Design for the Developing World: Common Pitfalls and How to Avoid Them

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Engineers face many challenges when designing for the developing world, which are not typically encountered in other design circumstances, such as a lack of understanding of language, culture, and context. These challenges often prevent engineers from having a sustained impact as they design for resource-poor individuals. In this paper, reports from 41 engineering projects in the developing world were analyzed, and common pitfalls were identified. The data came from Failure Reports from Engineers Without Borders (EWB) Canada and from the authors' own field reports. After the pitfalls are described, the authors present a visual tool called the Design for the Developing World Canvas to help design teams that are developing manufactured products to avoid these common pitfalls. This canvas can be used throughout the product development process as part of regular design reviews to help the team evaluate their progress in advancing the design while avoiding the pitfalls that engineers commonly face. [DOI: 10.1115/1.4032195]

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1 Introduction

The engineering profession plays a significant role in global development. One particular area of global development—poverty alleviation in developing countries—has interested many engineers from the developed world who are eager to use their skills to design affordably priced products that help resource-poor individuals [1]. Despite this desire, these engineers face several unique challenges when designing products for the developing world that can limit their impact. Such challenges include barriers in language, culture, context, and large geographical distances [2].

The purpose of this paper is to identify and articulate common pitfalls of design for the developing world and to present a simple tool to help design teams avoid them. Some common pitfalls were identified by examining Failure Reports [3–9] from EWB Canada and field reports from projects carried out by the authors. The pitfalls were then used to construct a visual tool—termed a *canvas*—to help design teams consider the facets of product development needed to avoid the pitfalls.

The concept of a canvas comes from the *Business Model Canvas* which was first introduced by Osterwalder and Pigneur [10] and quickly became popular as a visual way to consider and communicate each part of the business model. The present paper uses data from numerous engineering case studies to construct an engineering-related canvas—akin to the Business Model Canvas—that is created to help design teams avoid the pitfalls that have caused many previous engineering projects in the developing world to have little or no impact.

Within the engineering literature, Mehta and Mehta [11] presented the E-Spot Canvas as a way to help stakeholders in developing world projects—namely, designers, implementers, and end-users—to find a desirable balance regarding stakeholder equity, meaning which stakeholder will provide what quantity of time, money, and sweat-equity to the project. This tool is useful for helping stakeholders determine expectations and responsibilities before the project begins and does not focus on the overall product development process. The canvas presented in the present paper serves a different purpose—to help design teams periodically evaluate their progress in advancing the design while avoiding the pitfalls. The canvas introduced in this paper is called the Design for the Developing World Canvas and is specifically for teams designing manufactured products, but may also be useful for teams working on programs or services.

2 Research Method

In 2008, EWB Canada published their first Failure Report [3]. The purpose of this report was to share past failures with the goal that these failures would not be repeated by other engineers. After a positive response from the engineering community, it was decided that a similar report would be published each year. These reports document the experiences of practitioners working in the field on developing world projects. Most of these practitioners were hired as fellows and spent 12–20 months working in the field. The authors chose to study these reports from EWB Canada because, unlike projects often published in academic journals, these reports focus specifically on the challenges encountered and the mistakes made rather than highlighting the positive outcomes of the project.

Between 2008 and 2014, a total of 72 articles have been published through the annual Failure Report. Of these 72 articles, 27 described projects implemented in a developing world setting. The remaining articles consisted of failures in management within EWB Canada, failures in the organization of various student chapters of EWB Canada, and personal failures that may have occurred in a developing country but that did not give any specific information about the project being implemented. The authors of the present paper were careful to focus only on the challenges engineers face in working in a developing world context and not on the challenges engineers face when working within a nongovernmental organization (NGO) or when working on related projects in their home country (for example, advocacy and fundraising activities). This paper also examined 14 field reports for developing world projects completed between 2011 and 2014 by the authors; these

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reports were written during and immediately after the field work. A total of 41 cases were studied.

The authors examined a report for each project and extracted statements—either phrases or sentences—that explained the causes of failure for each project. This level of data granularity was chosen because it provided sufficient detail to understand the context and cause of failure. As often as possible, these statements were taken verbatim. For all projects combined, this generated a list of 225 statements. Redundant statements within a given project were then combined. For example, if a particular project had multiple statements referring to the same failure mode, these were combined into just one statement. Doing this for each of the projects individually reduced the set of statements from 225 to 142.

These 142 qualitative statements were then organized into themes using the KJ Method, which was developed to help reveal themes in ethnographic data from Nepal and often results in an affinity diagram [12]. This was done by a group of four researchers with experience in design for the developing world. Ultimately, seven distinct themes emerged and each of these themes is articulated as a pitfall in the following section, Sec. 3. By three sets of statistical correlation tests, the seven pitfalls were deemed sufficiently independent to stand as unique pitfalls (see Sec. 3). The seven pitfalls do not encompass *all* of the pitfalls an engineer may face in designing for the developing world; these are only the pitfalls found in this rare and valuable data set.

Any study that makes observations from human-generated data, such as the data reviewed in this paper, must recognize the potential for researcher bias. While extracting the 142 statements from the 41 cases, the researchers made a conscious effort to use a *nonjudgmental orientation* [13]. A nonjudgmental orientation requires the researchers to suspend personal valuation of any given cultural practices—especially to avoid the assumption that one practice is superior to another. In this case, the cultural practice is the design practice or philosophy of those who created the 41 case studies. While the authors have taken these measures to prevent contaminating the data, it is recognized that bias cannot be fully eliminated.

Upon identifying the seven pitfalls, a product development focused canvas called the Design for the Developing World Canvas was specifically created to help design teams avoid the pitfalls. To identify the key product development facets to include in the canvas, the authors (i) benchmarked the few existing canvases [10,14,15] to identify potential facets, (ii) evaluated those facets against the pitfalls, and (iii) added additional facets to support the unaddressed pitfalls. The choice of which facets to include was also influenced by traditional product development methodology and the authors own product development experience in the developing world. The layout of the canvas (described in Sec. 4) was chosen to subtly emphasize the coupling between its parts. All facets were chosen to ultimately help the design team avoid the seven common pitfalls.

3 Pitfalls

In this section, the seven common pitfalls are described and several examples from the cases are given for each. In Table 1, each of the pitfalls is articulated and a percentage is included; this percentage represents the number of statements extracted from the data related to that pitfall divided by the total number of statements.

It should be noted that in most cases reviewed, more than one pitfall was identified. Also notice that the first three pitfalls represent 78.9% of the statements. This was similar for both data sets with 77.5% of statements from EWB Canada and 80.3% of statements from the authors' field reports supporting the first three pitfalls. While the percentage of the last four pitfalls is significantly smaller in both data sets, they were reported in several cases. As such, this paper provides a more detailed discussion of the first three pitfalls and a shorter discussion of the last four. The seven pitfalls presented do not represent an exhaustive list, since they are derived from a particular data set based on the experiences of practitioners working in a nonprofit context. Other studies by the authors examine other data sets [1]. Also, while the data used to identify the seven pitfalls come only from developing world projects, these pitfalls may also apply to design in the developed world.

To show that the seven converged-upon pitfalls are practically independent and that no further combining of pitfalls is needed, the authors carried out three sets of data correlation tests: the Pearson linear correlation test [16], the Spearman monotonic correlation test [17], and the Kendall rank correlation test [18]. To carry out the tests, a matrix was created where the 41 cases were represented in the rows of the matrix and the seven pitfalls in the columns. The number of pitfall occurrences for each case was recorded in the body of the matrix. For example, case 1 had three occurrences of pitfall 1, one occurrence of pitfall 5, and no occurrences of the other pitfalls. Each column of the matrix was compared to every other column of the matrix to reveal the correlation between pitfalls and cases. From a practical point-of-view, this means that the authors examined whether any two pitfalls tended to occur at the same time, indicating that they should be combined.

All of the tests revealed weak correlations in the data set, except in two cases where a moderate linear correlation is found between pitfalls 2 (sustainability) and 3 (customer needs), and a moderate monotonic correlation between pitfalls 3 (customer needs) and 7 (forgetting that communities change over time).

The pertinent results are shown in Table 2. To find meaning in the table, recognize that a correlation coefficient (r) of 0 means no correlation and that a value of 1 means strong positive correlation. The authors adopted the traditional view for ethnographic data that $0 \leq r < 0.3$ represents a weak correlation, $0.3 \leq r < 0.6$ represents a moderate correlation, and $0.6 \leq r \leq 1$ represents a strong correlation. Regarding the p value statistic (p), the authors assume that $p \leq 0.05$ provides evidence that the observed correlation is not random.

The important thing to observe from this data is that in all cases the pitfalls—even those with moderate correlations—are sufficiently independent to be characterized as unique pitfalls.

3.1 Pitfall 1: Lacking the Contextual Knowledge Needed for Significant Impact.

In 28.9% of the statements, a lack of contextual knowledge led to failure. Contextual knowledge includes knowledge of the history and culture of the community. For the

Table 1 The seven common pitfalls with the percentage of statements from the reports analyzed that reflect each pitfall

Common pitfalls	Percentage
1. Lacking the contextual knowledge needed for significant impact	28.9
2. Neglecting to make a plan for or developing partners for long-term sustainability	26.1
3. Assuming the needs of the customers being served	23.9
4. Not making a plan for or developing partners for manufacturing	7.7
5. Lacking skills or expertise for a specific project	5.6
6. Miscommunicating or failing to develop trust with local stakeholders	4.9
7. Forgetting that communities change over time between field visits	2.8

Table 2 All nonweak correlations observed between pitfalls

Correlation test	Pitfalls involved	Correlation coefficient (r)	p value (p)
Pearson linear test	2, 3	0.3886	0.0100
Spearman monotonic test	2, 3	0.3571	0.0188
	3, 7	0.3197	0.0366
Kendall rank test	2, 3	0.3131	0.0212

purpose of this paper, this pitfall is not related to customer needs, which is discussed in pitfall 3. It is related, however, to understanding the local norms and conventions that determine how engineers should operate in a particular context. This was the most pervasive problem in the cases analyzed. Cultural nuances are most effectively learned by spending time in the context where the project will be implemented, but this is expensive and time-consuming. Because most projects in the developing world are carried out with limited resources, it is understandable that this challenge is encountered so often but it is important for engineers to realize that contextual knowledge, or lack thereof, has a significant impact on how well a project will be accepted and adopted in a community.

3.1.1 Examples of Pitfall 1. There are many examples from the cases where a lack of contextual knowledge led to failure. In Malawi, engineers worked with a rural entrepreneur to improve his cassava processing facility. The engineers first focused on the machinery, but then began to teach about business and supply chain management. This rural entrepreneur learned some useful skills and was able to temporarily increase his income, but the training he received did not allow him to sustainably grow his business so his improved cassava processing facility soon sat idle. Reflecting on this experience, one engineer said that she had "learned that the factory, while small and seemingly straightforward, is part of a much larger complex system of community dynamics, financial norms, interpersonal relationships, and Malawian society. Without appreciating it as such, we came up with a pretty blunt and inadequate solution to a complex problem" [19]. Understanding the history and culture of a community and how groups in that context interact with each other allows engineers to develop solutions that sustainably integrate into the context of a community.

In another case, a group of engineers attempted to collect feedback on a product they thought would be helpful to rural farmers. Customers were responding well during field tests, indicating that this area might be a viable market for the product. Later, the engineers received feedback from customers who had purchased the product. Some customers said that they decided to purchase the product, not because they thought it would be useful to them, but because it was a "cool, American invention." The engineers did not expect to have this cultural difference affect their field tests.

Events in one community, such as elections, re-elections, and several major holidays, meant that local workers could not be trained when originally planned. This delayed the start of the project for almost 3 months [20]. These delays are more commonly accepted in other cultures, but are not often accounted for in Western engineering schedules.

In another case, engineers implemented a pilot program in one region. After it was shown to be successful there, the engineers expected to be able to partner with the local government to implement it in the surrounding regions. They later found that this was not possible because of the funding structure of local governments. In this context, local governments receive funding for specific projects from the national government and from donors and any money received must be spent on that specific project. Because the local government had no flexibility, they were not able to divert funds to the new program even though it had been shown to be successful. The engineers did not understand this funding structure before implementing the program and were not able to expand the program because of it [21].

One engineer said that their project failed because "we were in a hurry, we were overconfident, we didn't have adequate cultural or historical knowledge, and we didn't do the homework that might have told us in advance what we were going to learn the hard way" [22].

Another important aspect of the local history is projects that have been implemented in that community in the past by other groups. In most situations, engineers will not be the first group of outsiders to come into a community with the intention of having a positive impact. Past experiences with similar groups will affect the expectations of community members and should be considered by the engineers before they begin. In one case, engineers had successfully implemented a program and were planning a small celebration for the community with the modest budget that remained. When it became clear to the community leader that the community would not be getting an elaborate party, which a previous group had provided, he was upset because his expectations were not met and he encouraged community members to discontinue their participation in the program [23]. If the engineers had known this local history earlier, they would have been able to handle the situation without offending community members or affecting the impact of the program.

3.2 Pitfall 2: Neglecting to Make a Plan for or Developing Partners for Long-Term Sustainability. In 26.1% of the statements, engineers worked on projects that required a long-term plan, often far longer than the engineers could stay in the community. A lack of community partners to implement the project long-term often leads to unfinished projects or projects that have very low impact. Projects may also require that a certain level of customer service be offered with a product. When the engineers are not in the community over an extended period of time or when engineers do not have the skills or language ability to offer that customer service, the project is not likely to have a significant impact.

In the cases studied, there were several specific causes of failure related to this pitfall. Listed from most common to least, they are:

(1) Lacking the channels for delivery
(2) Inappropriate program strategy or structure
(3) Ineffective transfer of responsibility to local stakeholders
(4) Lacking the resources or partners to scale up
(5) Depending heavily on the skills of a single person
(6) Lacking continuity between volunteers or other workers

3.2.1 Examples of Pitfall 2. In many of the cases, having no way to deliver/distribute the product or service was the major cause of failure. In these cases, the product or service was working but there was no way to get it to the people who needed it. In Zambia, an engineer helped to deliver a planer to a carpenter living in a remote area. The planer was installed incorrectly, destroying a critical component and leaving the planer inoperable. The engineer did not establish a system for repairs and had no plan or partners for long-term sustainability. Because the carpenter lived in such a remote area and because replacement parts and repair expertise were not readily available, it was 4 months before the planer was fixed. The carpenter was not pleased with the service he had received and having such expensive equipment sitting idle meant it was not having the intended impact [24].

In other cases, projects had an inappropriate strategy or structure for the context in which they were implemented. In one example, an engineer was asked to help rural entrepreneurs gain access to expensive machinery that would help grow their small businesses. The engineer started a nonprofit organization and later decided that a for-profit model would lead to greater accountability and success. But as a for-profit company, he reported that there was no mechanism for him to receive donations from other nonprofits. In order to continue purchasing the equipment that would help his customers, he was forced to spend his time focusing on the activities that would be most profitable to keep the business going instead of spending time in the field getting to know his customers and their needs. In reporting his experience, he says that he made the switch to a for-profit organization too soon and should have remained a nonprofit so he would have had more freedom to spend time learning from his customers in the field. In this case, the structure of the organization was inappropriate for the desired impact [25].

In several cases, unsuccessful attempts at transitioning leadership of a project to local partners were the cause of failure. In several cases, this transition was difficult because the local partner, a regional government, did not have the funds to support the program once the engineers left [23,26,27]. In another case, the local partners did not have the training to support the program [21]. In one case, an engineer implemented a program in a community and the program was successful while the engineer was present. Because of this, he expected the local government to continue it when he left, which they did not. Looking back, he says that his team failed to work within the constraints of the local government. The engineers had proven the program to be successful but maintaining it was outside of the budget the local government so when the engineer and his funding left, the program was discontinued [23].

Some cases showed that the cause of failure was related to challenges faced when scaling up a project. In one case, an engineer had developed a training program that would help rural farmers market their produce more effectively. He saw that the program was useful but it needed to be implemented by government workers who would be the ones actually training the farmers. He tried to implement the program in one area but had little success with the government workers there so he decided to try the program in a few surrounding areas, hoping that if the program went well in other areas the original area would be more inclined to participate. The program was still evolving to meet the needs of farmers in this area and in the end, the engineer said he had involved too many people before the program was ready. He tried to scale up too quickly and said that in the future, he would work with a smaller group of highly motivated government workers while making adjustments to the program and focus on spreading the program when it was more refined [20].

Several cases highlighted a project relying too heavily on the skills of a single person as the major cause of failure. This can be dangerous to the sustained growth of the program because if that one person leaves, the project is likely to end. This almost happened in the case of an agricultural school that helped farmers increase the profitability of their farms. Farmers were having success with the program and the program was growing when one of the key instructors was offered an opportunity to pursue a graduate degree and abruptly left. No one else at the school was qualified to teach those important classes and they thought the program would soon end [28]. In this case, they were able to find another instructor at a nearby university to teach and keep the program running, but in many cases the program ends when the one spearheading it leaves. Partnering with others and training them, particularly those who are already a part of the community, to manage a program can be an effective tool in improving sustainability.

3.3 Pitfall 3: Assuming the Needs of the Customers Being Served. In 23.9% of the statements evaluated, the pitfall of the project was that engineers made assumptions about what resource-poor individuals in the community wanted. These assumptions are often based on a limited familiarity with the lifestyle, opportunities, and challenges of those living in poverty. Engineers will be more effective as they understand the problem from the perspective of resource-poor individuals before trying to solve it.

3.3.1 Examples of Pitfall 3. One example that clearly shows a lack of understanding of customer needs was reported by an engineer who raised money to fund a computer lab in Tanzania. Ten computers and a solar power system were installed. During a site visit 6 months later, he learned that the computer lab had failed to have a positive impact in this community. Three of the computers had been stolen, two had been infested with local ants, and two others had so many viruses that they were not functional. Only three of the computers were still operating but they were locked in an office where they would be kept safe, but were inaccessible to community members. While reflecting on this failure, the engineer says his group "failed to learn in advance what sort of computer lab they might want in their school (instead, we made assumptions from 8000 miles away)" [29].

In another situation, engineers developing a food processor made the assumption that the processor had to be manual because it was going to resource-poor individuals. While testing it in the field, several community members suggested that the machine be electric so that the food processing would be easier. People in this community had access to plenty of electricity and were willing to use it for processing food. This is certainly not true for all developing communities, but engineers should discuss these things with resource-poor individuals before beginning the project instead of making unsupported assumptions.

A group of engineers were trying to make the process of washing clothes less labor intensive and time-consuming, so they developed a hand-powered washing machine. They assumed that the look of the product would not matter much to the people in the community as long as the machine was inexpensive and performed well. As the engineers tested a prototype in the community, it became clear that people were not interested in their prototype, despite the fact that washing clothing is a significant challenge. It was constructed of "cheap" materials causing the people in the community to feel that it would not last long and was a poor investment. In response, the engineers redesigned the machine using higher quality materials. Although this redesign almost tripled the cost of the machine, people in the community were much more willing to purchase it because it looked professional and durable.

Several engineers reported that working closely with their customers often and in the customer's context helped them stay focused on what their customers actually need [30,31]. In a related case, the engineers were in the field developing a small kiln to fire pottery as a way to increase income. While the engineers had lived in the community for 3 months and had access to end-users, the kiln was heavy and difficult to transport, which discouraged them from taking it to potential customers for feedback. This lack of feedback meant that the engineers had to make design decisions based on unsupported assumptions which led to a product that was not as successful as it could have been with more user input.

Another assumption engineers commonly make is that *any* solution to the problem is better than what people in the community already have. This is simply not true. In one case, engineers assumed that resource-poor individuals would be willing to spend one full day of each month maintaining a water filter in order to have clean water. While the filter worked well and was proved to prevent illness in this community, over time it became clear that resource-poor individuals in this context were not willing to accept this extra inconvenience in order to consistently have clean water. Their need for convenience was overlooked by engineers who assumed that any solution was better than nothing.

3.4 Pitfall 4: Not Making a Plan for or Developing Partners for Manufacturing. For engineers designing a physical product, manufacturing in the developing world poses a significant challenge. While this only represented 7.7% of the statements, it is still a pitfall worth recognizing. If a product is designed but there is no plan for the manufacturing of it or there are no partners with the capability to do the manufacturing, the product cannot be distributed to resource-poor individuals who could benefit from it.

3.4.1 Examples of Pitfall 4. In several cases, products failed because the necessary parts were not available locally or because local resources and manufacturing capabilities were different than expected. In one case, a pump was made using pipe that required a very tight tolerance to create a seal. The variation in wall thickness was much greater in the local pipe than the engineers expected and this prevented the pump from sealing properly. This difference in locally available materials had a significant impact on the team's plan for manufacturing.

In another case, the engineers wanted to use local materials to build a fruit press. Because wood is a common construction material in the particular community, the frame of the press would be made of wood by a local carpentry shop. Plans were sent in advance but when the engineers arrived in the community weeks later, the carpenter had not completed the order as planned. This problem was not a matter of miscommunication. Rather, the problem was that the partnership was not developed enough for the carpenter and the engineer to work effectively together. The carpenter was able to produce the needed parts before the engineers left, but not having the parts ready slowed the engineers' progress. While this team had found a local carpenter, they had not yet built a partnership with him that would allow the product to be manufactured at a higher volume and have a significant impact.

Another problem mentioned in the cases was the difficulty in communicating to local manufacturers the dimensions of the parts. In one case, the engineer entered a welding shop with engineering drawings made in a computer-aided design program. He gave the drawings to a welder and after a few moments, realized that the welder did not understand the orthogonal views. While this is not universally true in the developing world, in this case the welder was not accustomed to this type of drawing. Instead, he preferred to hand-sketch isometric views of the parts in his notebook while talking to the engineer about what the dimensions should be. Similar interactions happened with several welders in this community. There was no language barrier in this case (since the engineer was fluent in the local language), but there was a cultural barrier. In the engineers' work-culture, orthogonal view drawings are the standard, clearest way to present a part. With these local manufacturers, the drawings were a source of miscommunication because they are not a conventional part of the work-culture in that area. Engineers working in the developing world must be willing to adapt to the conventions of their manufacturing partners.

3.5 Pitfall 5: Lacking Skills or Expertise for a Specific Project. In 5.6% of the statements, the pitfall was that engineers were working outside of their skills or expertise. When engineers enter a developing community, they are typically seen as problem solvers. While engineers are indeed excellent problems solvers, it is not true that every engineer has the skills to solve all the problems a community may face. Engineers should be careful to balance their desire to be helpful to resource-poor communities with knowledge of the limitations of their own skills and expertise.

3.5.1 Examples of Pitfall 5. Many of the cases reviewed reported on the difficulties of program evaluation, which is the assessment of the impact a program has had on the community. While program evaluation is certainly important, the engineers on the team are typically not trained to perform this evaluation. In one case, an engineer pointed out that the problem their organization is trying to solve is part of a complex system that has many factors affecting it. When trying to evaluate how well a program solves a problem, it can be difficult to determine whether an improvement was, in fact, made because of the program or if there was another factor that resulted in the improvement [32]. Engineers are typically not well trained in evaluation but other professionals, such as social scientists, do have this training. Engineers could either seek training from these professionals before attempting to evaluate a program or have these professionals conduct the evaluation.

One specific example of this was reported in a case from an agricultural school in Ghana. An engineer working with the school was asked to evaluate a new program. The program appeared to be quite successful and if she could provide some data about how successful it was, they would be able to attract donor funding to expand the program to other schools. The engineer conducted several interviews to collect qualitative data about how the program affected individual's lives, but she also wanted to conduct a survey to gather more quantitative evidence. She designed a survey using a Likert scale and began collecting data. She reports: "Unfortunately, after several weeks of surveying, I realized I could not use the results in any meaningful way. This was because I had not designed the surveys properly, nor had I realized how difficult it would be to rigorously measure the Likert scale results." She later stated that she failed to devote the time needed to design a useful survey and failed to seek out experts who could have helped her. Because the information she had collected was not rigorous enough for quantitative analysis, she missed an opportunity to have donors help scale the program and provide greater impact [33]. The engineer in this case could have increased impact by either seeking out training on survey design or by leaving the evaluation to another professional who had the proper training and experience.

3.6 Pitfall 6: Miscommunicating or Failing to Develop Trust With Local Stakeholders. In 4.9% of the statements, the pitfall can be attributed to miscommunication or failure to develop trust with local stakeholders. Building strong relationships can be difficult in unfamiliar cultures but these relationships have a significant impact on the outcomes of projects in developing communities.

3.6.1 Examples of Pitfall 6. In one case, an engineer pointed out that keeping the incentives of each stakeholder clearly aligned can lead to greater impact. He also pointed out that a focus on building relationships and trust is needed to work effectively in a community [24].

An example of miscommunication and lack of trust was shared by an engineer working in the Philippines. It was her responsibility to transition leadership of a program from EWB Canada volunteers to a local government bureau but was told that their workers were too busy to take on the management of another project. To solve the problem, she arranged funding from EWB Canada for the local bureau to hire an additional worker who would lead the program. With this arrangement, EWB Canada would pay the workers salary for 1 year and if the project was a success, the bureau would continue to pay the salary in future years. The bureau accepted and an additional worker was hired. As the worker began, there was miscommunication about who the worker should report to. While she was officially working for the local government, she was being paid by EWB Canada and this arrangement caused her to question which organizations protocol should be followed. In failing to follow the protocol of the local government, the worker lost the trust of her employer.

While reflecting on this experience, the engineer recognized that having the worker be paid by one organization but reporting to another made it difficult to keep incentives aligned and to promote trust between stakeholders. She also said, I didnt really trust that my partner [the bureau] would figure out a way to continue the project in my absence so I forced a solution on them [34]. This lack of trust between stakeholders can seriously affect the sustainability and impact of projects in the developing world.

3.7 Pitfall 7: Forgetting That Communities Change Over Time Between Field Visits. In 2.8% of the statements, engineers specifically mentioned that they did not consider how communities would change over time and this affected the sustainability of the projects they were working on. While 2.8% is not a very large portion, it is the author's experience that this pitfall affects projects that continue over several years more than the engineers involved typically recognize.

3.7.1 Examples of Pitfall 7. In one case, an engineer was attempting to place a short-term volunteer in a community to collect information about their District Water and Sanitation Team so that they could help support and improve the Team's activities. He considered the various districts they had worked in over the past few years and chose the one he thought was best. This district was one that they had worked in several years ago but that they had not had volunteers in for the previous 2 years. The new volunteer was placed there but after a few weeks, it became clear that the volunteer would not be able to collect the information needed in this district because the key people they had worked with in the past were no longer in this community. This engineer said that "through this failure, our team now recognizes that districts and communities are dynamic and change over time, and that the process by which we select where to work must reflect this" [35].

4 Design for the Developing World Canvas

In this section, a visual tool is introduced to help design teams avoid the pitfalls described in the previous section, Sec. 3. The tool is called the Design for the Developing World Canvas, as shown in Fig. 1, and is loosely based on the Business Model Canvas [10]. The canvas presented here differs from the Business Model Canvas in two important ways: First, it was created specifically for the development of manufactured products (not the development of businesses), and second, it was created specifically in response to the seven pitfalls described in the previous section, Sec. 3. In this way, the canvas is customized for designing products for the developing world.

Generally, the purpose of this canvas is to help design teams periodically evaluate their progress in advancing the design while avoiding the pitfalls. Using the canvas to prepare for, conduct, or follow-up on a design review is particularly valuable since the canvas deals with high-level interdisciplinary items that are often the focus of design reviews. The canvas is a valuable tool for a range of project scopes, from planning preliminary field studies for collecting customer feedback to planning for the entire life cycle of the product. When using the canvas, the team should identify the scope (or subscope) of the project that will be focused on while using the canvas so that it can lead to appropriate decisions.

It is worth noting that the canvas does not simply articulate the pitfalls and encourage the team to consider them. Instead, the canvas emphasizes key facets of product development that should be considered to avoid the pitfalls. It helps the team see the weakest facets of the product development so they can take action to strengthen them.

By strategy, the canvas is *explicitly* linked to the product development process and *implicitly* linked to the seven pitfalls. To understand why the authors choose an implicit link to the pitfalls, it is valuable to recognize that all canvases are framed with a *progression* focus, where each part of the canvas is included to help the team consider essential things that should be put in place to progress forward. In contrast, all of the pitfalls presented in Sec. 3 are derived from the study of failure and are expressed as things that should not be done. To fit naturally into the traditional framework for canvases and to be a desirable tool that complements the teams forward progression, the canvas emphasizes design progression—not pitfall avoidance.

Simply having each section of the canvas filled in will not benefit the design team. The value of the canvas is the discussion it

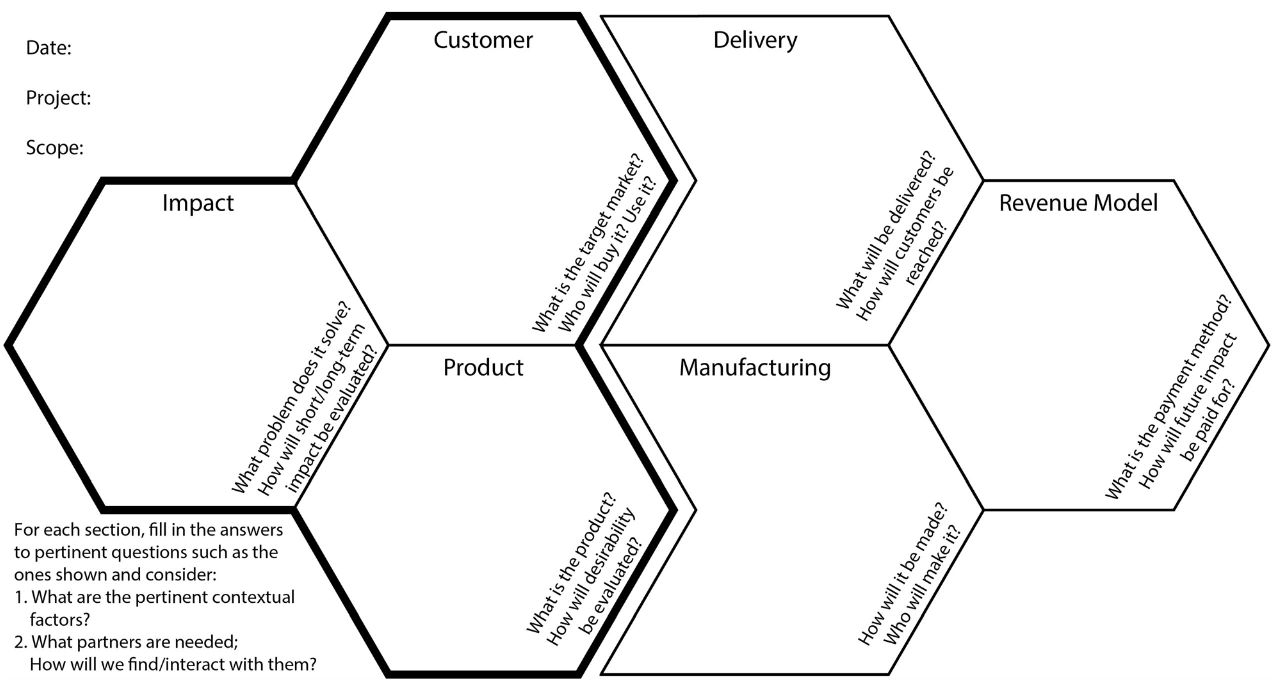

Fig. 1 The Design for the Developing World Canvas. Each section of the canvas represents an essential part of product development that if thoughtfully considered will help design teams avoid common pitfalls of designing for resource-poor individuals.

will facilitate within the design team. It is the thoughtful discussion and deliberate decision making that will allow the team to avoid the common pitfalls.

To introduce the canvas, a discussion of its structure is provided, followed by a description of each of the sections. How the canvas helps design teams avoid each of the pitfalls is then described.

4.1 Structure of the Canvas. The canvas consists of six sections purposefully arranged as shown in Fig. 1. Each section represents a key facet of product development that, if considered periodically, can be used to avoid the pitfalls described in Sec. 3. These facets are Impact, Customer, Product, Delivery, Manufacturing, and Revenue Model. For each section, pertinent questions, such as those provided on the canvas, can be answered by the team in the space provided. Each section of the canvas will have some influence on each of the other sections; this layout was chosen to show the key interdependencies.

The three sections on the left-hand side—Customer, Product, and Impact—are outlined in bold because they are the core of the canvas. These sections should be the first to receive the design team's attention and are highly dependent on each other. While the design team can start with any of these three sections, decisions made for any one of these three will affect the possibilities available for the other two. After questions related to the three core sections have been answered, the design team can move to the remaining sections on the right-hand side of the canvas.

The Delivery section is closely related to the Customer section and is therefore positioned next to it in the canvas to emphasize this relationship. To illustrate the close connection, assume the target market is rural farmers; the delivery may require local agents who visit the homes of the farmers to offer the product. Alternatively, if the target market is an urban population, a storefront on a main street may be a more appropriate delivery method. The target market will affect the choice of distribution system.

The Manufacturing section is placed next to the Product section because of the dependency they have on each other. Decisions about the type of product being designed, the materials that will be used, etc., will have a significant impact on where the product is manufactured and what manufacturing processes will be required. The manufacturing processes available locally may also affect the design of the product.

The Revenue Model section is closest to the Delivery and Manufacturing sections because they will have a noticeable effect on the profit generated or lost by the manufactured product. The revenue model will also be affected by and will affect the other sections of the canvas.

In this section of this paper, each part of the canvas and how to use it are discussed. Following that discussion, the ways the canvas helps design teams avoid each pitfall are outlined.

4.2 General Considerations: Contextual Factors and Partners. For each of the sections in the canvas, the design team should consider the contextual factors that are pertinent to that section. For clarity, we define contextual factors to be facts, circumstances, or other influences that shape the customer's environment. These contextual factors are not likely to be well understood at the beginning of a project, but will develop over time as the team seeks to learn more about the customer, the community, and the problem being solved. The IDEO.org's Human Centered Design Toolkit [36] contains many design methods that can be used to collect this information in a developing world setting, and Fuge and Agogino [37] offered suggestions for the circumstances where each of these methods is particularly useful and appropriate. Ideally, members of the team would be immersed in the context and perform field studies to better understand the context as they design the product. When this is not possible, the team can work with partners and interact with customers to deepen their understanding of the context. This understanding will help the team avoid each of the pitfalls because as the team better understands the context, they will be more capable of making design decisions that are appropriate for that context. When the design decisions are appropriate for the context, the capacity for impact is much higher.

Each of the sections in the canvas is likely to require a partner to have sustained impact. These partners may be organizations, businesses, manufacturers, or individuals that help the design team meet their objectives for that particular section of the canvas. The design team should go through each section and consider who they will partner with and how they will interact with that partner. Other researchers, including Zimoch et al., have found that having partners greatly increases the impact of their products [38]. Establishing responsibilities is an important part of interacting effectively. Carefully selecting these partners will allow the team to have a longer-term impact than if the team tries to complete each part of the canvas on its own.

4.3 Impact. In this section, the design team should clearly articulate the impact they intend the product to have. Depending on the goals of the team, they can focus on any combination of social impact, economic impact, and/or environmental impact. Pease et al. suggested developing an *impact hypothesis* [39]. Teams should write about the impact they intend to have in this area on the canvas. The design team should use this section to answer questions including: What problem does the product solve? and How will impact be evaluated?

4.4 Customer. This section describes the segment of the market that will both be interested in and benefit from the product. Having a very specific target market will allow the design team to determine the needs of the resource-poor individuals in that target market and design a product that specifically meets those needs.

In this area on the canvas, teams should state what their target market is. If the team has not yet decided on a target market to pursue, they should list the candidates so that they can make a decision as a team or leave the area blank as an indication that they need to discuss this section again when there is more information that will help them make a decision. Note that for some products, there may be more than one target market [40]. In other cases, the person who purchases the product may be different from the person who actually uses it. For example, an NGO may purchase the product and distribute it to resource-poor individuals. If this is the case, the design team should be aware of how this will affect the product development.

In this section, the design team should answer questions such as: What is the target market? Who will buy it? and Who will use it? They should also develop and answer any other questions that are specific and pertinent to their project.

4.5 Product. In the product section of the canvas, the team will describe the basic product they are designing and how they plan to evaluate the product's desirability. As with all other sections of the canvas, the team will also describe the pertinent contextual factors and needed partnerships as well as how they plan to find or interact with those partners. The purpose of this part of the canvas is to help the team focus on what is being designed and how it serves the customer and leads to the intended impact.

While most design teams will not need a canvas to encourage deliberate and thoughtful discussions about the product itself, the canvas will help the team recognize that the product is only one part of a larger system designed to have impact. To complete the product section, the team should answer questions such as these while considering other parts of the canvas: What is the product? and How will desirability be measured? Note that *desirability* in this case generally refers to product-specific performance. Ideally, the product-specific performance measures will be clearly related to, but distinct from, the impact section of the canvas. A clear relationship between the two allows the design team to focus on the product, while understanding how changes to the product affect the overall impact. For example, Johnson and Bryden recently developed product-specific safety measures that ultimately connect to the overall impact of their designs in the developing world [41].

Green et al. [42] presented a method that can be used to help engineers collect contextual information related to customer needs. This method consists of five steps: (1) Identify relevant contextual factors, (2) generate list of contextual questions to be answered, (3) gather customer needs and answer contextual questions, (4) aggregate customer needs into a weighted list, and (5) form context scenario(s) using the answers to contextual questions. This method can be used to help the team effectively discover needs that will determine the specific requirements for the product.

4.6 Delivery. The delivery section describes how the product will get to the customer. Connecting a useful product with interested customers can be difficult, especially in a developing community where infrastructure may be lacking. A well-thought-out delivery method could allow the product to have a greater impact. The delivery of the product can also have a surprisingly significant affect on the cost of the product. This can be further explored in the Revenue Model section. One portion of the delivery that is often neglected is the marketing of the product. Postel et al. note that marketing the product in a way that is accessible to users, however, unconventional, leads to greater success [43].

Austin-Breneman and Yang [44] presented three guidelines for engineers designing products to be sold by microenterprises. The guidelines are: (1) Design for the entrepreneurs business plan, (2) establish a reliable brand identity, and (3) consider multifunctionality. Microenterprise has proven to be an effective method of distribution in many developing communities. If the team chooses to focus on microenterprise or on income-generating products, these guidelines may be useful to them. Austin-Breneman and Yang also point out that while designing for microenterprise, the design team may have two customers—the end-user as well as the microentrepreneur. When filling in the Customer section of the canvas, the team may choose to have one or more target markets (customers), as long as each is clearly identified.

In this area, the team should write the details of the delivery plan. The design team should answer questions related to: What will be delivered? and How will customers be reached?

4.7 Manufacturing. This section describes the team's manufacturing strategy for the product. This potentially involves several different suppliers and manufacturing processes. Nevertheless, the team should list sources for the different parts of the product, being careful to align process capability with the needed part. The design team should consider the manufacturing location that is most appropriate for the product. Some teams may choose to have each part made locally in an effort to support the local economy. Other teams may choose to manufacture the product in another location and import it to their customers as a way to capitalize on the economies of scale. Some teams will have a combination of the two. The design team should choose whatever strategy is most appropriate for their specific project.

As an additional resource—tightly coupled to the manufacturing and product sections of the canvas—a list of design for manufacture and assembly principles has been adapted for use in the developing world and may be useful when selecting a strategy [45].

In this area of the canvas, the team should answer questions related to the manufacturing. For example: How will the product be made? and Who will make it? The team should also identify the needed partners and plan interactions with those partners.

4.8 Revenue Model. This section describes the financial information the team will need to consider as they make decisions about the other sections in the canvas. At its core, this section requires the team to think about how the impact (far left portion of the canvas) will be paid for now and in the future. This section is described as the *Revenue Model* since it is built on the general assumption that if all entities in the supply chain make money, the impact of the project can be sustained for longer than if they do not [46].

In this section of the canvas, the design team will write the cost to manufacture and deliver the product, the price they intend to sell it for, and any profit margin the team needs to include. The team should consider questions like: What is the revenue strategy? and What is the payment method?

The design team may want to consider different payment options. In the authors' experience during pilot tests of new products, resource-poor individuals in many communities are accustomed to paying for more expensive products in installments and are often willing to pay a significantly higher price if they can pay over time. Accepting payments may be logistically complicated for the design team, but it may also increase the product's impact by making it available to a wider range of the target market.

4.9 How the Canvas and Pitfalls are Linked. While the link between the canvas and pitfalls is implicit, it is powerful. Table 3 shows each pitfall and the sections of the canvas that, if thoughtfully considered, will help the team avoid the pitfalls. The following sections, Secs. 4.9.1–4.9.7, provide further discussion regarding the information found in the table.

4.9.1 Avoiding Pitfall 1. The canvas directly helps teams avoid pitfall 1: *Lacking the contextual knowledge needed for significant impact* when it prompts the team to consider pertinent contextual factors for each section of the canvas. Identifying pertinent contextual factors as well as the needed partners are general considerations because they apply to each of the sections of the canvas. Partnerships, in particular, are essential for understanding the context of the community, the problem to be solved, and how the product will help resource-poor individuals.

The impact section of the canvas compels the team to ask what problem the product intends to solve and how its impact will be measured. This helps engineering teams that tend to focus more on the product to not lose track of the intended impact. The canvas

Table 3 Link between pitfalls and sections of the canvas

Pitfall	General considerations	Canvas section
1. Contextual knowledge	Context, partners	Impact, customer, product
2. Sustainability	Context, partners	Impact, delivery, revenue model
3. Customer needs	Context, partners	Impact, customer, product
4. Manufacturing	Context, partners	Manufacturing
5. Lacking expertise	Context, partners	Impact
6. Miscommunication	Context, partners	Customer, delivery
7. Changes over time	Context, partners	Regular use of the whole canvas

also encourages the team to identify their target market and seek a deeper understanding of the customers' context as they explore potential needs and solutions. This understanding will help the team avoid pitfall 1 because a deeper understanding of the context leads to more contextually appropriate design decisions. Thoughtfully completing the product section of the canvas also helps because it causes the team to discuss what the product is, how it is going to be used in a specific context, and how its desirability is going to be evaluated.

4.9.2 Avoiding Pitfall 2. Pitfall 2: *Neglecting to make a plan for or developing partners for long-term sustainability* can also be avoided by using the canvas. For example, when a team carefully considers the impact section of the canvas, the team naturally begins to think about long-term impact and the sustainability they want their product to have in the context it is designed for. Whether using the canvas to characterize long- or short-term impact, the team will want to choose effective partnerships, knowing that long-term sustainability is unlikely without those external relationships. Partnerships aimed at sustainability will likely be needed in multiple areas of the canvas, such as the delivery and revenue model sections. As the team considers the delivery section of the canvas, mechanisms for delivery can be explicitly chosen to remain in place after the core design team has moved on to other projects. If the revenue model is organized so that it is contextually appropriate and so that the intended impact can be paid for now and in the future, then the product can be distributed to a greater number of customers in the future.

4.9.3 Avoiding Pitfall 3. As the team thoughtfully uses the canvas, pitfall 3: *Assuming the needs of the customers being served* can also be avoided. In an interconnected way, the core of the canvas, as outlined in bold, focuses the team on the needs of those being served. For example, the impact section asks the team to articulate what problem is being solved, and how the impact will be measured; the customer section encourages the team to define who would want the product and how they would use it; and the product section requires the team to establish how the desirability of the product will be evaluated. Each of these sections—if conscientiously considered—allows the team to question their assumptions which undoubtedly leads to more accurately discovering the true needs of the target market. The general considerations of context and partners are invaluable to avoiding this pitfall because they help the team recognize that essential information often lies outside of the team's knowledge base.

4.9.4 Avoiding Pitfall 4. Not making a plan for or developing partners for manufacturing is pitfall 4. The manufacturing section of the canvas is designed to help the team avoid this pitfall. In this area of the canvas, the team should answer questions related to the manufacturing, such as: How will the product be made? and Who will make it? The team should also identify the needed manufacturing partners and plan the interactions with them. The answers to these questions and reflections on context and partnerships will guide the team to make decisions that help them avoid pitfall 4.

4.9.5 Avoiding Pitfall 5. Another pitfall that can be avoided using the canvas is pitfall 5: *Lacking skills or expertise for a specific project*. Specifically, the impact section can help the team thoughtfully decide whether the skills of the team align with the desired impact and the way it will be measured. This will allow the team see what expertise may be missing and find the appropriate partners with that expertise.

4.9.6 Avoiding Pitfall 6. Pitfall 6: *Miscommunicating or failing to develop trust with local stakeholders* can be avoided as the team carefully plans their interactions with each of the partners they choose. This thoughtful interaction will build trust over time. Trust with customers is also essential for avoiding this pitfall. This begins as the team considers the customer section of the canvas and starts to understand more fully who the customers are and what they need.

4.9.7 Avoiding Pitfall 7. The last pitfall, pitfall 7: *Forgetting that communities change over time between field visits*, can be avoided by periodically reviewing the canvas throughout the product development process—especially as it relates to a growing understanding of the context and its dynamic nature. The design team should review the canvas on a regular basis as they learn more about the community and learn new information that will affect the various facets of the design as captured in the canvas.

5 Case Study in Using the Canvas

5.1 Background. The Design for the Developing World Canvas was used to create a cookstove pot skirt which is a reconfigurable flue that reduces emissions, fuel used, and time spent cooking traditional meals. The canvas helped the team prepare for a 2-week early-stage field study to rural Peru, where most people cook over an open fire. The design team consisted of engineers who have worked on a total of 14 designs for the developing world projects in the last few years. While it was not practical in this case to have two teams working on the project where one used the canvas and one did not to compare, the team can make comparisons—albeit anecdotally—to previous projects completed without the canvas.

5.2 Use of the Canvas. The canvas was used in during a weekly design review for the 5 weeks preceding the field study as well as three times during the field study. During the design reviews, a blank canvas was filled out with the canvas from the previous week as a reference. In one-on-one interviews, all members of the team agreed that using the canvas did not feel intrusive and did not feel like an extra activity they had to do apart from the product development. During the first design review using the canvas, the team had information to put in some of the sections but others were blank. As they worked through the canvas each week, they noticed that some of the sections were becoming well defined and they were able to spend most of their time working on the sections that were less defined. Filling out the canvas typically took an hour and the discussion the team had led to a series of tasks to be completed. Each team member was given several tasks at the end to keep the design moving forward. These were reported then on in the following week's meeting, using the sections of the canvas to drive the agenda.

5.3 Benefit of Using the Canvas. Compared to the teams previous design for the developing world experiences, using the canvas allowed them to be much more effective at collecting a high quantity and quality of customer feedback on the product, which was the goal of the field study. Using the canvas, the team quickly decided the impact they wanted to have with this field study—at this stage of the product development, the team was most interested in collecting early customer feedback. The discussion facilitated by the canvas helped them see that taking 10–20 sets of pot skirts would not be enough, as would have been more consistent with the team's previous developing world projects. The team made the goal to distribute 70 sets of pot skirts during the trip. Talking about and deciding on this number affected their choices in other sections of the canvas, for example, they knew they could not manufacture this many by themselves so they sought out appropriate manufacturing partners and planned their interaction with them. Also, they wanted to give users time to test the pot skirt prototype for several days before the team interviewed them for feedback. This meant that they needed a strong plan for delivery, which the canvas helped them develop. Using this plan, they distributed 66 pairs of pot skirts in their first 4 days in the field. Several days later, they were able to collect feedback from 42 users. The team's discussion while using the canvas helped them allocate resources to match their goals for intended impact.

The members of the team had not had that kind of success in a 2-week field study before and each member of the team said they felt that the canvas helped them achieve this because it guided them to consider not just the product, but the structure that supports the product as well. Nearly all members of the pot skirt team had previously worked on another product that was also tested in Peru. Designed without the canvas, the product was one of the teams' cleverest mechanical products. Here, the team was very focused on the design and largely neglected the supporting structure. They had only two prototypes which they produced themselves and this represented the majority of their effort. When they arrived in the field, the supporting structure was not in place because the team had not worked to develop it. The team had a difficult time distributing even two prototypes and was not able to collect a useful amount of customer feedback. The members of the pot skirt team agreed that they had used the canvas for their earlier projects, significantly different outcomes would have been likely.

6 Discussion and Conclusions

Engineers have an important role to play in global development, but face many challenges as they design products for resource-poor individuals. These challenges can cause both experienced and inexperienced engineers to make poor design decisions in a developing world context. In this paper, the authors reviewed reports of 41 engineering projects in the developing world and identified seven common pitfalls that engineers encountered. Examples from the reports for each of the pitfalls were given.

After the common pitfalls were identified, the authors presented the Design for the Developing World Canvas as a visual tool to help engineers avoid these pitfalls. Other canvases, such as the Business Model Canvas [10], exist and may be helpful for design teams, but the canvas presented in this paper was created specifically for engineers designing manufactured products for customers in the developing world. It is particularly useful in this situation because each section represents a key facet of product development that can be easily forgotten in the product-centric environment that often surrounds engineers. As the team considers those facets individually, they will have a more holistic approach to solving problems faced by resource-poor individuals.

The canvas is most valuable when used to prepare for, conduct, or follow-up on regular design reviews. When the team answers questions, as prompted by the canvas, a deeper appreciation for the complexity of the problem emerges, encouraging the team to more carefully choose solutions. The canvas can be adequately completed by an individual in about 30 min or in a team setting in about 60 min.

The team may also use the canvas *after* a project has been completed to evaluate a project—especially a failed project. Filling out the canvas at this point will help expose the strengths and weaknesses in the team's approach, which can clearly lead to future improvements and greater impact.

A strong message of this paper is that simply having the canvas filled out for a project has little value for the design team. The practical value of the canvas is in the discussions it facilitates and the awareness of the areas being or not being addressed by the team. Having a visual tool to represent each of the six sections allows the team to consider and discuss each section with relative ease. It shows the team the weaker areas of the product development and can help the design team understand the next actions to take or the next questions to answer. This will guide the team to work on the next most important aspects of the design. It is natural when using the canvas to assign responsibility and resources for completing essential tasks.

Ultimately, the process of regularly using this canvas allows the design team to thoughtfully consider and make deliberate decisions for each of the facets of product development related to the seven common pitfalls. This leads the team to solutions that avoid those pitfalls and allows them to have greater potential for long-term impact.

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