CalcuCafé: Designing for Collaboration Among Coffee Farmers to Calculate Costs of Production

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Many smallholder coffee farmers in Latin America join cooperatives for increased access to global markets. This requires them to understand their costs relative to a complex sustainable coffee production process. To that end, we designed CalcuCafé, a web-based application for cooperative technicians and coffee farmers to calculate a farmer's costs of coffee production. We iteratively developed and evaluated CalcuCafé's design with members of two coffee cooperatives in Peru. Our research uncovered different expectations about the application between technicians and farmers, stemming from differing backgrounds, goals, and perspectives. Learning to use the application in a group setting helped overcome these differences and facilitated collaboration, resulting in a strong buy-in for the application. Our paper contributes a research and design effort to support smallholder coffee farmers, an underrecognized group at the intersection of HCI for sustainable agriculture and HCI for development.

CCS Concepts: • **Human-centered computing → Collaborative and social computing**

KEYWORDS

Coffee; farming; Latin America; agriculture; sustainability; HCI4D

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1 INTRODUCTION

Smallholder farms of less than two hectares constitute around 85% of global farming [18]. Smallholder coffee farming is similarly prevalent, with 25 million smallholders growing 80% of the world's coffee supply on five hectares or less [12][15][60]. However, while most smallholder farming plays a crucial role in food security and nutrition for farming families through self-provisioning and increased family income when participating in local markets [4], smallholder coffee farmers in low-income countries rely primarily on global coffee value chains, as domestic markets are relatively small compared to those in North America and Europe.

To overcome the lack of operational scale, networks, and infrastructure required to access global markets and information, smallholder coffee farmers often form cooperatives that they own and

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manage [60]. In addition, nonprofit organizations such as Fair Trade USA (FTUSA) and Rainforest Alliance have developed certification initiatives to facilitate smallholder coffee farmers' integration into global specialty coffee chains, communicating to buyers the voluntary adoption of sustainability standards by the cooperatives and their farmers [53]. Coffee cooperatives are key to promoting the goals of these nonprofits, supporting individual farmers by employing coffee agronomists, called technicians, who work with farmers to adopt new farming practices, standards, and technologies toward maximizing the production, quality, and profitability of their coffee.

Consumers are willing to pay higher prices for certified sustainably-produced specialty coffee [60][61], but sustainable production is also costlier [20]. For example, organic coffee production imposes regulations on applying chemicals, and shade-grown certification requires adopting farming practices that preserve tree canopy and biodiversity. Despite the environmental benefits, practices such as shade-grown production can also mean slower ripening cycles, smaller yield, and higher prevalence of fungal diseases [39][50].

To ensure the continued participation of smallholder farmers in global specialty coffee markets, farmers need to cover their costs, including the opportunity costs of dedicating effort and land to coffee production. Extensive studies towards understanding the cost factors associated with sustainable coffee production are underway, with economists developing models to establish benchmarks for the cost of sustainable coffee production [17][26][58], to be used by stakeholders invested in the fair-trade coffee industry, including importers, roasters, nonprofit agencies, governments, and consumers.

In the spirit of the Fair Trade principle of *transparency* [16][60], our research seeks to expand the benefits of this cost model to those involved in growing and producing coffee – farmers and cooperatives. Accessing, understanding, and monitoring their costs could help coffee farmers identify gaps between their income and expenses, motivating changes to their business plans and farming practices to improve productivity and profitability.

To this end, we designed CalcuCafé, a web-based application that allows smallholder coffee farmers and cooperative technicians to input key variables related to their production costs and output a breakdown of their cost structures. As part of the design process, we conducted fieldwork in rural Peru, iteratively developing and testing CalcuCafé with two coffee cooperatives. The feedback we received from farmers and technicians through usability testing, contextual inquiry and conversations suggested the feasibility of a tool for farmers to understand their production costs and to make informed investment decisions. However, we also uncovered different expectations between coffee farmers and cooperative technicians, stemming from differing education levels, goals, and perspectives. The existing dynamic that emerged from this asymmetry was heightened by the introduction of the application, since technicians are more comfortable using computers than farmers. Learning to use the application together in a group and switching to a mobile-responsive design helped overcome these differences and highlighted the collaborative nature of the cooperative.

Our paper contributes, first, by applying HCI and CSCW research on sustainable agriculture in the context of rural development. We address significant economic and social issues related to a sizable, yet underrepresented, part of the global population, through a culturally-conscious design approach, which emphasizes understanding the specific cultural conditions of the target audience and examining the cultural appropriateness of design choices [57]. Our second contribution is in responding to specific economic challenges that compromise the sustainability of coffee production, by designing a tool for farmers to understand and overcome low profitability. As such, our design empowers smallholder coffee farmers with access to cost data and models in the collaborative context of their cooperatives, informing decisions that facilitate the economic sustainability of specialty coffee farming.

2 BACKGROUND AND RELATED WORK

2.1 The Role of Cooperatives in Sustainable Coffee Production

While it is expected that the demand for coffee will double in the next two decades [32], a cup of coffee still costs a consumer about the same price every day [12][52]. For farmers, the story is strikingly different. Factors such as changing weather conditions, plant disease outbreaks, volatility in international coffee prices, social and political instabilities, and the natural delay of several years between planting and the first harvest leave smallholder farmers exposed to substantial market uncertainty and risk [60]. The dominance of large coffee buyers and roasters in coffee markets raises concerns regarding arbitrage and market power [52][53]: while large coffee corporations demand compliance to corporate definitions of sustainable production [41], it is unclear to what extent they share the benefits of specialty coffee with smallholder farmers [14]. Moreover, the poorest smallholder farmers may not have the assets and skills to participate in global specialty coffee markets [20] and they are especially vulnerable to economic hardships associated with low and unstable prices, as well as high labor costs [35]. Unlike large corporations, smallholder farmers are disadvantaged by limited access to the innovation, technologies, and information needed to improve productivity, increase income, and make informed investment decisions.

Coffee stakeholders have identified the low profitability of smallholder farming as one of the main challenges for this sector, and it is unclear if the current conditions of coffee farming are attractive enough for future generations of farmers to ensure continued production of coffee [8][17][32]. Preserving the sustainability and growth of smallholder coffee farming within the global coffee value chain is therefore in the interest of the coffee industry as a whole. In this context, farm-support programs are seen as a key response to sustaining farming and production given changing socio-economic environments and industry needs [23].

Innovative business models, private nonprofit initiatives, and certification schemes (e.g. Fair Trade and Rainforest Alliance) are based on product quality, transparency, and traceability, aimed at protecting smallholder coffee farmers from the imbalanced relationships in the coffee industry. Such initiatives help integrate smallholder farmers into global specialty coffee chains by establishing direct, long-term trading partnerships between coffee roasters and farmers to improve economic, social and environmental outcomes [1][33].

Coffee cooperatives are a key agent to achieving the goals shared by certifications, alternative business models, and the industry. As member-owned organizations, cooperatives provide members with collective power to fulfill contract expectations and negotiate either directly with buyers or with social lenders, who facilitate open contracts with buyers as collateral for short-term, agricultural financing [62]. In addition to facilitating the negotiation process, cooperatives gather the volumes and qualities required by clients, sign the contracts, and manage and allocate the price premiums paid by coffee buyers. Cooperatives are therefore crucial for linking smallholder farmers with high-value markets [60]. Coffee farmers who are not cooperative members face higher economic risks, often selling their coffee to local middlemen (called “coyotes”) for much lower prices compared to the prices received by cooperative members [30].

Cooperatives also provide a variety of business services to their members, such as access to credit, technical assistance, and information about market trends and conditions [62]. Cooperatives often employ expert agronomists – technicians – who work with members to maximize the production, profitability, and quality of their coffee. In our own fieldwork, we found many technicians to be of the younger generation of coffee farmers. Many have a university degree in agriculture or a related field and are passionate about coffee production. They utilize their agricultural knowledge to assist coffee farmers towards adopting new farming practices, standards, and technologies. In contrast to technicians, coffee farmers tend to be less educated, making the role of cooperatives even more critical to their economic viability. With our goal to empower coffee farmers, we decided to leverage the organizational context of cooperatives and to base our application on the collaborative relations between farmers and technicians.

2.2 Understanding the Cost of Coffee Production

The coffee trade has been around for over 500 years, yet the fundamental economics of coffee production are not widely understood. Despite the increasing popularity of certification and direct trade initiatives which recognize paying farmers a price premium in addition to the price determined by international markets, there is still a surprising lack of information on the costs and benefits of producing specialty coffee [27]. Furthermore, the true cost of coffee production is at the heart of many of the industry's biggest challenges: farm profitability and financing, labor shortages, farm worker rights, generational succession, and gender equity. While the coffee industry moves to make coffee the first sustainable agricultural commodity [51], companies work to address these challenges [17].

Initial efforts toward understanding the cost of coffee production include collecting data from farmers about their production costs and developing economic models that reveal the main variables and parameters to be considered in determining cost structures [26][58]. Based on an extensive survey distributed to 515 smallholder coffee farmers in Colombia, Honduras, Peru, and Mexico, the model identifies cost factors associated with all steps of coffee production: preparing the land, purchasing seeds, seeding, planting, weeding, fertilizing, picking coffee cherries, processing and transporting the harvest, and so on [17].

In the spirit of *transparency* along the supply chain [16], there is value in providing farmers and cooperatives with access to this cost model. This could assist cooperatives in informing buyers about the minimum conditions required to cover their members' costs of production, improving negotiations for better contracts with coffee buyers. In addition, this could improve individual farmers' understanding of how their production expenses affect their income and productivity, toward long-term improvements of their farming and business practices.

One challenge in facilitating coffee farmers' access to the cost model is the high level of complexity of the coffee production process in specific operational conditions. Smallholders' profitability is based on a complex relationship between their productivity, production expenses, and prices received for their coffee, depending on particular farm conditions (e.g., altitude and soil quality [27]) and time frames (short vs. long term). For instance, farmers may seek to increase their immediate profitability by saving on investing in machinery. While such costly investments increase short-term costs, they benefit the production system in the long-term [17].

We address this challenge by simplifying the cost model, and by leveraging the relationships between farmers and technicians and the collaborative nature of cooperatives. We designed an application for farmers, with the help of technicians, to input data about their production costs and farming practices, interpret the cost model outputs and their implications, and estimate cost and profit changes as a result of simulated changes to their farming and business practices. Inputs include basic features of their farm, such as size, plant age, farming method and labor costs. Outputs consist of a cost breakdown visualization of their variable, fixed, and total costs. Farmers could then simulate changes to their original inputs. For example, farmers could estimate the cost tradeoffs of planting new plots using manual labor versus renting the appropriate machinery.

2.3 HCI for Sustainable Agriculture Development

Following Blevis' call to consider sustainability as a design value [2], HCI research on designing for sustainability has been growing, focusing on individual consumers [11], predominantly middle-to-upper class [28]. A similar consumer-centric research exists in the context of HCI for sustainable food systems [7][31][37]. Research and design efforts in communities of food producers have responded to recent calls to expand beyond consumers [3][7][56] and to consider broader challenges along the food supply chain: trust in others' sustainability practices, actors' autonomy, and food policies and regulations [44]. These research efforts include, for example, urban farming [25][38][43][46], Computational Agroecology [54][55], and rural farming as a deliberate choice made by highly-educated individuals [22][36]. These farmers based in high-income countries often have access to information technologies for both agricultural and business decisions. In contrast, the low-income coffee farmers we interacted with in Peru rely on agricultural and business knowledge delivered in-person by cooperative technicians and between members.

In an attempt to avoid the pitfalls of relying on persuasive technology to provoke the user to become more sustainable [6], our design does not offer specific recommendations for more financially-sustainable production practices. Instead, we rely on the expertise of technicians and farmers to identify what in their production practices would need to change to improve their profitability and economic sustainability. We hope that this will also help us avoid exporting Western ideals of sustainability and productivity to non-Western cultures [3].

By targeting the economic sustainability of smallholder coffee farmers in Peru, our research intersects HCI for sustainability with HCI for development (HCI4D). While most research in HCI4D has focused on education, access, and health, the link to sustainability has been identified as an area for growth [9][29][59]. As agriculture becomes more technical, scientific, and precision-based, research in developing communities has focused on systems that provide farmers with access to agricultural information [48]. Such access is necessary for farmers to increase their productivity and to continue growing food in the long run, especially as resources such as land and water are becoming scarce with growing demand and climate change [45].

Existing research in this area includes a voice-based online community for farmers in rural India [49], a voice-based marketing tool for agricultural products in rural Ghana [10], a local-dialect messaging system connecting farmers to extension officers in rural Uganda [42], and a participatory digital video repository for disseminating agricultural information to farmers in India [19]. Following this line of research, we aim to provide coffee farmers with a tool to calculate their costs based on their production practices, yet leave the agricultural knowledge of how to adjust these practices to the expert technicians and coffee farmer peers.

3 CALCUCAFÉ DESIGN

CalcuCafé was designed iteratively, with each version followed by a field visit to cooperatives in Peru to evaluate the design and receive feedback. Our initial design was based on conversations with stakeholders in the specialty coffee industry: cooperative members – managers, technicians, and farmers (videoconferencing to Peru and a field visit to Mexico) and FTUSA representatives who work directly with coffee farmers. In these early explorations, we attempted to understand coffee production and business practices, components of coffee production costs, organizational structures, and end-users' needs and goals. Later, we shared sketches of design concepts and solicited feedback from those stakeholders. We describe here the initial design, and later report on changes we made as a result of our field visit to Peru.

3.1 The Cost Model

The cost model was developed based on data collected through comprehensive, in-person surveys with 515 farmers in Colombia, Honduras, Peru, and Mexico [17][26][58]. These surveys captured details about the specific resources required for all activities necessary to establish, grow, and manage one hectare of coffee: purchasing and transporting materials (seeds, netting, soil, fertilizers, etc.), frequency, length, and number of people required for activities (planting, fertilizing, weeding, harvesting, etc.), and annual costs (cooperative membership fees, land taxes, etc.). Surveys also inquired about income, productivity, and profits, in order to determine breakeven points between costs and prices for financial sustainability.

We used a basic input-output cost model, in which inputs, i.e., independent variables, are based on farm characteristics (e.g., land size) and specific expenses the farmer has spent this year (e.g., a day laborer's wage), and outputs, i.e., dependent variables, are computed based on the inputs and present the farmer's cost structure. The methodology for constructing the cost model underlying our tool differs from an accounting approach to measuring cost structures [17]. First, opportunity costs are calculated not only for labor, but for other production factors such as land and physical capital. Second, the methodology considers a 9-year investment window, in which different expenses are incurred at different stages of development of the coffee plants, from land preparation and nursery for young plants, through harvesting and ongoing maintenance of coffee-producing plants, to older, less productive plants that need to be uprooted and replanted.

We simplified and converted an extensive spreadsheet-based model to an interactive farmer-facing tool. Based on conversations with specialty coffee stakeholders --- cooperative technicians, FTUSA representatives, and coffee value chain economics researchers --- we identified the most important input and output variables to be included in the interface, leaving the other variables to be estimated based on previously collected data. For instance, the amount of labor hours for activities such as weeding could be estimated based on the method of farming (organic or non-organic) and plot sizes.

3.1.1 Inputs. Input variables are fed into the cost model and serve as the basis for calculating the cost structure for a specific farm. These include expenses that the farmer made on producing coffee and specific farm characteristics that affect these expenses.

Land size and configuration. The productivity of coffee plants varies depending on their age. A coffee plant in its first 2 years involves expenses around land preparation, nursery, and planting, and does not produce any coffee. As the plant grows, its productivity increases, peaking at 5-8 years. At this stage, the farmer's expenses are related to maintenance (e.g., pruning, weeding) and harvesting. Productivity then starts declining around year 9, and around ages 15-20 farmers often decide to uproot coffee plants and replace them with new ones. To simplify the interface, we created three categories for coffee plant ages – young, mature, and old – to represent levels of plant productivity and expenses. Farmers input their number of hectares in each category, based on the age of their plants.

Farming method. The farmer inputs whether their farm is organic, chemical, or transitioning from chemical to organic. Production costs vary depending on whether the farmer uses organic or chemical (non-organic) methods. While chemical methods are related to expenses on pesticides and fertilizers, organic methods involve opportunity costs such as lower productivity [39]. As farmers recognize the financial benefits of organic coffee pricing, they may transition from chemical to organic methods. During transition periods, farmers must bear the costs associated with organic farming without earning the premium that comes from the sale of certified-organic coffee.

Day labor wage. Almost 70% of the total cost of coffee production is labor [26]. Labor costs vary from region to region, and farmers decide on hired day laborers' wages based on tradeoffs between their own resources and a desire to offer laborers a fair pay, conforming to a regional norm termed "jornal" in Spanish. In the specific region in Peru we were designing for, farmers often pay laborers a daily wage that does not include room and board.

Productivity per hectare. The simplest production cost model is the quantity being produced multiplied by the price to produce this quantity. Productivity per hectare is inputted as the weight of coffee produced in kilograms.

3.*1.2 Outputs.* The cost model outputs include the total cost incurred by the farmer in the recent year, broken down to various types of costs: variable, fixed, and additional costs. These costs are benchmarked against the price the farmer received for the coffee she or he has produced in order to identify the farmer's timeframe for financial sustainability: moving from uneconomical in the short-term (<1 year), to viable in the short-term (1 to 2 years), medium-term (2 to 5 years), and long-term (>5 years).

Variable costs are related to the daily operations of growing and producing coffee. These include hired labor, transportation costs, and production inputs such as fertilizers and pesticides. If the price a farmer receives is less than the total variable cost, then coffee is uneconomical to produce in the short term.

Fixed costs must be paid whether or not any coffee is produced. These include annual expenses such as cooperative membership fees and property taxes, and long-term investments and supplies such as fencing materials and machinery. If a farmer meets the fixed cost benchmark, production is considered financially sustainable in the short term.

Additional costs include depreciation of tools used in more than one growing cycle, the opportunity costs of land and farm management, as well as amortized costs of establishment. By factoring in depreciation, reinvestment, and opportunity costs on top of variable and fixed costs, we can offer a guide for determining whether a farm is profitable over time. If a farmer meets the additional cost benchmark, coffee is considered a viable activity in the long term.

3.2 Intended Users and Scenario

Farmers visit the cooperative a few times a year: to deliver their harvest, receive payment, participate in cooperative meetings, and attend workshops and training sessions to learn about new agricultural practices. In our preliminary explorations, we learned that during these cooperative visits, farmers often seek one-on-one advice from technicians to resolve issues such as plant disease, pests, and post-harvest processing problems. We initially envisioned integrating CalcuCafé in the context of these individual consultations.

In deciding the form factor of the application, mobile seemed an obvious choice considering its prevalence in Latin America [24]. But, because computers were available in cooperative offices and not all farmers had smartphones or Internet connectivity, we decided to initially design a desktop web application. Because many coffee farmers had never used a computer, this supported our intended scenario of CalcúCafe being used in a technician-farmer consultation.

Depending on the farmer's level of confidence in using computers, either the farmer or the technician could operate the interface. Our assumption was that with technician support, the farmer could decide on changes to make to their farming and business practices to improve profitability. For instance, they could decide to switch to organic farming. This requires a large investment of variable costs in the short term, but increases income in the long term.

3.3 Workflow and Implementation

After creating an account and logging in, the *input screen* (Fig. 1) prompts the user with questions relating to the input variables of the cost model: land size and configuration (hectares per plant age category), farming method (organic, chemical, or in transition from chemical to organic), day labor wage, and average productivity per hectare in kilograms. After submitting these details, the interface generates the *output screen* (Fig. 2), presenting the farmer's costs of production as a stacked bar chart.

The stacked bar is divided into variable costs, fixed costs, and additional costs per kilogram in the local currency, corresponding to the cost model outputs. A second bar on the same graph shows the average costs for all farmers in the cooperative, allowing the farmer to compare their costs to the average. Our decision to present the costs using a bar chart was based on preliminary conversations with technicians, who stressed the importance of a simple user interface with visuals and graphs rather than numbers and text. The stacked bar, as opposed to other types of data visualizations (e.g., pie chart), visualizes how the different costs of production outputs (variable, fixed, and additional costs) add up on top of each other, and allows comparing to cooperative averages or to future projections via a side-by-side bar chart.

We included in the output screen a horizontal line that indicates the price a farmer receives for their coffee (see "Current Price" in Fig. 2). The line serves as a visual benchmark for farmers to see at what level their current production is economically viable: long term – if the line crosses above the entire bar; mid-term – if under the additional cost benchmark; short-term – if under the fixed cost benchmark; or not at all – if under the variable cost benchmark.

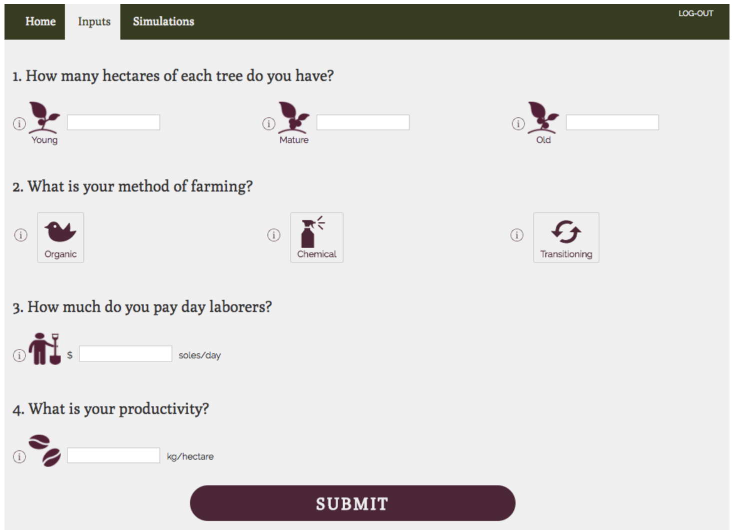

Fig. 1. CalcuCafé input screen for entering input variables. The interface was entirely in Spanish, the figure shows the English translation.

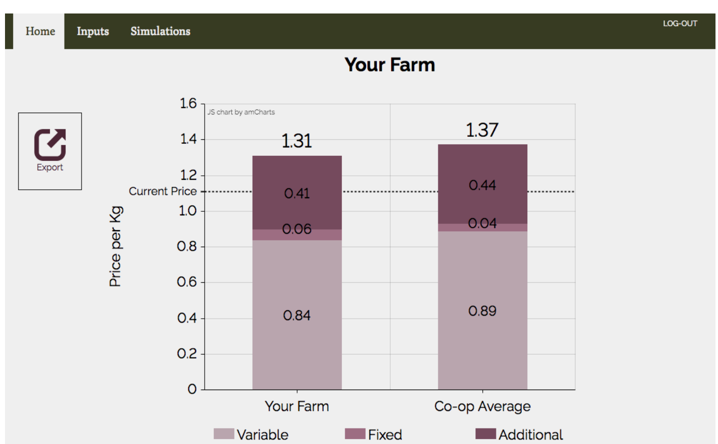

Fig. 2. CalcuCafé output screen that visualizes the cost model outputs for an individual farmer.

In many cooperatives, farmers often meet their variable and fixed costs benchmarks, but fail to meet their additional costs [17][58]. In our own fieldwork, we found that farmers often generate additional income to diversify their income and bridge this gap, for instance by selling honey or through paid employment. By visualizing this discrepancy, we hope to spark discussion between farmers and technicians as to how they can change farming practices to be more economically viable in the long run.

We included additional information to explain the meaning of each element of the cost model in both the input and output screens. This information appears as tooltips upon hovering over each element, to avoid visual clutter and information density. We used colloquial vocabulary, terminology, and concepts to explain in plain language each element in the cost model.

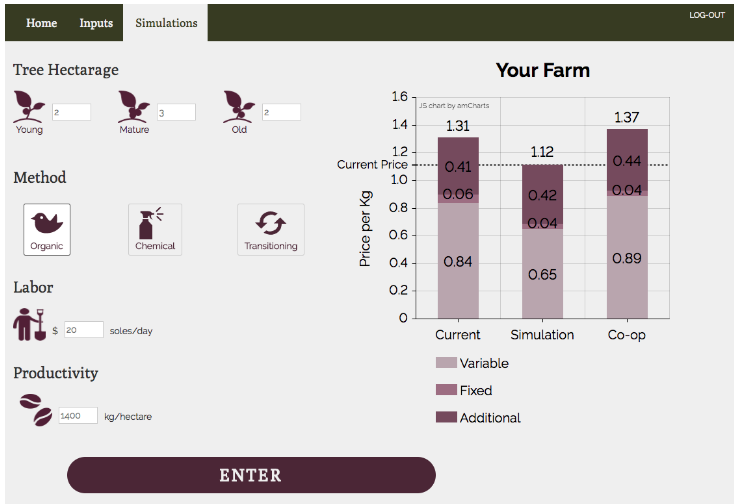

Fig. 3. CalcuCafé simulation screen for simulating changes to the cost model, based on predicted changes to a farmer's inputs and productivity.

To estimate potential cost changes in response to changes in production practices, we included a *simulation screen* (Fig. 3). The farmer can manipulate the four input values to see real-time changes to the cost bar chart. For example, the farmer could switch their farming method from chemical to organic or change the day labor wage. The cost of production bar chart changes accordingly, presenting side-by-side visuals of the current (actual) costs, projected (simulated) costs, and cooperative average costs to allow for comparison.

We also included a print feature, which creates a PDF file with the data inputted by the farmer and the resulting bar chart (see "Export" in Fig. 2). Given the intended scenario of use on a cooperative computer, this allows the farmer to take with them a record of their costs of production when they leave the cooperative offices.

For our evaluation purposes, we implemented only a front-end prototype, to test the degree to which the user interface made sense to farmers and technicians and fit within their practices.

4 FIRST VISIT TO PERU

4.1 Methods

In August 2017, we traveled to Jaén, Peru to conduct fieldwork and carry out evaluation sessions in two coffee cooperatives (referred to as Coop1 and Coop2 for anonymity). Both were chosen based on their close relationship with FTUSA, advanced infrastructure, financial stability, scale of development, support for members, and technical savvy. Coop1 was founded in 1999 and comprises of about 2,500 members, and Coop2 was founded in 2008 and has about 1,700 members. Both cooperatives have advanced facilities with warehouses, quality control laboratories, and administrative offices.

4.1.1 Evaluation Sessions and Focus Groups. At the cooperatives, we recruited onsite technicians and farmers, who had come in with their harvest. While the cooperatives originally sought to help us recruit younger, more tech-savvy farmers, we asked them to help us identify a more representative sample of their members.

Fig. 4. Joint session in an office in Coop1 involving a farmer (left) and technician (middle) interacting with the tool while "thinking aloud" with the researcher (right).

Participants were recruited for two types of evaluation sessions. The first involved a technician interacting with the CalcuCafé prototype alone, and the second involved a farmer and technician (who was already briefed on the tool) interacting together (Fig. 4). The purpose of running two separate kinds of sessions was to simulate our intended use case of an experienced technician who is already familiar with CalcuCafé assisting a farmer in interacting with the interface and interpreting the economic terms and the cost model. As such, the two sessions complemented each other, providing us with insights into the usability of the application, demonstrating opportunities and issues around the use of CalcuCafé in context, and uncovering differing expectations in use-case scenarios between farmers and technicians. Extensive fieldnotes were taken during both sessions.

We carried out a total of 13 evaluation sessions: six technician-only sessions and seven technician & farmer joint sessions with a total of 11 technicians and 7 farmers (all male but one, ages 30-50). Farmer participants had either a secondary education or non-university post-secondary education; all technician participants had university degrees in agriculture or engineering.

Each session began with informed consent and a set of background questions about participants' relationship to the coffee production industry and their methods for tracking expenses and calculating their costs of production.

Sessions then segued to a usability test, in which participants were asked to complete a series of tasks with the prototype. These tasks included inputting their production variables, interpreting the cost of production bar chart, and simulating changes to their cost structures by removing a plot of old coffee plants and increasing the plot size of their young coffee plants. While interacting with the interface, participants were asked to "think aloud," voicing their thoughts, questions, and concerns as they interacted with the prototype (Fig. 4). After completing the tasks, we solicited their feedback on the design and integration into their current coffee production process.

More stakeholders at each cooperative were interested in participating than could be accommodated by the evaluation sessions. We therefore organized a focus group session in each cooperative, for a total of 10 additional participants, including technicians, administrative staff, and farmers (2 female: 1 admin and 1 technician). While administrative staff were not necessarily intended as primary users, their acceptance and trust were important to the success of the application in the context of the cooperative administration. During the focus group sessions, we projected the interface on a screen and walked the audience through its functions and features. We solicited feedback from the group about the design and facilitated a discussion about the opportunities and limitations of CalcuCafé, taking extensive notes of participants comments, questions, ideas, and opinions about the application and its potential uses.

Sessions were carried out in the cooperatives' main offices, the environment where we sought to integrate CalcuCafé. A Spanish-speaking researcher facilitated each session, while another researcher observed and took notes. Sessions lasted 40-60 minutes, depending on participants' level of engagement with the interface and the questions. Sessions were audio-recorded with permission from all participants and later transcribed and translated to English for analysis.

4.1.2 Tours, Visits, and Conversations. To expand our understanding of how CalcuCafé could be integrated within the context of coffee production and cooperative operations, we supplemented the evaluation sessions with ethnographic research. This included comprehensive tours of the cooperatives and informal conversations (many of them over meals) with coffee farmers, technicians, and cooperative employees.

During the tours, technicians walked us through facilities while showing and describing to us the journey that coffee takes at the cooperative. Farmers bring their coffee to the cooperative after it has been depulped and dried at their farm. The coffee is weighed and a sample is taken for a series of quality tests. These tests examine moisture levels, physical appearance of the beans, and coffee taste by trained cooperative staff. Quality control is done blindly, using codes instead of names to avoid preferential evaluations of family and friends. The scores received by a farmer on both qualitative and quantitative measures affect the price they receive for their coffee.

Finally, we visited the home and farm of a female farmer member of Coop2, which provided a unique perspective as 87% of the cooperative members are male. Through this experience, we sought to better understand the lifestyle of coffee farmers, their family structures, and their work habits. In our conversation with the farmer and her family, she discussed her farming practices, as well as her motivations, concerns, and hopes for the future. At her home, she showed us her notebook for tracking expenses and annual balance sheets, and on her farm, she showed us her coffee plants in various stages of growth. In passionate detail, she described to us the historical and cultural significance of her land, her cultivation practices, and her other activities, including land reforestation.

During these tours and conversations, we took extensive fieldnotes and photos with permission for later analysis. While these tours, visits, and conversations did not point directly to specific design decisions of CalcuCafé's user interface, they provided us with broader insights into the life and work of coffee farmers and cooperative technicians and a fuller picture of the dynamics among them.

4.1.3 Data Analysis. Our data consisted of translated transcripts from the evaluation sessions, and fieldnotes and photos from the tours and visits. The data analysis process employed open coding of all transcripts and fieldnotes by the research team. We iteratively read transcripts and fieldnotes, then extracted, discussed, and summarized themes and insights from the data from all sessions and visits. As the data analysis process proceeded, we started paying specific attention to two types of themes that emerged: feedback about the CalcuCafé design (from the evaluation sessions and the focus groups only), and insights into the dynamics between farmers and technicians that emerged from the fieldnotes and transcripts of the entire dataset. As such, every transcript was read over and coded multiple times for research insights and design feedback. For anonymity purposes, we refer to farmers in our data by F#, and to technicians by T#.

4.2 Findings

4.1.1 Design Feedback. The evaluation sessions and focus groups centered around the interface design of CalcuCafé in order to iterate upon and improve the prototype. All participants (except those with limited computer experience, like F5) were comfortable navigating between screens and interacting with the various features of the prototype.

We found that the design accorded with the mental models of both farmers and technicians around the most important aspects of coffee production that should feed as input variables into the cost model. The tooltip information helped technicians and farmers understand the cost breakdown into variable, fixed, and additional costs, while the simulation sparked conversations about applying these changes to future investments and decisions.

We received consistent feedback on specific aspects of the design that needed improvement to fit local practices and conventions. For example, farmers and technicians in this region measure productivity per hectare in *quintals* (a sack of coffee weighing 55.2 kg), and in order to enter their productivity into the interface, we observed many of them pull out a smartphone, open a calculator app, and quickly convert their productivity from quintals to kilograms.

We also received suggestions for changing inaccurate terminology. For example, we used the term *chemical* for non-organic farming methods; participants felt this had a negative connotation and preferred *conventional* or *traditional* instead. Similarly, for the plant age categories, participants suggested the terms *in-growth* and *in-production* instead of *young* and *mature*, respectively, to represent the level of productivity of the plants rather than their age. This suggestion was supported by an observation during our farm visit, in which careful maintenance of the coffee plants allowed F7 to continue harvesting coffee from older trees.

In regards to the model inputs, all technicians (although none of the farmers) expressed interest in seeing more kinds of input variables feed into the cost model. For example, T4 indicated that transportation sometimes greatly contributes to a farmer's costs, especially if the farm is distributed across distant plots not easily accessible by road, requiring animals (such as mules) to carry supplies in and harvests out. T2 expected to input labor and supply costs specifically for weeding and fertilization, two major activities associated with cultivating coffee plants: *"The cost to remove the weeds, cost for fertilization—I mean, those weren't there."* These details, technicians asserted, would provide a more accurate picture of the costs associated with coffee production. While CalcuCafé's backend cost model accounts for these factors in computing the final cost structure, hiding them from the interface caused some technicians to doubt the reliability of the calculation.

These findings demonstrate an iterative design process in which we adjusted the cost model based on technicians' and farmers' perspectives and practices, to create a design that is more aligned with their worldviews. Our next set of findings offer deeper understandings beyond usability and mental models, surfacing issues related to the relationships between farmers and technicians.

4.1.2 Farmer-Technician Dynamics. Our initial design was framed upon several assumptions about the relationship between technicians and farmers. Specifically, we expected that CalcuCafé would be optimal in a scenario where a technician would guide the farmer through the application and offer advice in a one-on-one consultation. Intrinsic to this scenario, however, was a power dynamic between technicians and farmers, which the application revealed and, to some extent, magnified.

One source of differences between farmers and technicians was their respective levels of computer skills. Our initial assumption was that farmers would lack the technological experience to effectively operate the interface, while technicians would have the requisite skills and background to not only interact with the interface, but guide farmers through it.

The technicians in the evaluation sessions held this opinion as well. In many technician-only sessions, technicians stated that farmers would be incapable of using CalcuCafé on their own. For instance, T2 found the application intuitive and easy-to-use, but not for farmers: *"If I made my father do [the tasks], he wouldn't be able to. It depends on the level of education of the farmer to be able to handle it. Therefore, I assume that the application is more oriented towards technicians."* T3 also commented on farmers' computer literacy: *"They wouldn't know how to log onto any webpage or anything, because of their level of education."*

This assumption was initially corroborated when farmers struggled with basic computer interactions. In some sessions, farmers were unwilling to touch the keyboard and mouse and preferred to have the technician completely operate the application on their behalf. As sessions went on, farmers became noticeably more relaxed, remarking that CalcuCafé seemed less intimidating after they had used it for a while: *"The first impression was, maybe because of a lack of—a lack of practice, you think that it's going to be hard, you know? It's clear, but it's—once you get into the system, you adapt, you know? I think it's easy, I mean it's not difficult, you know?"* (F3)

This initial discomfort in using a computer was a marked contrast to our observation of farmers' high proficiency in using mobile devices. A design mistake involving an incorrect unit of measurement for coffee productivity was overcome by farmers through a quick mathematical conversion on their mobile calculator app. During our farm visit, the farmer (F7) and her daughter proudly walked around with a tablet computer, the farmer taking photos and the daughter playing games on it. Our decision to design the prototype for a desktop computer intrinsically disadvantaged farmers and, potentially, contributed to their dependency on technicians to navigate the interface.

A second source of misalignment we observed was participants' expectations of and engagement with the economic cost of production model. All the technicians were excited about the cost model available through the application and voiced ideas and expectations for future iterations of CalcuCafé. They quickly grasped the input variables and the cost breakdown outputs, requesting more complexity and specificity in the model. For example, T2 listed additional farming methods beyond *organic* and *conventional* that represent different certifications that some farmers have and that affect their production costs. Likewise, T4 requested that the model include input variables for transportation, fertilization, and irrigation. Overall, technicians wanted greater control over the model to generate a more accurate cost of production calculation and to better accord with their existing conceptual models of coffee production.

Although farmers did not express the same degree of excitement and engagement with the cost model as did technicians, they too felt comfortable interpreting the model overall. We intentionally chose terms and concepts that farmers were familiar with from their daily coffee farming practices, and provided plain-language explanations for these concepts in the interface. Misalignment arose where technicians expected farmers to be incapable of understanding the economic cost model on their own. In one technician-farmer joint session, when the researcher asked the farmer F1 to interpret the cost breakdown bar chart, the technician T3 cut in, arguing that F1 *"wouldn't understand it"*, to which the F1 disagreed and, rather fervently, insisted that he did.

Four technicians (T2, T4, T5, and T7) and one farmer (F6) imagined CalcuCafé to be rolled out in conjunction with a training program to equalize the differing levels of familiarity and comfort with both the technology interface and the underlying economic model. T5 suggested: *"In order for producers to use it, there needs to be training, because we don't all have the same abilities when it comes to handling those systems. Those of us who are farmers are not able to use that technology, so that's why the cooperative or whoever is providing that tool would need to train us."*

Overall, while the application was well received, we identified several key changes needed to better support farmers' independent use of the application within the collective nature of the cooperative. Our next design iteration, therefore, addressed some shortcomings from the first version, implemented a functional backend, and changed the scenario of use to support farmers and technicians learning collaboratively from and with each other.

5 CALCUCAFÉ DESIGN UPDATES

The next version of CalcuCafé incorporated changes based on the feedback we received during the first visit to Peru. This included changes to the cost model, use scenario, user interface, and implementation.

5.1 Cost Model

Based on the feedback we received, we added three new inputs that participants believed were important to make visible in the cost of production calculation. *Transportation* costs were cited by T5 and T1 as an important factor in their cost structure: high altitudes, remote farms, and geographical distribution of plots contributed to substantially higher transportation costs. *Fertilizer* costs were also mentioned by T2, T3, and T6 as a major cost that varied greatly from farmer to farmer, directly associated with yield, and a significant factor in farmers' expenses. Finally, we learned that the *price* a farmer receives for their harvest is not the same for all cooperative members, but varies across farmers depending on the quality level of coffee they produce. Technicians wanted to educate farmers about successfully achieving high quality, highly-priced coffee at the same level of expenses.

5.2 Usage Scenario

Our initial intended scenario of a technician-farmer consultation in front of a desktop web application inadvertently contributed to the dependence of farmers on the computer expertise of technicians and tilted the power balance to favor the technician. To address this, we decided to change the application form factor from desktop to mobile, and to change the context of CalcuCafé's use from an individual consultation to a group workshop.

Instead of having technicians work with farmers one-on-one, we imagined having technicians train farmers to use the application in a group workshop. A group training session where farmers learn together to understand and use the application could instill a sense of community through discussions around the implications of their cost structures to their individual farming practices and to the cooperative at a broader scale. This would also support the collaborative culture of the cooperative, encapsulated in the slogan of Coop2, "Somos familia, somos calidad", meaning "We are family, we are quality."

A mobile-friendly CalcuCafé could ease some of the power dynamics that stem from differences in computer literacy we observed when technicians had primary control over the application. Given that many farmers *did* have smartphones (consistent with the growing prevalence of smartphones in Peru [24]), a mobile app could benefit them in operating the interface independently after leaving the cooperative offices where they received the training in a group session. All of the participants suggested a mobile version of CalcuCafé, as T2 noted: "*Farmers don't use computers [...] even though they're scared, they can handle it with fear, but [phones are] what's easier for them, so I think the application should be oriented towards mobile technology.*" We therefore updated the design to be responsive and accessible from web browsers on mobile devices.

5.3 Workflow and Implementation

In order to encourage farmers to use the application independently, we added an on-boarding tutorial that walks users through the application when they first log in. The tutorial explains the purpose and functionality of the application step-by-step, while also clarifying and contextualizing some of the economic terminology used in the system. The tutorial was designed to be self-guided, although in practice, during the group workshops described below, we observed that all participants went through the tutorial together.

In addition to redesigning the user interface to be mobile-responsive, the next version of CalcuCafé included an implementation of the cost model and backend logic using a Microsoft Azure server platform. Farmers could now input their own production inputs and get accurate outputs specific to their farm data. With the backend implemented, we could evaluate not only the degree to which the interface design and interaction workflow made sense to farmers and technicians, but also their responses to the actual cost model of their farm data and how simulating different cost scenarios would inform their farm management decisions.

6 SECOND VISIT TO PERU

6.1 Methods

In March 2018, we revisited Jaén, Peru to continue our fieldwork and evaluation in Coop2. Our sessions during this visit focused on the implementation of the economic model and how CalcuCafé could fit into the cooperative's workflow. This trip did not include some of our previous methods such as usability testing, because the core interaction workflow design was unchanged from the first visit, and the first round of usability testing validated that CalcuCafé could address needs identified by farmers for understanding their costs of production. Rather, the methods for this visit evaluated the new usage scenarios of group workshops, providing a more in-depth view of the context in which CalcuCafé could be used collaboratively amongst farmers and technicians.

At Coop2, we met with the same technicians from our first visit and with farmers recruited by the technicians before our arrival. Participants were recruited for four different 1-2 hour long sessions over three days. All sessions were in Spanish and began with an informed consent procedure.

6.1.1 Technician Training Workshop. The purpose of this session was to simulate an actual workshop for training technicians on CalcuCafé. Three Spanish-speaking researchers facilitated a session in which technicians were trained as a group on how to use the updated CalcuCafé application. Four technicians (1 female, average age 29) participated. We projected CalcuCafé on a screen, and walked the technicians through the application as they set up accounts, added input variables (many inputted their family's farm data), interpreted the output chart, and simulated changes to their cost data. Participants used their own smartphones or tablets provided by FTUSA. We facilitated a discussion among technicians as they used the application, probing their thoughts about the input variables and explaining the meaning of the output charts. For the simulation feature, we asked technicians to simulate a good year and a bad year related to their productivity and expenses, and discussed what steps they would take in each situation. This session lasted about two hours.

6.1.2 Farmer Training Workshop. The next morning, one technician led a training session for eight farmers (all male, ages 30-46), intended to simulate an actual workshop in which technicians train farmers. Three additional technicians who participated in the previous workshop sat together with the farmers. Farmers came prepared with notebooks to write down notes. Three of them had smartphones, while the others used tablets provided by FTUSA. The leading technician projected the application on a screen, and guided farmers through the interface, explaining the economic terms and the cost model breakdown (Fig. 5). The other technicians sat near the farmers and helped as needed. The researchers observed the session from behind, took notes, and only intervened to resolve technical issues (e.g., when wi-fi went off). The session lasted about two hours.

Fig. 5. Farmer training workshop involving eight farmers interacting with CalcuCafé on mobile devices. A technician led the workshop while researchers observed and recorded farmers' interactions with the application and with each other.

6.1.3 Farmer Feedback Sessions. Following the farmer training workshop, we held group interview sessions with the participating farmers. We asked questions about their level of comfort in using CalcuCafé independently, their overall understanding of the data and cost model, and their trust in the application. Because of time constraints, we held three sessions in parallel with two researchers and two farmers at each one (instead of individual feedback interviews with each farmer). Given our observations in the first visit relating to the power dynamics between farmers and technicians, we intentionally included only farmers in these interviews. The sessions were audio-recorded with permission from all participants and later transcribed and translated to English for analysis. These sessions lasted about one hour.

6.1.4 Technician Co-Design Workshop. On the third day, we held a collaborative brainstorming and co-design workshop with the same four technicians and the research team. The purpose of this session was to ideate functionalities and data requirements for a technician-facing interface for a future version of CalcuCafé. We held a brainstorming discussion with technicians about what kinds of functions they would want and need to help farmers better understand and manage their production costs. The discussion naturally transitioned into data required to accurately operate the functions, aggregation levels and filters, simulations, and usage scenarios for the application. All technicians engaged in brainstorming on a white board, discussing each function, its specifications, and potential visualizations. While the workshop was centered on a future technician interface, insights from this session relating to cooperative goals and operations, sustainability of coffee farming, farmer education, and more, are relevant and therefore were included in the analysis.

6.1.5 Farm Visits. We supplemented the workshops and sessions with visits to two coffee farms of Coop2 members, both about an hour and a half away from the town center. These farms are at a relatively low altitude, translating into lower transportation and labor costs. The farmers showed us around their farms and talked us through the machinery they use to process their coffee cherries. Similar to our first visit, these tours do not immediately relate to the design of CalcuCafé, but gave us a broader view of the contexts in which farmers work and live and how CalcuCafé could fit within these contexts. For example, one farmer was transitioning to organic production, showing us his struggles to control pests that were decreasing his productivity with new organic methods he was unfamiliar with.

6.1.6 Data Analysis. We took extensive notes during all sessions and tours, as well as photographs and audio-recordings with permission. At the end of each day, we met as a group to summarize our observations, impressions, and understandings, and to write fieldnotes. We applied open coding for all transcripts and fieldnotes, first extracting activity notes from the data, then clustering the activity notes during an affinity diagramming session to discover themes. The research team discussed, interpreted, and summarized the themes from all datasets, going back to recode the data (transcripts, fieldnotes, and debriefing notes) with the identified themes. As in our findings from the first visit, we preserve the participants' anonymity by referring to farmers by F#, and to technicians by T#.

6.2 Findings

6.2.1 Design and Use. The design feedback from our second visit was based on an evaluation of a full-stack implementation of the application. Because this version included a functional backend, participants were able to calculate production costs for their own data, which increased their interest in the results and created a stronger buy-in for the application. Entering and visualizing personal farm data contributed to trust in the application, because the outputs validated farmers' perceptions of their costs.

The backend platform of CalcuCafé introduced a new step for account creation. This required participants to use their emails and create a password, which proved difficult during the farmer training workshop. Four of the eight farmers did not have an email account, and the other four accessed their emails so rarely that they did not remember their passwords. Farmers worked around account creation by either sharing emails or using technician-created emails, which revealed implications for a culture of sharing and a lack of concern surrounding digital privacy. Once all 8 farmers were logged into CalcuCafé, the rest of the interactions went smoothly.

During the input phase, we observed additional instances of the cooperative culture of sharing. F2 was unsure about what price he received for his coffee (the price differs between farmers based on the coffee quality they produce), and he openly asked a technician, who looked it up in a spreadsheet and read it out to him in front of other farmers. Additionally, while inputting variables, all farmers looked at each others' screens while assisting each other. As U.S.-based researchers, we were surprised to observe this level of comfort in sharing personal financial data.

After inputting all the variables, farmers moved on to interpret the output charts. F1, F3, F4, and F6 voiced some confusion about how to draw insights from the bar charts, and consulted with other farmers and technicians about how to interpret their outputs. Technicians and farmers voiced that they did not find it useful to compare one farm against the cooperative average, because farmers in the cooperative vary too much in their farming practices and circumstances. Instead, they suggested comparing one farmer to other farmers with similar production practices and circumstances. Capturing this, F4 said, "*there's a member who produces coffee at 1000 meters, another at 1500 meters and another at 2000 meters. That's my idea, because it will be a different reality. I imagine that the one at 1500 meters has a different way of producing*." This proposal also came up during the technician co-design workshop: two technicians proposed a design in which they could compare the financial and cost data of one farmer to that of a selected high-performing farmer to learn how to improve productivity, quality, and profitability. Again, farmers and technicians were not concerned about disclosing personal financial data to others in order to help cooperative members become more financially-sustainable.

6.2.2 Farmer Empowerment and Collaboration. The cooperative is very data-driven and its members keep extensive records of their expenses. F1 summarized this year-long accounting process: *"There's a farmer's notebook where we update all of our expenses that we invest in between harvests: fertilization, pruning, drying, everything that has to do with managing the farm. Then you have the harvest, post-harvest, and at the end of the year you do a balance of how much you invested, how much you earned per quintal or how much you lost. So that's when a farmer knows how much they made, whether they profited, broke even or lost money. And in the meantime, they don't know about it."* This suggests that instead of a year-long process of collecting transaction-level data, CalcuCafé gives farmers information about their economic viability based on a concise number of input variables, allowing them to make farming decisions throughout the growing cycle.

A major change in the conceptualization of CalcuCafé was not necessarily in the user interface design, but in the ways in which it was used by technicians and farmers. Instead of one-on-one technician-farmer consultations, we shifted to group workshops, in which farmers and technicians sat in a group and learned together to use the application (Fig. 5). They not only helped each other understand user interface features, but also discussed the input and output variables and held conversations around various simulated scenarios. F3 commented on the farmer training session: *"It was excellent, especially the way of communicating with farmers. The way of communicating with words, in our language."* Unlike one-on-one sessions, we observed a level of confidence in learning about and understanding production costs, at the individual farm level and for the cooperative as a whole. The group workshops, of both technicians-only and technicians with farmers, naturally segued into an open discussion of cooperative goals around the cost of production and the role that individual farmers play in achieving them.

The collaborative workshops helped reduce the gap between technicians and farmers that we observed in our first visit. During the farmer training workshop, when one farmer was struggling with an interface feature or found it difficult to understand economic concepts, they found that others were as well. As a result, instead of feeling incompetent in front of a technician, they felt comfortable discussing their problems and helping each other solve them. Additionally, discussions around the inputs, outputs, and simulations helped farmers and technicians co-construct an understanding of the application and the cost of production model. A similar collaborative process emerged in the technician training workshop and in the technician co-design workshop, where technicians discussed the cost of production model, limitations of the application, and opportunities for design, development, and deployment.

We also observed that encouraging technicians and farmers to use CalcuCafé on their own mobile devices increased their comfort in using the application. In contrast to our first visit, where farmers had difficulties using CalcuCafé on a desktop, the mobile form factor allowed them to move through and operate the application more seamlessly. As a result, both farmers and technicians were optimistic about farmers using CalcuCafé autonomously on their own after getting trained on it. We were concerned that farmers would not have internet access on their farms, as we found out during our farm visits, but farmers and technicians were not worried about this issue. F4 said during the feedback interview: *"most of us – let's say about 90% of people have internet access right now"* and T1 explained that the speed of infrastructure development in Peru is so rapid that everyone will soon have internet.

Farmers and technicians agreed that the mobile system is also a way to engage the younger generation of coffee farmers. They suggested that the children and grandchildren of farmers, being more immersed in new mobile technology, could help older farmers use the application. When asked about how comfortable he thinks farmers will be in using CalcuCafé, F1 said in the feedback interview: *"you have to integrate the young people, the farmer's children."* Getting the younger generation involved might even further reduce farmers' reliance on technicians.

Overall, use of the fully-implemented prototype highlighted the team-oriented culture of the cooperative. The change from one-on-one sessions to group workshops allowed farmers to feel more comfortable, since they were all learning together. Farmers were willing to help each other use and understand the tool, even if it meant revealing what we might consider sensitive personal data.

7 DISCUSSION

Our findings from both versions of the CalcuCafé prototype suggested that technicians and farmers welcomed the application and appreciated how it could help farmers understand production cost structures to improve the long-term profitability and economic sustainability of their farming practices. At the same time, the design and evaluation of our initial desktop web application revealed different expectations and abilities, stemming from divergent computer literacy, education levels, and perspectives on the coffee business. These differences were alleviated in the group workshop settings and by switching to a mobile-responsive design.

7.1 The Link to Sustainability

Our findings point to opportunities and challenges in intervening in food production as part of HCI efforts to design information technologies that support sustainable practices [3]. Incorporating information technologies in food production systems is unexceptional in high-income countries (e.g., [25][36][43][54][55]), although designing them involves challenges [38] and might clash with perceived values around connecting to the land [46]. In low-income countries, where farmers have limited access to information to enhance productivity, increase income, and adopt environmentally-sustainable farming practices to continue growing food in the long term, information technology may play a key role [18][48], especially given increasingly challenging climate conditions for farming [45].

When working with populations in developing communities, efforts to design information technologies for sustainable food production need to avoid imposing solutions without fully engaging with the cultures and experiences of the people in these communities [13][63]. We therefore revisited our initial assumptions, responding to what we observed by changing not only the design, but also consulting with our participants on usage scenarios that more accurately reflect their experiences and cultural expectations around interactions with each other and with technology.

Overall, the coffee industry is currently focused on environmental sustainability, especially adapting to climate variability [8]. The farmers we engaged with in our research already practice high levels of environmental sustainability in their farming practices: many of them are certified organic and are committed to preserving the tree canopy and biodiversity of the forests where they grow coffee plants. Yet, for the coffee industry to be sustainable, researchers must consider economic and social sustainability as well, offering solutions that allow coffee production communities to be financially stable and continue their sociocultural traditions [5].

CalcuCafé explicitly seeks to improve long-term farmer profitability, and as such, focuses on the *economic sustainability* of the farmers, their families, and their communities. The use scenarios --- the group workshops we held in our second visit, and the ones our participants envisioned in which younger family members assist older farmers --- also support *social sustainability*, i.e., the continued growth and preservation of the sociocultural aspects of coffee-growing families and communities. Farmers and technicians we interacted with suggested that introducing information technologies such as the CalcuCafé application could make coffee farming more attractive to the younger generation to continue participating in coffee farming as part of the family business.

We learned that cooperative members value working and learning with each other toward becoming better farmers and business people. They openly compare and contrast cost data with each other, and were sharing email accounts and passwords when that helped them achieve their collective goals. Supporting strong relationships among farmers therefore supports sustaining and strengthening the business model and the core values of cooperatives, reducing smallholder farmers' reliance on middlemen and increasing their independence and power in global specialty coffee value chains.

Our research follows calls for HCI researchers to engage with issues of food and sustainability in different cultures, populations, and across generations, which would help us consider "future scenarios for sustainable food systems supported by digital technology, including uncertain and unpredictable climates, untrustworthy business models and supply chains, and challenges around increasing poverty and social injustice." [44]. Our findings, while situated in the specific context of coffee farmers in a particular rural area of Peru, demonstrate the importance of considering both personal experiences and broader perspectives on the production side of food systems. Based on our experiences, we call sustainability HCI researchers to strive to interact with communities on multiple aspects of sustainability---environmental, economic, and sociocultural---because these aspects are inextricable for the members of these food production communities.

7.2 Learning with Peers

Our findings also suggest the ways in which the farmers and technicians we met learn and operate best: *with each other.* We initially assumed that the tech-savvy, agronomy-trained technicians could help farmers operate the desktop web interface and interpret the cost model toward making informed investment decisions to increase productivity and profitability. However, this scenario unintentionally contributed to differing expectations around the purpose and use of the application and a dependence of farmers on the technicians' expertise. The scenario we implemented in the second visit, in which farmers and technicians learned and operated the application together in a group, relaxed the pressure of farmers to perform in front of technicians.

In a group setting, participants felt that they were part of a collective effort, and helped each other learn the interface and the cost model, technician and farmer alike. Further, the group setting promoted deeper discussions around what it means to be profitable, and the important roles that farmers play in contributing to broader cooperative goals of coffee quality, productivity, business and marketing, and more. Finally, we found that participants' perspectives around sharing financial farm data supported ideas around learning from each other: there are no competitive secrets, and sharing successful farming and business practices for the collective benefit of the cooperative rallied members around its vision statement: "we are family, we are quality."

Our findings are similar to previous efforts to design technologies for farmers in rural India. In these contexts, it has been found that farmers value sharing best practices with each other online [21]. Further, including farmers in a database of instructional agriculture videos has been suggested to promote farmer education toward adopting expert advice [19]. And, while farmers express a preference to learn from experts, they act upon and respond to information provided by peers more than experts [47].

Our research goes beyond these existing findings from rural India about disseminating information to support farmer education. Our findings suggest that creating spaces for farmers to learn not just *from* peers but *with* peers may more broadly contribute to strengthening the relationships between farming community members. Obviously, farming in rural Peru is different from rural India, and outlining the specific differences between these two contexts is beyond the scope of this paper. We therefore call HCI4D researchers to explore the idiosyncratic circumstances in which their designs might fully benefit the individuals and communities using them.

Or course, focusing on the idiosyncratic circumstances, in our case, of two specific cooperatives in one location in Peru, also presents a limitation. While many coffee cooperatives in Latin America share similar characteristics and face similar challenges, the differences between them compelled us to design a localized solution for the current circumstances they operate in. Our focused design process encouraged participation by farmers and technicians from Coop1 and Coop2, but potentially led to overfitting the application to their specific needs, which might prove difficult to expand and generalize to coffee farmers and cooperatives in other regions in Peru and Latin America. Our design can be considered a proof-of-concept, and our multidisciplinary research team is already forming concrete plans for next steps in developing a cost of coffee production calculation application to be used by farmers and cooperatives throughout Latin America.

8 CONCLUSION

The coffee farmers we met in Peru know that consumers in wealthy countries value the high-quality coffee they produce, and take pride in their agroforestry practices to maintain biodiversity and environmental sustainability. This stands in striking contrast to farmers' subsistence-living conditions; few see long-term profits from producing coffee, and many rely on other means of income, even in the relatively stable coffee farming community we visited in Peru. This low profitability for smallholders compromises the sustainability of the coffee industry.

Going forward, it is imperative to validate whether an application for calculating costs of coffee production can fulfill its promise to contribute to the economic sustainability of coffee farming, namely by providing accurate cost data for cooperatives to negotiate fairer prices on behalf of their members. Deploying such an application in the long run may reveal its viability within the constraints of everyday business, farming practices, and goals set by farmers, technicians, and other cooperative stakeholders.

High-value food chains in general, and the specialty coffee industry in particular, are ripe for growth through advanced information technology [40]. This is driven by stakeholders who increasingly demand product-specific details beyond price—including indicators of impacts on natural resources, greenhouse gas emissions, smallholder farmers, and farm workers [20]. To accommodate these demands, NGOs and firms are increasingly adapting information technology to support the development of new multi-attribute production standards. The lessons from coffee production can be extended into future work in other emerging specialty value chains for agricultural products such as cacao, fruits, and vegetables, which likewise involve smallholder farmers in low-resourced regions globally [34].

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