The missing H in ICTD: Lessons learned from the development of an agricultural decision support tool

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ABSTRACT
This paper describes the challenges faced in ICT-D by reviewing the lessons learned from a project geared at improving the livelihood of marginal farmers in India through wireless sensor networks. Insufficient user participation, lack of attention to user needs and a primary focus on technology in the design process led to unconvinced target users who were not interested in adopting the new technology. We present some of the benefits ICTD can reap from incorporating human-centered design (HCD) principles and holistic user involvement and methods that have been shown to improve the design of socio-technical systems in the field of human computer interaction (HCI). In turn, to meet the challenges in the development arena HCI and HCD have to incorporate well established (participatory) action research and rural appraisal approaches that help achieving sustainable outcomes.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User-centered design

General Terms
ICT-D, wireless sensor networks, mobile phones, agriculture

Keywords
ICTD, WSN, Human-centered design, mobile phones, case study

1. INTRODUCTION
ICTD projects have many goals. Funding organizations have been demanding measurable results such as sustainability to better justify allocation of funds. The scientific ICT community needs to further their research careers but their recognition does not hinge on these criteria. In development parlance the *activities* carried out within the time-frame of the project produce *outputs* which ideally should result in *outcomes* in the mid-term (after the project has ended) and have long-lasting *impact* such as structural changes [1]. This scope is typically larger than that of the typical HCI study. Real end-user uptake is usually outside the scope of most HCI studies and left to industrial players. The same goes for standard desirable development outcomes such as local empowerment and capacity building along with policy implementation. In the development arena uptake and sustainable use of technology are key performance criteria for project evaluations. Development work often relies on the involvement of NGOs as intermediaries to connect with the local communities to help achieve these ambitious goals that include some form of community development.

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The research described here addresses the livelihood of resource-poor farmers, a large share of the population in many developing countries. Despite the long tradition of agriculture and its development through informal research many farmers in developing countries are struggling with the move from subsistence to input-based farming that includes specialized seeds, fertilizers, pesticides and herbicides in conjunction with uncertain availability of water. Adoption of innovations in the farming context has been thoroughly studied in the past by diffusion scholars and the US agricultural extension services were a large success. Decision support systems (DSS) for farmers, however, have not seen much uptake in developed countries. Wireless sensor networks (WSN) that could help reduce the effort required to gather data from the field to feed DSS are in their infancy. This makes adoption of DSS in agriculture by resource-poor farmers in developing countries a challenge.

We provide background on innovation diffusion, the modes of farmer involvement in research and the up-to-now disappointing adoption of DSS in agricultural contexts. Section 3 reviews the approach taken in an ICTD project developing WSN-based DSS and describes the problems encountered. We then discuss the value of early prototyping with users and human subject consent forms as boundary objects and present some wider ranging conclusions for ICT4D. The outlook presents our revised approach to the next phase of the project.

2. BACKGROUND
Diffusion of agricultural innovations has a long tradition that predates HCI research by half a century. The US introduced extension services in 1914 to *"relay useful and practical information on subjects relating to agriculture and home economics"* and has been encouraging people to apply it. The success of the US model of agricultural extension and its innovation-development process was largely attributed to the fact that 50% of the funding was targeted at diffusion activities. The

local-level extension agents not only brought innovations tested by research universities to the farmers but also gathered feedback and tried to understand their needs. This information was fed back to the agricultural agency, thereby fostering organizational learning and change. For example the initial focus on increasing production was extended to include farmers' information and entertainment needs. In spite of the proliferation of mass media a ratio of one extension worker to 100 farmers was maintained and, according to Rogers, much of the uptake of innovations could be attributed to the trust relationship between the farmers and them. Despite extensive research on the topic of adoption and diffusion of innovations, e.g. [2] many ICTD projects devote most of their attention to research activities unrelated to diffusion. For adoption that involves risk trust lies at the heart of adoption. Few if any development projects can rely on an organizational infrastructure and locally trusted diffusion agents that made agricultural such a big success in the US. Especially when the time frames for these funded activities are short. NGOs have become popular partners to provide easy access to users since they are trusted by locals. An entrepreneurial approach through the introduction of product or services is one approach to sustainable development projects. But similar to the NGOs researchers in the ICT domain are rarely interested in investing time and effort in the entrepreneurial side or diffusion activities, as this does not further their scientific careers. Due to the situation of academic procedure and funding there are few incentives for outcomes or impacts of their projects.

In terms of participation of farmers in the research process Biggs classified four modes of farmer participation: contractual, consultative, collaborative and collegiate [3]. In the contractual mode the farmer's involvement is similar to that of a paid participant in a typical HCI study. The farmer acts and gets remunerated as a service provider of land, resources or services to the research project. The consultative mode follows a doctor-patient relationship in which the researchers tries to elicit problems and suggest possible solutions to the farmer. In the collaborative mode the role of the farmers is more emancipated as they engage in continuous collaborations with the researchers as partners in the research process. This goes beyond typical user involvement in participatory design in which participants rarely have ownership of the object of research and its insights and therefore obtain no direct benefit from the on-going research. In the collegial mode the researchers actively encourage the farmers actively encourage the farmers to pursue research and development in rural areas. Local outreach – activities that improve people's livelihood in the area where the research is conducted is another way to secure benevolent attitudes from the population towards the research activities. This may appear to some just as an act of courtesy to or incentive for the local population to support and not sabotage research activities.

In agriculture crop simulation models have been used in decision support systems (DSS) but this research community was largely unfamiliar with diffusion theory, HCI and HCD. Reviews of decision support systems in agriculture in general [4], [5] and in particular in development contexts [6] read like poster motivations for human centered design. Poor adoption abounds and is linked to unclear target users, non-inclusion of end-users prior or during development, mismatches between solution and end-users problems, users' distrust in the technology, lack of field testing and last but not least insufficient training and support. In his review of the introductions of various information systems (IS) Heeks labeled the mismatch between the assumed and actual use contexts for IS in developing countries responsible for the failure of many IS innovations the *design-actuality gap* [7].

3. WSN FOR DSS

In 2004 the share of agriculture in employment in India was still at 67% [8]. In the province of Karnataka the size of the farms of 87% of farming families was less than four hectares. The share of these small farms accounts for 50% of the total cultivated area, that of marginal farmers (less than one hectare) 39%. In South Asia marginal farmers have profited comparatively little from the economic boom and poverty reduction of the last two decades [9].

The initial project set out in 2004 to help marginal farminers in India through wireless sensor networks (WSN). The partners in the project included two technical partners - one in India and one in Switzerland - working in the field of WSN, an atmospheric research institute and a local NGO in Chennakeshavapura - a small village in the Karnataka province. Marginal farmers in these regions mostly rely on rain for their crop. Draughts are common and rain-fed farmers are faced with large uncertainty about their yield at harvest time (typically expressed in kilogram per hectare) due to the influence of the amount and distribution of rain fall, pest and diseases of the crop and the availability of fertilizers and pesticides.

3.1 Technology

A WSN consists of a set of nodes also called motes. Each mote contains sensors to monitor environmental parameters and a radio component to communicate with other motes in a networked multi-hop fashion. This allows for timely delivery of information and has demonstrated its value in a range of environmental monitoring contexts such as forest fires and avalanche detection. Commercial WSN solutions exist for home and building automation. In an agricultural context WSNs can be used to collect data relevant to plant physiology e.g., soil moisture. Fed into existing crop simulation models the WSN data can be turned into forecasts of crop yield. With Moore's law as a guiding light it proponents deem it only a matter of time until the decision making of farmers in developing countries can be supported by WSN deployments in conjunction with crop simulation models.

Within the project the technical setup in the field included two WSN clusters. The collected data of each cluster was forwarded first through a base station node - a single board computer (SBC) acting as a *gateway* from the cluster through its wifi access point to a local server in the village. The server in turn forwarded the data to a central server at the research institute in Bangalore. This wifi gateway approach was abandoned due to the SBC's high cost and its power requirements. The technical personnel moved to a GPRS based gateway as the mobile phone network in the area improved. From then on the base station forwarded the data directly to the central server.

Agricultural research has created powerful crop simulation models that can be harnessed to predict crop yield. Their accuracy depends on the availability of environmental parameters such as e.g. soil type, soil moisture and temperature, ideally over the life-time of the crop. Such a diary of local environmental data is currently not available. For example, the geographical resolution of data on rainfall as measured by official weather stations is too coarse. Last but not least the predictions from crop models reflect the uncertainty of the input parameters. The farmers have to make do with uncertain rain falls and are struggling with making the best decisions under these conditions.

3.2 Methods and Course of Action

The project started with a series of parallel activities: reviews on appropriate sensor board solutions, sensors for environmental monitoring and crop models. The local NGO in collaboration with another research institute gathered general information needs on farming and livestock management [10]. First Rao *et al.* identified livelihood activities of the rural community through a survey of each neighborhood or caste group in the village. The approach included all members of the community since the researchers deemed that the introduction of a new technology might affect them all. According to their major livelihood people took part in group meetings and focus groups. The meetings centered around the information needs of participants' livelihood activities and the participants identified problems and prioritized them by consensus resulting in a ranked lists of information needs. Between three to six interested individuals then joined a round of focus groups hosted in the home of one of them to provide details around each identified problems in two to four hour facilitated discussions. High school teachers were then instructed through blueprints to follow the same approach in 14 other localities. The information needs in the community were diverse and demonstrated that environmental data could be valuable to the farmers. Due to later disputes about ownership the user needs data remained unpublished.

Further user involvement in the project was mainly contractual. However, no formal contract was established nor remuneration was offered. But the prospect of a better future through the technology was deemed enough of an incentive for the farmers to:

1. protect the hardware if it was put into their plot for testing purposes,
2. report on the conditions in the field and
3. provide feedback on the value of the technology.

Technical research on WSN components and software was coupled with development of integrated boxes that could be deployed in the field and withstand the climatic conditions. The main problems perceived by the researchers were due to the deployment of the hardware in the field. Energy was by far the biggest constraint. The lifetime of the WSN motes powered with two 3.6V lithium Ion batteries was typically in the range of weeks due to the synchronization overhead between the nodes (from wake-up to full operation) and networking overhead. The reliability of hardware was another concern – malfunctioning and failure of node hardware due to unknown causes, lightning strikes and theft. This created the need for many new technological improvements – theft and dead mote detection algorithms. Non-cooperating farmers that did not allow the placement of motes on their plots for propagation purposes required longer range radio connections. Radio wave propagation changed during the year for example due to crops growth and required higher margins during deployment. Overall, this did not leave room for exploring the needs of the marginal farmers and how the overall system could be designed in order to support them. Especially the question about how the collected data would be presented to the prospective users was left unaddressed. One notable exception was a controlled lab experiments geared at assisting novices in deploying a WSN. A metaphor of radio reception was chosen for people to gauge signal strength and connectivity of motes in a hands- and eyes-free way when deploying the motes [11]. However the participants in the study were ICT students in Switzerland not farmers or extension workers in India.

On the occasion of a local festivity one of the technical researchers gave a presentation to an unmoved community about the value of the research and his vision about the future in agriculture through WSN. Not only at this occasion did it become clear that the target users were not interested in the technology, which they had experienced only through the presence of grey boxes installed by technical personnel in some fields. Informal discussions with marginal farmers revealed that they were not interested in any technology that does not bring them rain, a perennial borewell, a road to the village or monetary advantages e.g. through loans or subsidies [12]. Another researcher noted that "*access to marginal farmers is not easy as they are very cautious; also, there is a significant danger in raising their expectations when approaching them.*" A representative from the local NGO qualified that marginal farmers generally felt left behind in the existing innovation processes, did not understand the scientific agricultural jargon used by the personnel deploying and maintaining the WSN (e.g. soil moisture and evapotranspiration) and felt uncertain about the cost benefit ratio of the WSN technology. In order for the farmers to adopt an innovation the benefit has to be clearly demonstrated and be substantial. Marginal farmers would not consider improvement in harvest in the range of 30% given the uncertainty and assumed added cost and effort. It should be noted that the marginal farmers had never experienced any interaction with the data from the WSN. The project then refocused on scientists as the target user. A web based application that allowed for monitoring environmental variables was developed and deployed. Each participating scientist completed a survey prior to a two-week test run. Data logging showed that only six of the thirty participants had used the system. The researchers were asked to identify possible use cases for WSN in the context of agriculture in individual debrief interviews. The four use cases that emerged focused on soil science, entomology, crop physiology and water management.

4. DISCUSSION

The project was confronted with theft of sensor nodes and very little interest from the farmer side. Theft could partly be attributed to the fact that one of the participating farmers was quite rich but overall the lack of communication with the local population as to what the technology was achieving and how the community would benefit from it seemed to be the main problem. One of the values of HCD could lie in getting buy-in from the farmers by letting people experience potential benefits through interaction with early prototypes.

In the project the bigger cultural differences appeared to be between technology savvy scientists and rural farmers not between Indian and Swiss partners. Human subjects procedures – usually dreaded by researchers in HCI - might help to put the involvement of farmers on a solid footing and serve as basic guidelines for technical personnel not familiar with user based research. Participant consent forms along with description of standard protocols for interaction with participants could be seen as a *boundary object* which provides different angles of understanding for partners from diverse scientific backgrounds.

5. CONCLUSIONS

The cost-benefit of ICT and participation in research projects need to be clearly communicated to potential target users. This was particularly problematic, as the project provided no opportunity for farmers to experience any benefits first hand as no user interface was ever made available. Lo-fi prototyping and other participatory techniques that are standard in the tool set of HCD provide many opportunities to envision use of technology. Consent forms could become a potential boundary objects that help not only scientists of different disciplines and participants but also the funding agencies. On a more strategic level our community needs to further raise funding organizations' awareness of the value of HCD in delivering research that addresses the needs of people in developing countries. The iterative approach of HCD also makes for a good transparent way to monitor progress and therefore aide in project evaluations.

6. OUTLOOK

For the follow-up project a different strategy was devised. One technical partner is working in tandem with an HCI partner on the application while the NGO is again providing a basis in the village for field trips and access to the local community. The mobile phone provides the only feasible information platform under unreliable availability of electricity. It is one of the biggest successes in rural ICT development - a poster child of a sustainable technology. The cell towers are independent of the energy grid and ordinary mobile phone use is possible with the available windows of opportunity for recharging the battery. Most importantly, many mobile phone models serve as programmable platforms. The target application(s) running on mobile phones should be able to convey the following information and procedural knowledge to potentially illiterate but numerate users:

a) Farming strategies (such as choice of crops, choice of mono and multiple crops), price, expected yields and risk scenarios based on predictions by the weather board (see [13]).
b) A schedule for farming practices
c) Crop-model based predictions of worst, average, and best case yields in financial terms
d) Probabilities of and control strategies for pest and disease incidences for crops
e) Guidelines for harvesting
f) Economic aspects of water management of existing bore well use or procurement of water in relation to c)
h) Local water levels and their fluctuations in bore wells

Methodologically the biggest change to the project's predecessor is the reliance on an HCD approach. Through initial interviews with rain-fed farmers and extension workers we will try to understand how they currently obtain the relevant information for the above topics and which role mobile phones play in their daily activities. After having understood whether the farmers themselves or extension workers will be the primary users of the application we will create personas, usage scenarios and storyboards to communicate the user needs to the development team and help in the iterative design process. We are planning to create instructional video footage for best farming practices. In participatory design sessions we will try to elicit suitable ways to convey the desired information to the target users and find appropriate interaction designs. We plan to engage in action research with the local NGO to understand and improve their way of interacting with the local community through ICT. The first way to provide a tangible benefit to local rain-fed farmers participating in our research could be to disseminate day wage labour opportunities through mobile phones. Our planned research will extend the existing knowledge on mobile accessibility for illiterate users such as [14].

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