex usage enviro	X	X	X	
Enviro interactions				
Mod mat flow				
Mod energy flow				
Mod info flow				
Interact w/infrastr				
User interactions				
Mod physical demands	X	X		
Mod sensory demands				
Mod cognitive demands				
Cost				
Purchase cost				X
Oper./maint. cost	X	X		X

By having a multitude of innovative characteristics, the MTNtrike should be a breakthrough product relative to WC and handcycles. However, the MTNTrike is not yet successful in the marketplace despite earning innovation awards—only 100 units have been sold in 2014 after being on the market since 2011 [31]. Even though cost is specifically noted by Saunders as a secondary innovation characteristic [6], it nevertheless seems highly prioritized by wheelchair users in both developing and developed countries. While it may not have been necessary to design a product for the developing world to uncover the latent need of cost for developed world users, it took the constraints of the developing world to accurately prioritize the ultralow cost and high performance required for the LFC. Deriving the GFC from the LFC has resulted in an off-road mobility aid that is significantly less expensive than competitive products.

Low-cost seems to be a keystone feature that can catalyze successful products in developed markets. Affordability was the most important factor for survey respondents in this study, with 50% disagreeing or strongly disagreeing with the statement "can user afford the mobility products you desire out of pocket?" In a free response question, 75% remarked cost as the predominant reason for not acquiring their ideal mobility aid.

Saunders' framework indicates that the GFC is an innovative product that has a high likelihood of commercial success. In November 2014, the GFC was launched on Kickstarter and met its funding goal of $50,000 in 5 days. A total of 374 backers pledged 79,072 USD toward the GFC project and 24 chairs were preordered by backers. Currently, GRIT is on track to deliver the initial GFCs. Preproduction versions of the GFC have been met by praise by users at various Abilities Expos held during the campaign. The response to the GFC by the Kickstarter community is another strong indicator that the product has a high likelihood of commercial success.

5 Discussion and Conclusion

The GFC is an example of a reverse innovation: it resulted from the LFC, an innovative product designed for developing countries, that when adapted to meet the specific (latent and expressed) needs of users in developed countries, demonstrated unique features that position it to be an innovative product in the global market. Developing world wheelchair users experienced highly prioritized needs that were not obvious in a developed world context, such as the ability to go off road. This may be due to the wheelchair accessible infrastructure found in much of the U.S. and other developed countries. In many scenarios of daily life, conventional WC afford most of the mobility required by developed world users. However, this study shows that there are many other performance scenarios, such as navigating grass or climbing an incline, where mobility and quality of life could be improved. Collectively, developing world wheelchair users were shown to be lead users for their developed world counterparts by expressing magnified but similar needs in mobility limiting scenarios.

The LFC and GFC were created in a serial process; after wheelchair users in developed countries learned about the LFC through the media, their demand for the product motivated our team to design the GFC. It may have been possible to design both the LFC and GFC in parallel by doing concurrent needs assessments in

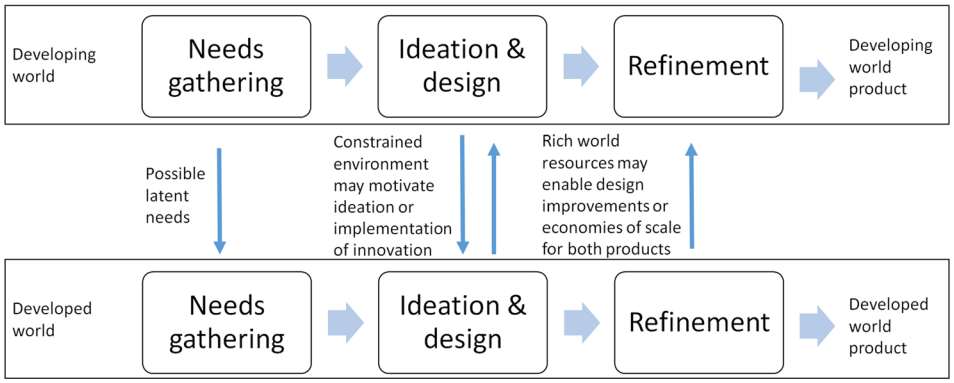

Fig. 7 Process diagram for parallel reverse innovation

both developing and developed countries and then creating a single product platform that could be adapted between markets. Product designers and engineers should consider whether serial or parallel reverse innovation (Fig. 7) is most appropriate for the global products they aim to create. If developing countries elucidate latent needs and impose design requirements that are obviously relevant to developed markets (such as high performance at ultralow cost), then parallel reverse innovation might be feasible. It should also be noted that desirable features of a reverse innovation do not have to only flow from developing to developed markets—they can go the other way too ("Refinement" stage of Fig. 7). For example, the seat of the GFC was designed for mass production using sheet forming to lower part count and manufacturing cost. We plan to implement this architecture in future versions of the LFC to further lower its cost. Local production was initially considered for the LFC. However, ensuring that each LFC/GFC adheres to quality control measures set forth by international wheelchair standards organizations is difficult at the local production level.

The opportunity of leveraging the highly constrained environments of developing and emerging markets to drive innovation of global product platforms is likely to become a common trend in product development. Billions of people in poor countries stand to benefit from innovative new technology, and there are billions of dollars to be made by engaging the rapidly growing population of consumers in emerging markets. By understanding the needs of users in poor countries and contrasting them with users around the world, designers can unlock latent needs for the global population. This study indicates that working with the relative extremes and overlap of socioeconomic continuums may result in the identification of a broader and more comprehensive set of needs. These continuums include variations in income (rich/poor), demographics (developing/developed world), ability (differently abled/strongly abled), and age (old/young). Mattson and Wood [27] created principles to help.

This study demonstrates that people in developing and emerging markets can be lead users for their counterparts in developed countries. Because users in poor countries experience challenges that are similar, but more severe, than those experienced by users in other parts of the world, they can elucidate latent needs that lead to the innovation of global products. To successfully practice reverse innovation, designers must first understand the needs of stakeholders in the developing world. This insight will lead to the creation of high-performance, low-cost, innovative solutions that address the most compelling development challenges that affect quality of life, as well as unlock massive markets of new consumers in emerging economies. By contrasting the needs of developing versus developed world users, and investigating how high-value technologies designed for poor countries could be adapted to wealthier markets, designers can gain insight into *how* to engineer reverse innovation and create successful global products. We have demonstrated this process by translating the LFC into the GFC, which is positioned to be an innovative, successful product in the developed world.

6 Limitations

The analysis presented in this paper was conducted subsequent to the design of the LFC and GFC, which were created to meet compelling social needs and new market opportunities. The design science followed the actual design of two artifacts, rather than being used to influence their creation. As a result, our methods used to collect data from different user groups were not perfectly aligned, and some level of interpretation (which is described in Secs. 3 and 4) was required. Our data collection was also focused specifically on understanding how the LFC should be modified for users in developed markets, rather than openly exploring the desirable features that an as-yet-designed, off-road mobility aid should entail. This was done intentionally, as we had substantial evidence (from press, user interaction, awards, etc.) that a version of the LFC, not a totally new design, had market potential in developed countries. We were confident that the LFC could be a reverse innovation. Investigating why it forms the basis of this paper.

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