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Centering and Engaging Farmers in Technology Development to Facilitate Innovation Adoption: Designing Your Approach[1]

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Introduction

Most large-scale research projects, especially those funded by national or state grants, will require engagement with people beyond the researcher teams, such as in the local or impacted communities. Such a requirement may include needing a model for change in behavior, knowledge, or attitudes as a result of the engagement. While Cooperative Extension as a system has worked with individual farmers and in workshops for years, many individual researchers and program personnel without contact with farmers may not be as familiar with farmers' needs and concerns; such lack of familiarity holds true even for faculty with Extension appointments (Stofer & Wolfe, 2018). This publication discusses how large-scale research programs can better engage farmers and perhaps set up structures for long-term engagement with a variety of research projects. We use the example of the National Science Foundation (NSF)-funded Internet of Things for Precision Agriculture (IoT4Ag) Center, a multi-university effort to design the "smart farm" of the future to ensure water and energy sustainability for food production (Kagan et al., 2022). Researchers, engineers, scientists, and program designers can use the information from this publication to engage better with farmers and to ensure programs and products from research are beneficial and easily adopted. This publication shares background on the importance of engagement and several high-level strategies for consideration as you approach engagement, especially for the first time, illustrated by the work of the IoT4Ag Center. Overall, the strategies center the farmer, addressing how to design engagement around audience needs, understand externalities, and determine shared values, highlighted by a case study of how engagement has gone wrong. This publication is one of several around engagement, supported by the work of the IoT4Ag Center. For more specifics on how to conduct engagement using the frameworks outlined in this document, see Naranjo and Stofer (under review).

This publication is one of a series related to work from the Internet of Things for Precision Agriculture (IoT4Ag), a National Science Foundation-funded Engineering Research Center, NSF Award EEC 1941529.

What Do We Mean by Engagement?

Engagement may simply be a way to share results through multi-way vs. one-way communication (Stofer, 2017), or it may involve communities in deciding longer-term action plans to address issues such as climate change (Monroe & Oxarart, 2020); each of these can be part of a larger engagement in research. For this publication, engagement means involving people outside of traditional academic or other professional research appointments in a variety of ways in the research project, ideally from conceptualization through to sharing results (Stofer, Lopez, & Farag, accepted).

Most scientists and engineers developing large programs will work on challenges that do not have clear solutions. Involving the end users of, and additional people potentially impacting or impacted by, the research can be critical to facilitating smooth and widespread adoption of innovations. While Rogers (2003) postulated that diffusion of innovation to different groups of adopters should proceed linearly, Moore (1991) recognized gaps or chasms between those different groups that prove difficult to cross, and the gaps are widespread across innovations (Dedehayir, 2019; Li et al., 2025). Indeed, some researchers propose not only centering users' needs for the technology but also considering needs for adoption of the technology in design to promote maximal adoption (Chilana et al., 2015).

Why Does Engagement Matter?

User-centered design of solutions starts with researchers listening to users — in our case, as many user group representatives as possible — to understand farmers', workers', and communities' practices, local knowledge, barriers, and needs (Ingram, 2014). Researchers can waste time and resources by trying to force farmers to change their behavior to accommodate a solution developed using a top-down approach (Benyon, 2014). Developing bottom-up approaches enables widespread ownership of the research goals. In the case of IoT4Ag, for example, we are asking for input to drive the design of the technologies we hope growers will integrate into their operations.

Engaging with people who have vested interests outside the university, such as farmers, can help create more strategic, synergistic, sustainable, and aligned programs by helping everyone invested in the project, but especially researchers, understand how people are connected and interact with each other inside and outside the system.

Engineers and scientists can develop technologies using a mixture of sources. Some of these sources can be labeled innovation-oriented, such as what is popular at the moment according to peers and what feeds curiosity. Client-oriented sources include what is getting funded through grants or what the user needs. In the case of IoT4Ag, our users of internet-linked precision agriculture may be farmers, farmworkers, crop consultants, Extension personnel, farmer groups, industries and associations, or farmers' and farmworkers' communities. These sources of ideas should complement each other instead of competing. A problem of implementation can occur when a researcher decides on a solution but fails to understand the knowledge and needs of the farmers (Lindblom et al., 2017; Mackrell et al., 2009; Matthews et al., 2008; Rossi et al., 2014). This leads to a gap of relevance when researchers create a technology that farmers may not want or need (McCown et al., 2009).

Barriers to Adoption of Precision Agriculture Technology

Addressing barriers early on can help engineers and scientists design products most likely to be adopted. There is a rich literature on why some precision agriculture technologies, such as those at the heart of the IoT4Ag Center, have been adopted and others have not. Table 1 shows a list of factors that at least partially explain why people are not adopting technology. See Appendix 2 for full references of reviewed articles.

These factors come from 75 publications examining farmers around the world, as synthesized by Naranjo, a research assistant for over five years in the UF/IFAS Department of Entomology and Nematology and now a graduate student in the School of Forest, Fisheries, and Geomatics Sciences examining resources and conservation. Papers ask several different questions. They found multiple, varying, and sometimes conflicting results as to the importance of each factor among different farmer groups. Moreover, many studies have not always addressed why the farmers face particular barriers (e.g., by exploring the history that brought farmers to that current barrier). The studies generally look at position (i.e., basic statements of a stance), but they do not examine underlying values and interests, the reasons behind positions that can offer areas of commonalities and allow negotiation. Exploring shared values and interests through engagement rather than trying to negotiate on positions allows more acceptable solutions to come forth. See Appendix 1 for suggested questions to reveal these values and interests.

Technology Development Done Wrong: Overlooking Social Impacts

Below is a sample of technology developed by a university that would have benefited from these types of engagement-oriented communications. In 1949, plant breeder Jack Hanna and engineer Coby Lorenzen from the University of California, Davis, created a machine that could pick and sort tomatoes. The technology sought (intentionally or not) to eliminate the need for Mexican labor brought in during WWII through the Bracero Program in 1942 (San, 2023). Conflict began as workers wanted to review protocols, as they faced discrimination, contracts only in English, poor wages, surcharges for room and board, deducted pay, and exposure to deadly chemicals (García, 2021; Robinson, 2010). The Bracero Program ended in 1964 as mechanization was becoming more widespread. The aftershock of the technology displaced 32,000 predominantly Mexican farm laborers in the 1960s. Eighty percent of the tomato farms, which were mostly small, went out of business due to inability to compete with farmers who could buy the equipment. Land degradation increased due to farmers' movement to flatter places that were more suitable for the machines. Larger operations increased their farm sizes and power as they bought and consolidated farms, and the machinery shifted toward preferring harder tomatoes. Ultimately, consumer preferences shifted to favor harder but less nutritious tomatoes. Subsequently, small tomato farmers sued the University of California (UC) in 1978 for improperly favoring large farmers, food processors, chemical companies, and machinery manufacturers, arguing also that UC officials were guilty of conflict of interest and unlawful expenditure of tax money. After more than 10 years, the state Supreme Court ruled in favor of the university. Along the way, the lawsuit raised public debate about agriculture innovation and who were the beneficiaries of the yearly 1 billion USD research budget. UC founded the Small Farms Center in 1979 at its Davis campus to focus on providing education and assistance to low-income and small farms in response to the negative publicity; however, the center closed in 2009 after budget shortfalls in the university's division of Agriculture and Natural Resources. The development of the tomato harvesters forced small farmers and laborers out of farming and left many to seek jobs in other industries. Ultimately, this changed small communities into ghost towns.

Table 1. Barriers to adoption of technology.

Barrier Types					
Socioeconomic	**Culture**	**System**	**Information**	**Agro-ecological**	**Application**
Technology cost	Benefits vs. profitability	Public unbiased advisors	Too much data	Farm size	Tested at different farms
Age	Different values and goals	Trust	No internet access	Land Ownership	Inflexible systems
Learning Curve	Confusion over definitions	Computer literacy in rural areas	Data ownership	Soil quality	Economic assessments
Farmers'/workers' education level		Networks among farmers	No ergonomic displays		
Lack of self-confidence		Environmental policies			

Determining Your Values to Determine Your Interest Holders

Determining the core goals is as important as discussing research goals. The "core values'' are values and beliefs of the researcher. The research goals are the objectives of a study. Researchers should discuss who the researchers are (e.g., their own background in terms of race/ethnicity, gender, age, and practical experience in the domain such as agriculture, as well as additional salient identities), who the additional interest holders are, why they have interest in the project, who is excluded and why, what factors influenced or informed the beliefs (religion, politics, etc.), and how values and beliefs affected the development of the research, methodologies, and theories. Research should be nonpartisan, so discussing biases before starting any project is essential (Lackey, 2007). However, science carries political implications, regardless of how it is conducted (Fuentes, 2024). Writing a research grant that is aware of its shortcomings, consequences, and limitations will help influence whom the research will affect and how it will do so. Collaboration with social scientists and adding researchers' subjectivity or positionality statements to team resources and ultimately publications can facilitate consideration of values and biases (Bilgen et al., 2021; Darwin Holmes, 2020); positionality statements help surface potentially hidden motivations such as funders or initial thoughts on a topic.

Below are some questions researchers should ask themselves based on Peshkin's work on subjectivity, with example answers from the UC case study (Peshkin, 1988).

- How does your race, religion, or gender affect where, why, or regarding whom you will conduct research?

Hanna and Lorenzen were both white men whose technology affected tens of thousands of Mexican and Mexican-American laborers. Most harvesters were Mexican men while most sorters were Mexican women, who were less likely to be directly displaced.

- What communities will you be (ostensibly) helping and why? Communities also include plant communities, animal communities, etc.
    - Farmers who have money to buy the machines could benefit at the expense of laborers.
    - Changes in Bracero policy such as better conditions and pay for laborers could affect farmers' bottom line.
- Is your research for everyone? Whom does it exclude?
    - Small farmers and Mexican laborers were excluded from the conversation as the technology would not favor them.
- How do you want to help and why?
    - Building a machine that could pick and sort tomatoes helps increase the country's food security and reduces dependence on foreign labor.
- How are you going to share your science?
    - Hanna and Lorenzen used Extension agents and demonstrations for farmers.
- How will people who are not directly influenced by this research be affected?
    - Eighty percent of small tomato farmers were forced out of business because they could not compete with bigger farmers. Customers' preferences were affected as the mechanical harvesters worked best with hard tomatoes compared to juicy tomatoes.
- Who holds knowledge?
    - Everyone holds a bit of the knowledge. Lack of formal or "recognized" education or expertise

does not mean lack of expertise. Years of hard work and experience in the fields bring a wealth of knowledge to technology and innovation discussions that balance a number of interests. Farmworkers and personnel with different responsibilities in the operation and overall food system possess different perspectives on how the innovation may help, hurt, or be neutral.

The Example of IoT4Ag

The vision at IoT4Ag is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment (Kagan et al., 2022). IoT4Ag unites faculty and students from the University of Pennsylvania, Purdue University, the University of California, Merced, and the University of Florida, plus evaluators at Arizona State University, with industry and government partners to transform agriculture. Researchers' disciplines include but are not limited to mechanical and electrical engineering, chemistry, plant pathology, and economics. The researchers work to create sensors, energy and communication systems, and response systems to help automate and support precision agriculture.

Especially in a center with people from different expertise fields and stages of their careers, engagement needs support. Engineers and scientists may engage with farmers differently because they play different roles in how technology and programs are created and adopted. Graduate students and new faculty who do not have prior experience engaging with farmers and other interested parties may have experience engaging with other communities, but may still need background on needs in their particular geographic areas or commodities.

In a 2022 annual project review, NSF provided feedback on IoT4Ag because the core values of IoT4Ag did not include a community component or a realistic way to achieve its goals, as it lacked farmer input.

The core values for the organization currently are:

- Product mission: Create transformational, high-value, integrated systems.
- Economic mission: Develop cheaper, more accurate precision agriculture with a clear value proposition for industry and well-suited commercialization.
- Social mission: Bring together academia, industry, and government with significant social impact by training and educating a future workforce.
- Sustainability mission: Address societal grand challenges of food, water, and food security.

The current engagement plan aims to develop more innovative, relevant technology by increasing interactions among scientists, engineers, farmers, and conservationists. Initial conversations have surfaced both potential benefits of technologies beyond benefits to the original large commodity growers the Center prioritized, as well as new ideas for technologies based on farmers' own ideas and needs.

In addition, our listening sessions with interest holders have helped refine our approaches to topics which are most relevant to farmers. For example, the Center organizes itself around both research thrusts, namely, types of technology, and Joint Operations, which are more focused on problem spaces such as water use, nitrogen use, and pest management. Discussions with farmers have helped us better position engagement around specific research thrusts such as communication and internet technologies for some groups and water management for others, given particular interests and other policies and constraints guiding their production. Discussions have also revealed uses for technologies for farmers beyond the Center's priority focus on commodity crops, such as wireless charging technology for sensors in small-scale operations that would allow automated notifications of pests such as gophers. Discussions with farmers from AgrAbility revealed greater needs for technology that accommodates their disabilities in current operations before they can consider adoption of new technology.

Conclusion

Building technologies or other innovations collaboratively based on end user needs remains a vital way to encourage widespread adoption of technologies to meet a variety of human and environmental needs. Successfully designing innovations together requires both identifying the research team's goals, values, and biases, and those of a variety of interest holders, so that the entire group can build and maintain trust throughout the research and development process. As with any group you wish to engage, farmers and associated farm personnel are not a monolithic group. Understanding their various backgrounds and perspectives, including some of the history of broader region-, nation-, and commodity-specific pressures, will go a long way to meeting them where they are and respecting their fields of expertise.

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Appendix 1: Suggested Questions

General Demographics Related to Precision Agriculture

- How old are you?
- What crop(s) do you grow?
- How many acres are you producing on?
- How long have you been farming the crop(s)?
- Do you have reliable internet on your farm?

Baseline Questions Related to Precision Agriculture

- What is your biggest roadblock when (insert topic)?
  - Are all the farmers or interviewees having the same issues?
- On a scale of 1 to 10, how likely are you to implement (insert research solution)?
  - How much do you trust scientists and engineers?
- How can we improve the likelihood of your implementation of (insert research solution)?
  - Where do you go for information, especially on new technology?
- Would you be open to participating in our research?

Appendix 2: References on Barriers to Precision Agriculture Adoption

- Socioeconomic factors
  - Cost of technology
    - Adrian et al., 2005; Batte et al., 2003; Beluhova-Uzunova & Dunchev, 2019; Blasch et al., 2022; Castle et al., 2021; Fountas et al., 2005; Franco et al., 2018; Jaafar & Kharroubi, 2021; Kernecker et al., 2020; Knierim et al., 2018; Kutter et al., 2011; Lambert et al., 2004; Pedersen et al., 2004; Reichardt & Jürgens, 2009; Say et al., 2018; Tamirat et al., 2018; Wiebold et al., 1998; Zhang et al., 2002
  - Farmers' educational level
    - Blasch et al., 2022; Daberkow & McBride, 1998; D'Antoni et al., 2012; Pierpaoli et al., 2013; Reichardt & Jürgens, 2009; Tey & Brindal, 2012; Torrez et al., 2016
  - Age
    - Ascough et al., 2002; Barnes et al., 2019; Blasch et al., 2022; Daberkow & McBride, 1998; Franco et al., 2018; Jaafar & Kharroubi, 2021; Knierim et al., 2018; Kutter et al., 2011; Lawson et al., 2011; Tey & Brindal, 2012; Tiffin & Balcombe, 2011; Walton et al., 2010; Wiebold et al., 1998

- Lack of self-confidence
  - Franco et al., 2018; Lioutas & Charatsari, 2020
- Learning curve
  - Adrian et al., 2005; Blasch et al., 2022; Eastwood et al., 2019; Fountas et al., 2005; Jaafar & Kharroubi, 2021; Kernecker et al., 2020; Reichardt & Jürgens, 2009; Say et al., 2018; Wiebold et al., 1998; Zhang et al., 2002

- Cultural and perception factors
  - Technology that is not built to meet the values and goals of the farmers
    - Caron et al., 2014; Ferrández-Pastor et al., 2018; Hüttel et al., 2022; Ingram, 2008; Kernecker et al., 2020; Lamba et al., 2009; Lioutas & Charatsari, 2020; Rogers, 2003; Sinclair, 2001; Tsouvalis et al., 2000
  - Perceived benefits vs. profitability
    - Aubert et al., 2012; Barnes et al., 2019; Kernecker et al., 2020; Knierim et al., 2018; Kutter et al., 2011; Montalvo, 2008; Pierpaoli et al., 2013; Reichardt & Jürgens, 2009; Robertson et al., 2007; Swinton & Lowenberg-DeBoer, 1998; Tey & Brindal, 2012; Wagner, 2009; Wiebold et al., 1998; Zhang et al., 2002
  - Lack of validation of environmental impacts or lack of belief that technology will improve stewardship
    - Barnes et al., 2019; Eastwood et al., 2019; Hanspach et al., 2013; Knierim et al., 2018; Lindblom et al., 2017; Lioutas & Charatsari, 2020; McDonagh, 2015; Preissel et al., 2017; Wiebold et al., 1998
- System factors
  - Lack of public knowledge advisors
    - Barnes et al., 2019; Busse et al., 2014; Daberkow & McBride, 1998; Eastwood et al., 2019; Franco et al., 2018; Knierim et al., 2018; Nettle et al., 2018; Prager et al., 2016; Reichardt & Jürgens, 2009; Robertson et al., 2007; Tey & Brindal, 2012
  - Lack of policy to increase computer literacy in rural areas
    - Busse et al., 2014; Eastwood et al., 2019; Fountas et al., 2005; Franco et al., 2018; Tey & Brindal, 2012; Wiebold et al., 1998
  - Lack of policy that provides monetary subsidies
    - Barnes et al., 2019; Blasch et al., 2022; Franco et al., 2018; Long et al., 2016; Onyango et al., 2021
  - Lack of trust
    - Adrian et al., 2005; Eidt et al., 2012; Jakku et al., 2019; Knierim et al., 2018; Kutter et al., 2011; Lioutas & Charatsari, 2020; Montalvo, 2008
  - Lack of networks between farmers
    - Edwards-Jones, 2006; Kutter et al., 2011; Oreszczyn et al., 2010
  - Lack of environmental policy pushing for PA
    - Knierim et al., 2018; Looney et al., 2022
- Information factors
  - Too much data
    - Eastwood et al., 2019; Pedersen et al., 2004; Reichardt & Jürgens, 2009; Van Meensel et al., 2012; Wiebold et al., 1998; Zhang et al., 2002
    - No ergonomic displays
    - Kernecker et al., 2020; Knierim et al., 2018; Onyango et al., 2021; Wiebold et al., 1998
    - Ownership of data
    - Kernecker et al., 2020; Kutter et al., 2011; Sørensen et al., 2003; Wiebold et al., 1998; Wolfert et al., 2017
    - No internet access
    - Adrian et al., 2005; Kernecker et al., 2020; Knierim et al., 2018; Krell et al., 2022; Say et al., 2018; Wiebold et al., 1998
- Agroecological factors
  - Soil quality
    - Kernecker et al., 2020; Wiebold et al., 1998
  - Farm size
    - Balogh et al., 2020; Blasch et al., 2022; Cullen et al., 2013; Faber & Hoppe, 2013; Ferrández-Pastor et al., 2018; Finger et al., 2019; Franco et al., 2018; Kernecker et al., 2020; Kutter et al., 2011; Lawson et al., 2011; Miller et al., 2017; Montalvo, 2008; Reichardt & Jürgens, 2009; Schimmelpfennig, n.d.; Schimmelpfennig & Lowenberg-DeBoer, 2021
  - Land ownership
    - Paustian & Theuvsen, 2017; Putler & Zilberman, 1988; Wiebold et al., 1998
- Application factors
  - Lack of validation of the technology in natural farm settings
    - Aubert et al., 2012; Lindblom et al., 2017; Lowenberg-DeBoer & Erickson,

2019; Melville, 2010; Reichardt & Jürgens, 2009; Rogers, 2003; Rossi et al., 2014; Wiebold et al., 1998; Zhang et al., 2002

- Inflexible systems
    - Fountas et al., 2005; Franco et al., 2018; Kernecker et al., 2020; Knierim et al., 2018; Kutter et al., 2011; Pedersen et al., 2004; Reichardt & Jürgens, 2009; Wiebold et al., 1998; Zhang et al., 2002
- Lack of economic assessments
    - Reichardt & Jürgens, 2009

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