Environmental Science and Policy 128 (2022) 154–164

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Participatory knowledge integration to promote safe pesticide use in Uganda

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ARTICLE INFO

Keywords:
Knowledge integration
Co-production
Design thinking
Uncertainty
Pesticide management
Uganda

ABSTRACT

Wicked problems exceed traditional sectoral and jurisdictional boundaries and involve multiple actors as stakeholders, victims, and culprits. Wicked problems inherently feature uncertainty and knowledge gaps. Science plays a crucial role in generating evidence for solving these problems and contributing to societal transformation. However, researchers may perceive and study problems detached from practitioners' perceptions of the world. We use the example of smallholder pesticide management in Uganda and the three types of knowledge approach, a framework borrowed from transdisciplinary research, to disentangle knowledge gaps. To identify these gaps, we integrated and co-produce knowledge in a two-day participatory workshop applying design thinking. Our results show, that a transition towards safe pesticide management depends on changes in the system, such as a revision and implementation of exiting regulation or professionalization of agro-dealers. Furthermore, this transition is only possible if interventions address target groups beyond the individual farmers (e.g. agro-dealers or district government officials). Compared to existing academic knowledge, co-produced knowledge provides a broader systemic perspective and yields more fine grained insights about potential new pathways. This investigation confirms, that practitioners' knowledge is more fine-grained and detailed, thus exemplifying how knowledge integration is essential to avoid a gap between what researchers investigate and what practitioners need.

1. Introduction

Amidst ever more complex environmental issues and their inherent interdependencies between stakeholders, jurisdictions, and sectors, society seeks to address so-called wicked problems.[2] Science has the fundamental task of investigating such wicked problems to reduce uncertainty through scientific investigation and provide evidence for new pathways for action (Lemos, 2015). While decision-makers often lack a detailed understanding of problems' characteristics and dynamics (Burger et al., 2015; Peters, 2017; Ingold et al., 2018), researchers may perceive and study problems differently from involved stakeholders, who need applicable knowledge as a basis for decision-making (Schäfer and Kröger, 2016; van Stam, 2019; Kleinschroth et al., 2021). Achieving a societal transformation towards sustainability therefore requires that research questions are aligned with practitioners' perceptions of real-word problems. Evading the "old and powerful myth that any and all science inherently meets society's goals" (Lemos et al., 2018, 722), this transformation is only possible if knowledge is co-produced between researchers and practitioners. We use the example of smallholder pesticide management in Uganda to highlight where knowledge gaps appear between what practitioners need and what researchers investigate, and we discuss how closing these gaps might facilitate a

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[2] We define the following terms: **Wicked problems** are difficult to disentangle, are continuously evolving and have no clear solution. They extend across media such as air, land, and water; across political jurisdictions and landscape boundaries; and across traditional policy arenas. Additionally, it is almost impossible to hold one single stakeholder accountable for the emergence of these challenges (Rittel and Webber, 1973); see also Batie (2008), Commission (2012) and Balint et al. (2011) for an applied definition of **wicked problems**). As **science**, we understand both natural science and social sciences, conceptualized as a quest for knowledge by researchers who investigate phenomena to generate academic knowledge. **Practitioners** are those who practice. We capture non-academic knowledge through their perspective. (For more information about the practitioners within our research, see the Methods section.)

https://doi.org/10.1016/j.envsci.2021.11.012
Received 8 March 2021; Received in revised form 14 October 2021; Accepted 12 November 2021

transformation towards sustainability.

Global pesticide use has been growing in recent decades (Zhang, 2018); it now requires 3.5 billion kg active ingredients per year and amounts to a global market worth 45 billion US dollars.[3] Most pesticides are used in agriculture to protect crops and yield from unwanted infestation. Balancing the benefits and costs of pesticide use poses a particular challenge for agricultural regions, which often are located in low-and middle-income countries (Schreinemachers and Tipraqsa, 2012). In these contexts, agricultural production is often dominated by subsistence smallholder farming, where awareness and formal education are often limited, making pesticide applications risky, with potentially harmful effects for farmers and the environment.

Problems related to pesticide management are characterized by a high level of uncertainty about causes, effects, and solutions and are thus considered wicked problems (Allen, 2013) (see also section 1 in the Supplementary Material (SM) online). In this context, decision-making is typically challenged by opposing interests and underlying conflicts, and researchers can ameliorate this situation by facilitating innovation and providing knowledge (Delgado et al., 2019). Transdisciplinary (TD) research aims at generating knowledge which is meaningful to practitioners (Klein, 2020) and which creates a comprehensive problem understanding. In TD research, knowledge is conceptualized as being of three types: systems, target, and transformation knowledge. These are gathered, exchanged, compared, and synthesized from various sources, including from academic and non-academic stakeholders while defining strategies to address real-world problems (Schneider and Buser, 2018; Adler et al., 2018; Sachs et al., 2019). This transdisicplinary process yields co-produced knowledge (Pohl, 2008; Klay et al., 2015; Howarth and Monasterolo, 2017)[4] which provides a holistic problem understanding across different scales and levels (Costanza, 2003). Here, we want to contribute to literature and consciously integrate and confront academic with co-produced knowledge (see (Binder et al., 2010; Le Bellec et al., 2012; Galvin et al., 2016) as examples of knowledge co-production related to smallholder pesticide management). This is why we pose the following first research question (RQ):

- RQ 1: What is the evidence for a gap between co-produced and academic knowledge about smallholder pesticide management?

The complexity of sustainability issues requires integrative approaches, which challenge conventional knowledge production and solutions (Maher et al., 2018). To co-produce systems, target and transformation knowledge, participatory approaches are used to identify practitioners' needs, disentangle their problems, and gather a comprehensive understanding of the problem context .[5] Design thinking (DT) is an approach that explicitly addresses characteristics of wicked problems such as multi-stakeholder perspectives, social complexity, and the difficulty of defining a straightforward solution (Buchanan, 1992; Dorst, 2010; Fischer, 2015). This participatory, bottom-up approach offers opportunities for the actors involved to assume ownership and commit themselves to further developing targeted interventions. In this paper, we use DT as an approach to integrate knowledge and thereby contribute to co-producing the three types as knowledge as we "start with the issue or problem and, through the processes of problem solving, bring to bear the knowledge [.] that contributes to a solution or resolution" (Meeth, 1978, 173). The DT approach has been applied in the Global South to resolve design issues in architecture (Katoppo and Sudradjat, 2015), urban planning (Delz et al., 2017; Raynor et al., 2017), and sustainable business models (Geissdoerfer et al., 2016). Regardless of a growing literature on pesticide management in the Global South and the acknowledgment of a gap between academic and non-academic knowledge in this context (see for example (Liebig et al., 2016)), there is little research about DT as a participatory approach to facilitate a better understanding of the problem context related to smallholder pesticide management. Consequently, we address our second RQ:

- RQ 2: How does design thinking support knowledge integration about smallholder pesticide management?

This paper makes a two-fold contribution: first, we match the consecutive steps of DT to the three types of knowledge (Adler et al., 2018). We conducted a participatory workshop at the end of a research project to integrate and co-produce knowledge with various DT tools. We then used the results of the workshop to compare our own academic knowledge with the co-produced knowledge to identify knowledge gaps. We conclude with an outline on how this participatory approach contributes to a sustainability transformation through problem definition and identification of actionable solutions. Second, we have selected pesticide management in the Global South as our problem context. Small-holder pesticide management is a rather novel policy issue and the need for risk reduction is often overshadowed by political narratives promoting intensified agriculture to ensure economic growth and food security (Stein and Luna, 2021). Grasping problem perception and co-producing knowledge in this context can help identifying new pathways for safe pesticide use that target different components of the system under investigation.

In this research, we expect to find gaps between the three types of co-produced and academic knowledge. *Systems knowledge* captures how stakeholders perceive the problem. We therefore expect different prioritizations of systems' boundaries, components, and processes. *Target knowledge* captures actors' values and beliefs about a more desirable future. Here, we expect practitioners to prioritize targets that are addressed only to a limited degree by academic work. Furthermore, we expect a target knowledge gap to offer a potential explanation for ineffective interventions due to a focus on artefact problems deduced from prior research as opposed to the real needs of non-academic stakeholders. *Transformation knowledge* captures how to move from the problem situation to a more desirable future. We expect co-produced knowledge to be more fine-grained and adapted to specific contexts, and thus to provide insights into obstacles hindering the successful implementation of research-recommended interventions.

The remainder of this paper is structured as follows: In the Methods section, we introduce our case, the participatory workshop, as a method for knowledge integration, DT as a systematic approach to facilitating this process, and our criteria for evaluating the workshop. In the Results section, we elaborate on the co-produced systems, target and transformation knowledge, and whether the workshop can be considered a success. We then confront the co-produced knowledge with existing literature to discuss the gaps within the three types of knowledge. We close this paper with a brief conclusion, including recommendations for closing the gaps and an outlook for future research.

2. Methods

2.1. Case

Our case is located in Uganda, which offers a typical example of smallholder pesticide management turning into a wicked problem: Agriculture is considered to be the backbone of the country's economy

[3] see also https://www.themarketreports.com/report/global-pesticide-and-agrochemical-market-to-2020-market-size-growth-and-forecasts-in-over-60-countries Global pesticide and agrochemical market to 2020: Market size growth and forecasts in over 60 countries by Report Buyer, last accessed November 24, 2021

[4] Co-production of knowledge refers to "a collaborative process of knowledge production that involves multiple disciplines and stakeholders of other sectors of society" (Pohl, 2008, 47).

[5] For an overview of different participatory approaches, see https://naturwissenschaften.ch/co-producing-knowledge-explained (last access: June 18, 2021), and (Lux et al., 2018; Jacobi et al., 2020)

(Rwakakamba, 2009), accounting for around 40% of the GDP and employing 80% of its labor force (Karungi et al., 2011). Many of the farmers operate as smallholders, cultivating their own land, providing food for their own families, and selling their surplus on local markets. A growing number of farmers are cultivating products for commercial purposes. Pesticides are applied to protect crops and livestock and for vector control. On-farm pesticide management is a growing issue: Kateregga (2012) as well as Staudacher et al. (2020) identify various challenges in pesticide management in Uganda, such as a lack of information on agro-chemicals; violation of the transportation and storage rules; lack of proper storage facilities; inadequate use, handling, and application of products; and inappropriate disposal of empty containers (Kateregga, 2012; Staudacher et al., 2020). The various steps along the pesticide value chain (see Fig. 1) are governed by a regulatory framework including acts, regulations, and policies (e.g., the Agricultural Chemicals Control Act of 2006). Despite these regulations, previous studies have underlined a lack of compliance, difficult enforcement, and illegal practices (Oesterlund et al., 2014; Okonya and Kroschel, 2015).

In Uganda, responsibilities for pesticide management are decentralized, making district government the protagonists of enforcement and even of formulating by-laws (Bazaara, 2003). Alongside governmental agencies and ministries, donor organizations and non-governmental organizations (NGOs) play a crucial role in sensitizing and capacitating smallholder farmers about pesticide management (Delgado et al., 2019). These stakeholders from the private sector shape matters related to pesticide management in Uganda, because central and district governments lack the financial and human resources to meet the demand for information provision (Isgren, 2018).

2.2. Workshop design and participants

Our goal was to present our research findings and validate their relevance with the local stakeholders (see (Winkler et al., 2019) and section 2 in the SM online for more information about the PESTROP project). We consciously chose to conduct the workshop at this stage of the research process rather than the ideal-typical TD setting, in which knowledge exchange is facilitated at the beginning of and/or throughout the research process (Hoffmann et al., 2019). We took the dissemination of new academic knowledge (output from PESTROP project) as the point of entry for the workshop and used the workshop to compare and validate this knowledge with non-academic knowledge. To disseminate the results from this research and integrate academic and non-academic knowledge, we invited a diverse group of 33 stakeholders from various levels and sectors (see Table 1 for more detail) for a two-day participatory workshop. Our previous fieldwork in the case study area had acquainted us with the stakeholders influencing or affected by pesticide management. It was our goal to include stakeholders who are crucial to the various steps along the pesticide value chain in Uganda and Waksio District. With support from our local collaborators, we were able to find suitable participants to cover all nine pesticide value chain steps (see Fig. 1). Stakeholders originated from diverse decision levels and sectors, which represents the complexity of the issue covered in the workshop. We also selected stakeholders that represented a broad age spectrum (between 25 and 65 years), among whom gender was distributed as equally as possible, and who covered various hierarchical levels (e.g. national government representatives and local smallholder farmers). To ensure privacy, we abstain from providing further detail.

Workshop facilitation and organization was provided by the first and third authors of this manuscript. They did not have any previous experience in conducting DT workshops. The second author was an active participant in the workshop and had never participated in a similar format (for a critical self-reflection of this dual role as authors of this manuscript and facilitators and participant of the workshop, see section 3 in the SM online).

2.3. Structure of the workshop to integrate the three types of knowledge

We follow the general idea of DT as an approach to facilitate participatory knowledge integration, using a variety of tools (see Table 2) .[6] DT can best be conceptualized as an iterative, human-centered process or approach to solving problems through creativity. Various schools and models propose different steps and phases of flare and focus [7] to facilitate DT (see Council (2019), IDEO (2015)). The workshop was conducted in five separate, consecutive steps: understand, observe, define, ideate, and prototype. Understand, observe, and ideate are steps that allow participants to fully explore other stakeholders' values, worldviews, and perceptions of the problem and solution, which are key traits of wicked problems. The define and prototype[8] stages seek a synthesis of these diverse problem perceptions and pathways for intervention.

Integrating systems knowledge. In steps one and two of the workshop, understand and observe, participants disentangle the specific societal problem, pesticide management, by defining the boundaries, the components, and the relevant processes in the system. The outcomes of the first step are rich pictures (see Table 2). Participants illustrate the components of a complex situation, share their own perceptions and learning from exchange with others (Cristancho et al., 2015; Bell et al., 2019). In the second step, observe, participants in speed meetings discussed their open questions about the issue of pesticides with other participants. This step was followed by group-wise collection of the key insights of the day. To conclude the first flare part of the workshop, we asked participants to prioritize these key insights.

Integrating target knowledge. The third step, define, unveils the target knowledge, which captures values and beliefs about a more desirable future. Although the overall goal, safe pesticide management, had been predefined by the workshop facilitators, we used this step to better characterize the targets that may be critical for a transformation towards safe pesticide management. This step advances beyond simple problem definition and encompasses a design vision for solution ideation (Both and Baggereor, 2009). The groups developed clearly understandable and communicable problem statements with the following formula: *Who (stakeholder group)* needs *what* because of *what (insights)?* (see Table 2).

Integrating transformation knowledge. In the fourth step, ideation, we asked participants to search for new potential solutions to the problem statement previously identified and defined, thus capturing their transformation knowledge (see Table 2). Each participant started explaining a potential option for intervention silently in written form before passing it on to their group members to complement (Lewrick et al., 2018). After three iterations, all options were discussed within the group, and each group constructed three main ideas to solve the issue. After a plenary presentation of their three main ideas, each group received feedback from the other workshop participants, after which each group selected one of their three main ideas to be specified in more detail during the fifth, prototype, phase (see Table 2).

2.4. Workshop evaluation

Our second research question addresses the feasibility and benefits of using tools from DT to integrate knowledge. We collected feedback from the workshop participants at the end of the workshop with which to

[6] For an extensive overview of tools used in DT, see Plattner (2010), Lewrick et al. (2018).

[7] The flare phase corresponds to broad ways of thinking, where participants generate as many insights and ideas as possible while keeping an open mind. The focus phase entails narrowing down ideas to generate selective problem statements (Woolery, 2019)

[8] DT usually includes a test stage, but this was not conducted in our case due to lack of time

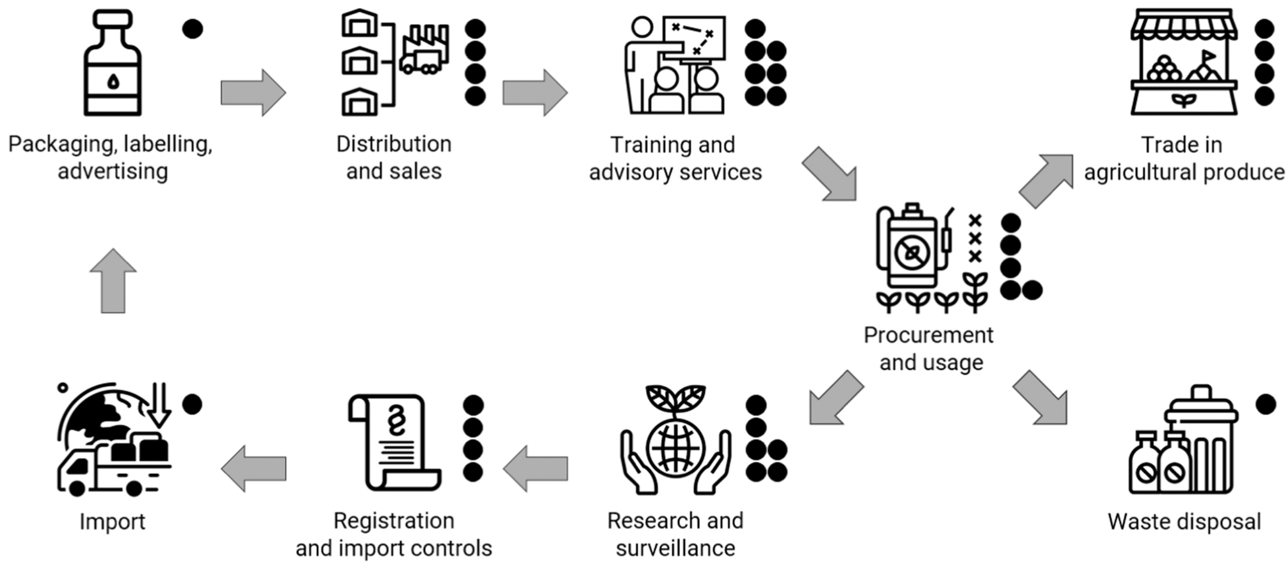

Fig. 1. The various steps along the pesticide value chain, own elaboration. This is an ideal-typical representation of a complex value chain; in this simplified chain, we illustrate only the consecutive steps, not interactions that happen across and between steps. The black dots indicate where we would place the 33 workshop participants.

Table 1
Participants of the design thinking workshop.

Actor type	Level	Group size
Representatives of the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)	National	4
Agricultural extension workers	Local	4
Environmental and agricultural officers from district government	Local	4
Farmers	Local	5
Representatives of agro-input business (synthetic and organic pest management)	Local/ national	6
Representatives of NGOs engaged in the promotion of safe pest management	Local/ national	6
Foreign scientists (excluding the three facilitators)	International	4
Total number of participants		*33*

Table 2
The structure of the workshop following the three types of knowledge and design thinking.

Type of knowledge	Step of DT	Tool
*Systems knowledge:*Analytical or descriptive knowledge about specific societal problems	Understand	Rich picture: grasp mental models of stakeholders (Checkland, 2000; Cristancho et al., 2015)
	Observe	Speed-meeting: exchange problem perceptions (Long, 2009)
*Target knowledge:*Normative knowledge about values and norms related to a more desirable future	Define	“Who needs what because of what?” and “5 why’s”: come up with a problem statement (Plattner, 2010; Lewrick et al., 2018)
Transformation knowledge: Practical knowledge about how to transform an existing problematic situation into a better one	Ideate	Brainwriting: brainstorm about potential solutions (Heslin, 2009)
	Prototype	Storyboard: develop one solution in detail (Andriole et al., 1989)

conduct a critical evaluation. We asked each of them for one positive and one negative statement about the workshop. All participants named one or more positive aspects (36 positive remarks), and most participants named one or more negative aspect (24 negative remarks). For this publication, we applied the evaluation criteria from Tobias et al. (2019) (see Table 3), which are typically used to evaluate TD research. We therefore translated and interpreted the participants’ feedback to match the evaluation criteria (see Table 1 in the SM online for the original feedback).

3. Results

The following subchapters present the knowledge co-produced in the workshop following the DT approach and tools.

Table 3
Evaluation of the DT workshop (excerpt and adopted from Tobias et al. (2019)).

Objectives of the workshop	Criteria specifying the objectives
1. Achieve a feeling of joint problem ownership among the project participants	All group members’ knowledge is considered important.
2. Facilitate the interaction between stakeholders with different problem perceptions	New perspectives/ideas are developed due to the confrontation with other group members’ problem perceptions. Joint products are developed (definition of new pathways for safer pesticide management).
3. Enable the workshop participants to link abstract (academic) with case-specific (non-academic) knowledge	Experiences with other knowledge types (both academic and non-academic) are integrated. New interfaces between the different types of knowledge (academic and non-academic) are discovered.
4. Encourage the workshop participants to incorporate the shared knowledge in their real-world situations	The participants are motivated to disseminate the jointly developed knowledge in their real worlds. Ideas are generated for new approaches and activities in the participants’ own real worlds.Ideas are developed for new collaborations between groups that have not yet worked together.

3.1. Systems knowledge

Participants' systems knowledge was integrated in the first two workshop steps: the participants illustrated their perspectives on how they experience and interact with pesticides in their daily lives, first individually (Fig. 2) and then in a group discussion among peers of the same stakeholder type (Fig. 2, see also Table 1). In the subsequent step, participants paired up and compared their worldviews with their partners', noting the most important insights. These key insights were then gathered group-wise, followed by a prioritization across all key insights. Fig. 3 displays the summarized results: *Agro-input dealers' services* and *gaps in policies and regulations* received the most votes overall, followed by eight other insights.

Based on these first insights, the main stakeholders of interest within the system are farmers, agro-input dealers, government agencies, and society as a whole. Processes concern on-farm management (e.g. pesticide exposure, PPE use), distribution of pesticides (e.g., agro-input dealers and illegal pesticides), and regulatory processes (e.g. governmental policy formulation and sensitization). The boundaries of the system largely correspond to the pesticide value chain (see Fig. 1), but components such as training, advisory services, research, and surveillance are of lesser importance.

3.2. Target knowledge

Once the participants had selected their key insights (see Fig. 3), they formed seven groups according to their interest in these insights. Each group drafted a problem statement with the following formula: *Who (stakeholder group)* needs *what* because of *what (insights)?*. The problem statements capture the importance of goals, or what they regard as relevant target knowledge in the system, to reach the overall goal of safe pesticide management (see Table 4). Substantial interest in the topic of the future of organic farming led us to split the topic between two groups (Table 4). Participants perceived farmers, extension officers, agro-input dealers, and government agencies to be the main stakeholders mentioned in the targets for safer pesticide management. Although these stakeholders appear along the steps of the pesticide value chain (see Fig. 1), industry, research agencies and large-scale pesticide distributors were not regarded as key stakeholders within the targets. Targets in the quest for safe pesticide management are related mainly to enhanced skills, information, and training.

3.3. Transformation knowledge

In the ideate and prototype phases of the workshop, participants were encouraged to brainstorm potential new ways forward. The proposed pathways for action (Table 4, 4th column) show which aspects are crucial to consider prior to designing interventions and public policies. At a *macro* level, one important aspect is the decentralization of training and services provided by central government agencies (Group 1). Extension officers and agro-input dealers often lack the financial resources to attend training in a larger town (Group 5). Training activities might thus fail, and these actors lack proper training, which is essential because they are the main information providers to farmers. Incentives such as certificates of attendance (Group 7) and restrictions or penalties (Group 1) are also considered key to enhancing the professionalization of these actors. At a *meso* level, coordination is a key aspect for successful interventions and public policies (Group 5), especially among central and decentralized agencies. To achieve coordination, workshop participants mentioned consultations as a potential platform for fostering collaboration and exchange and linking these agencies via research projects (Group 2). Coordination among initiatives, such as interventions by NGOs and training by extension officers, is also crucial to avoid overlaps and inefficiency. At a *micro* level, financial and human resources are key to compliance and success. Farmers, extension staff, and agro-input dealers need financial support to afford equipment, transportation, and gasoline (Groups 6 and 7). A lack of financial and human resources impedes the system from transforming towards safe pesticide use (see Table 4 for a summary of the co-produced knowledge).

In the paper-based prototype step of the workshop, in which participants elaborated on their preferred intervention, these macro-, meso-, and micro-level components became even more evident. We show one illustrative example of a prototype: the PPE group, which elaborated the bulk purchase of PPE (see Fig. 4). The group suggested that farmer associations buy durable, comfortable, high-quality personal protective equipment in bulk. The money saved will be forwarded, benefiting agro-input dealers and farmers.

3.4. Using tools from DT to integrate knowledge

We successfully integrated academic and non-academic systems, target and transformation knowledge in the workshop. To evaluate this success, we converted the feedback given by the participants (see Table 1 in the SM online) into evaluation criteria, as described in the Methods section. First, our workshop process achieved joint problem ownership by all participants. Mixing individual, group-wise, and plenary sessions and integrating non-academic and academic participants in each group enabled everybody's voice to be heard, and participants felt that they were part of both problem and solution. Additionally, rules were defined at the beginning of the workshop that guided the entire process and enhanced ownership of it. Participants mentioned in the feedback session that they felt it was a truly participatory process and that the academic knowledge was integrated well in the workshop. Second, the workshop enabled stakeholders to interact, but only to a limited extent. The workshop delivered some practical ideas for solutions (see Fig. 4). However, time constraints prevented the development of a joint product. Participants thus criticized the workshop for being too short and not including all stakeholders evenly. Third, workshop participants linked academic and non-academic knowledge. Non-academic participants encountered research findings, which was generally

Fig. 2. Individual (left) and group (right) rich picture.

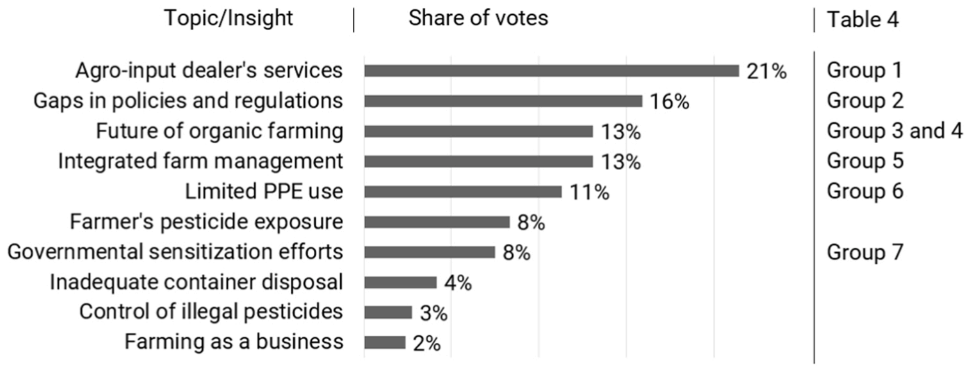

Fig. 3. Prioritization of insights: Number at outer end indicates share of total votes per insight/topic. PPE: Personal protective equipment.

considered a positive output. Researchers encountered non-academic knowledge which led to the formulation of new research questions and follow-up research projects (see Discussion). Fourth, even though participants were encouraged to incorporate and apply the knowledge they had gained in future projects by gathering commitments from them in the last part of the workshop, we do not know whether these commitments yielded action. Lastly, we provided space through the extensive breaks, allowing participants to make new acquaintances and develop new opportunities for collaboration.

The workshop was implemented successfully thanks to a range of organizational and informal aspects. First, the same moderators guided the whole process and followed a predefined timeline. Second, the venue of the workshop included a large hall with space for group tables and a plenary with a sound system, beamer setup, and complete catering. Participants felt very comfortable in this space and appreciated the venue. Third, we kept participants active in extensive opening and closing activities on each day. We provided coffee breaks and lunch and made sure to take a group photo and include ice breakers, energizers, and warm-ups to keep the atmosphere friendly. The entertainment component of this workshop was also highly appreciated, and participants underlined that “it was never boring”.

4. Discussion

4.1. Discussing the knowledge gap…

In this paper, we integrated academic and non-academic knowledge to enhance the academic problem understanding of pesticide management. The following chapter discusses the extent to which the co-produced knowledge is different from our own academic knowledge and whether we find knowledge gaps within each of the three types of knowledge. We also discuss the extent to which the DT approach lends itself to integrating diverse types of knowledge and to closing potential gaps.

4.1.1. … in systems knowledge

To our best knowledge, research on pesticide management in contexts related to the Global South has focused on on-farm management among smallholder farmers. However, workshop outcomes indicated that farmers are not exclusively responsible but fall victim to the system actors surrounding them: the agro-input dealers as the most immediate source of information on pesticide management and government agencies as the regulators of pesticide management practices. Agro-input dealers’ practices and knowledge have attracted little attention so far (for an exception, see Lekei et al. (2014)). Moreover, pesticide policies’ formulation and enforcement have been investigated only to a limited extent (Karlsson, 2004; Van Hoi et al., 2013; Mengistie et al., 2017). Such gaps in research could be closed by integrating insights from participatory approaches: in our case, the participation of practitioners from diverse backgrounds (farmers, district government officials, and pesticide retailers) enabled us to identify more detailed systems knowledge, confirming our expectations about systems knowledge: there are differences in the academic and non-academic prioritization of systems’ boundaries, components, and processes.

4.1.2. … in target knowledge

Safe pesticide management is not a straightforward goal, and the participants of the workshop selected seven targets that ought to be reached to ensure safe pesticide management in Waksio District and Uganda (shown in Table 4). The first target identified was professionalized agro-input dealers (Group 1). Often, these actors are the main source of information for the farmers and primarily contribute to how pesticides are applied on the field. Little research has examined agro-input dealers and how they receive and provide information. However, some studies recognize agro-input dealers and retailers as crucial actors of the system and see their key role as information providers (Wang et al., 2015; Jallow et al., 2017a, 2017b). The second target was revised public health and environmental policies (Group 2). This target concerning research and pesticide policies related to environmental and health protection is the subject of scientific investigation (Mol, 2009; Mengistie, 2016; Loha et al., 2018). Most of these studies come to similar conclusions: policy revisions are necessary to protect humans and the environment from pesticide risks. However, we could not find studies characterizing this revised legislation and how politically feasible these options are. Targets three, five, and seven concern informed farmers who need more information related to organic and conventional farming to improve pesticide management decisions. As mentioned before, research on individual farmers is dense, and many studies have investigated their knowledge, attitudes, and practices in pesticide management. The effects of better information and training on farmers’ willingness to adopt organic farming and more sustainable farming practices have also been investigated (Aidoo and Fromm, 2015; Ma et al., 2017). Group 4 considered technically skilled extension officers to be a crucial target for safe pesticide management. Research on extension officers and agents themselves is rare, but they are considered key in farmers’ pesticide management practices and clearly play an important role in resolving farmers’ unsafe pesticide management (Hashemi et al., 2012; Timprasert et al., 2014; Abadi, 2018). Lastly, affordable PPE is another key target for safe pesticide management. Making PPE more affordable for farmers has been discussed in research, which has even proposed several ways of reaching this goal (Feola et al., 2012; Henry and Feola, 2013). We find that key actors in the system and their needs are addressed to only a limited extent by research, such as questions related to agro-input dealers, government agencies, and consumers. Their needs have to be considered by research to eventually design interventions that actually improve situations. By taking non-academics and their target knowledge into account, researchers can learn to shift their focus and provide the demanded evidence.

Table 4
Summary of the co-produced knowledge. *Original: indicating unchanged phrasing from the workshop. Abbreviations: CSO, community service organization, IPM, integrated pest management, MAAIF, Ministry of Agriculture, Animal Industries and Fisheries, MoH, Ministry of Health, MoWE, Ministry of Water and Environment, NGO, non-governmental organization, PPE, personal protective equipment, PR, Policy and Regulation.

System knowledge (Group formation, original*)	Problem statement (Original*)	Target knowledge (Authors' interpretation)	Transformation knowledge (Original*, selected intervention in italics)
Group 1 Agro-Input Dealers: Are they offering the best service to farmers?	Agro-input dealers need more professionalization because they need to give accurate subscription and instructions along with safe use and handling of chemicals to the farmer	Professionalized agro-input dealers.	*Customized, decentralized training at low cost.* Certification label of for good practices. Restrictions and penalties for noncompliance.
Group 2 Policy and Regulation: Gaps in PR and PR implementation challenges	The government of Uganda needs to revise the existing public health and environmental policies because they need to safeguard consumers from indirect pesticide exposure in food and water	Revised existing public health and environmental policies.	*Research: there is need to undertake research by both public and private players (Research institutions, CSO), to generate facts on consumer exposure to pesticides and existing policy groups. .* Bench-marking: relevant policymakers (MAAIF, MoH, MoWE, Parliamentarians on selected committees) need to undertake visits to countries with good consumer protection policies to learn best practices. Stakeholder consultations: The relevant policymakers (see above), need to spearhead the process of consulting different players at different levels to generate ideas on protecting consumers from pesticide exposure to inform policy formulation.
Group 3 Future of Organic Farming A: market access, policies, volumes of bio-pesticides	Farmers and the entire community need organic farming information and accessibility of organic inputs because they don't know the benefits of organic farming.	Farmers and entire community informed about benefits of organic farming.	*Sensitization through organized community meetings, development of flyers, radio talk shows on organic farming, Whatsapp groups to farmer communities, establish demonstration sites.* Avail organic farming inputs to the community through establishment of organic agro-input centers within the farming communities. Government develop policies that support promotion of organic farming; these can incorporated in work plans and budgets for extension workers.
Group 4 Future of Organic Farming B: market access, policies, volumes of bio-pesticides	Extension workers need technical explanations because they are the ones who can change farmers' attitudes towards organic farming.	Technically skilled extension officers	Refresher courses for extension workers.. *Farmer group formation and establishment of demo sites/ exchange visits.* Regular Monitoring + Evaluation.
Group 5 Integrated Farm Management: Prevention before curation	Extension workers need more support because they need to close the farmers' knowledge gap for adopting integrated pest management	Supported farmers by extension officers to adopt IPM.	*Recruitment and training of extension staff.* Recruitment and training of extension staff. More resources for doing extension work.
Group 6 PPE use and Pesticide knowledge: Lack of best practice	Farmers need PPE to be less expensive because they cannot afford it.	Affordable PPE.	*Bulk purchase of PPE: Farmers form association/groups for bulk purchase of PPE at discounted amount and reduced transport cost.* Tax reduction: Government to reduce tax on PPE and compensate by increasing a relative percentage of tax on pesticides. Also should create policies that encourage local production of PPE, e.g. low interest rate loan for local manufacturers. Increasing farmers income: through encouraging formation of savings groups/ cooperatives/ farmer union/ associations for cheap and quick access to loan for

(continued on next page)

Table 4 (*continued*)

System knowledge (Group formation, original*)	Problem statement (Original*)	Target knowledge (Authors' interpretation)	Transformation knowledge (Original*, selected intervention in italics)
			the purchase of PPE.
Group 7 Sensitization: Missing on all levels	Farmers need more information on pesticide use from the extension workers, NGOs and other organizations because some agro-input dealers also lack information about pesticide use	Farmers informed by extension workers, NGOs and other organizations about pesticide use.	Government trains extension workers and agro-input dealers and awards them certificates. Employ agents which routinely visit the farmers and report back to the extension workers. Drama group with live music about pesticide use.

4.1.3. ... in transformation knowledge

We acknowledge that some pathways for action proposed at the workshop have been covered previously, such as sensitization programs in communities to provide information about the disadvantages of pesticide use (Hashemi et al., 2012; Jors et al., 2014), the need to establish farmers' cooperatives (Zhu et al., 2014), and the importance of monitoring and surveillance along the pesticide value chain (Houbraken et al., 2016; Vaidya et al., 2017). Nevertheless, the workshop provided essential, context-specific details to enhance interventions and even policy effectiveness at the macro, meso, and micro levels and the feasibility and enforcement of interventions and public policies. Coordination among agencies and the provision of financial and human resources are key for a transformation towards safe pesticide management.

4.2. Significance of this research within the wider research scholarship

This research underlines the significance of participatory approaches to integrating and, as a result, co-producing knowledge. In general, the participation of users and target groups of proposed interventions allows us to grasp the full complexity of wicked problems, and to align diverse problem perceptions and to formulate new pathways in accordance with users and target groups (Sanders and Stappers, 2008; Simonsen and Robertson, 2012; Ssozi-Mugarura et al., 2017). Additionally, participatory approaches build bridges and enhance social and cultural understanding between researchers and users and, as in our case, local communities Sabiescu et al. (2014). In general, our results show that it is crucial to continue to provide venues with room for exchange and collaboration to foster a broader understanding within and across stakeholder groups, which is in line with research on participatory design and participatory action (Susman and Evered, 1978; Bjögvinsson et al., 2012; Luck, 2018). More specifically, our results show that participatory approaches are beneficial to enhancing mutual understanding for problem contexts between researchers and the researched, and that such an approach is also desirable for linking decision-makers with the governed. Within the workshop, the group focusing on policy and regulation considered stakeholder consultations (see Group 2 in Table 4) as a way of supporting the revision of existing public health and environmental policies in Uganda. This solution has a strong participatory component to it, and policy design research has long acknowledged multi-actor processes and the need for more contextual approaches to tackling wicked problems (Ostrom, 1996; Daviter, 2019; Ansell and Torfing, 2021). In Uganda, where public and private stakeholders shape decision-making about pesticide management, collaborative governance arrangements could be enhanced through participatory processes, which provide the chance for exchange and consultation.

4.3. Making a participatory process work

The following paragraph discusses the various aspects contributing to a successful implementation of the workshop as well as cross-fertilization with follow-ups.

An exchange between academic and non-academic stakeholders is desirable at the very beginning of a project, for instance to formulate research questions and to test feasibility, or throughout the project to enable feedback and enhance mutual learning (Hoffmann et al., 2019). We conducted the workshop at the very end of a research project, in the dissemination phase, with the main objective to integrate and validate knowledge, rather than collecting and gathering new data. We conclude that this timing is also beneficial in various ways: First, the complex thematic and societal context in which we operated requires case knowledge, familiarity with the needs of stakeholders, and an established network to conduct and implement a workshop. Thanks to our exceptional long-standing research collaboration with local partners, we had access to a diverse pool of participants and had already been in touch with most of them before the workshop. Second, conducting the

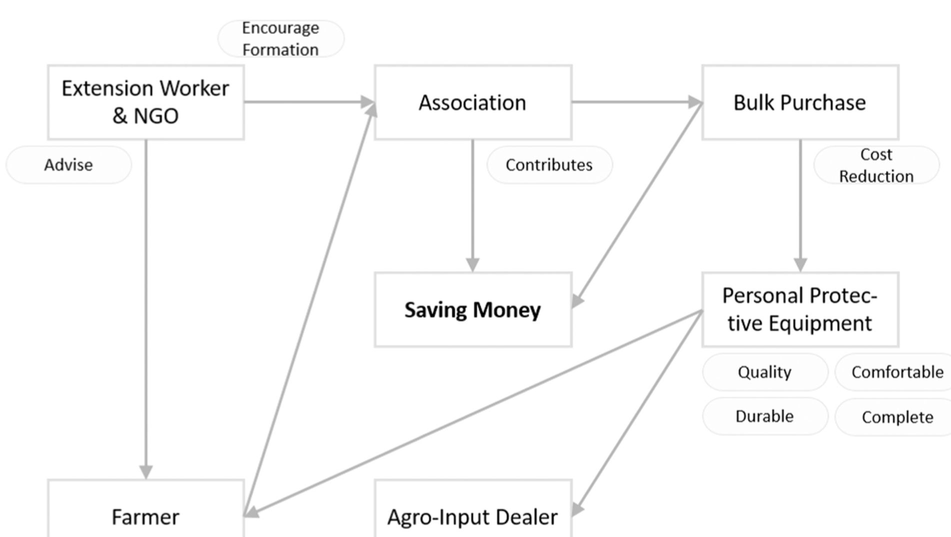

Fig. 4. Prototype of the PPE group to purchase PPE in bulk. The original drawing lacked contrast, so we here display a digital rendering of the drawing.

workshop at the end of the research project, enabled us to reflect on results with the stakeholders involved in the issue under investigation. The workshop enabled us to validate our findings and we were able to identify the gaps between academic and non-academic knowledge. A major finding of the workshop was the need to investigate agro-input dealers, who play a crucial role both as pesticide distributors and as information sources for farmers. This insight was used to design and conduct a follow-up project investigating the knowledge, attitudes, and practices of 402 agro-input dealers in Uganda (Staudacher et al., 2021). Other key insights, such as the need to revise legislation, has led to another research project investigating how stakeholders from different levels and sectors collaborate to regulate pesticide management.

4.4. Strengths and limitations of the DT approach

Wicked problems in the Global South are often investigated by researchers from the Global North. In this research context, mutual familiarization is necessary to overcome socio-economic and cultural differences between practitioners and researchers (Hurni and Wiesmann, 2014). DT facilitates familiarization in a participatory processes and thus lends itself well to discussing wicked problems and actionable interventions. First, it enables participants to follow a clear structure with alternating elements of flare and focus. The DT sequence of steps forces a systematic approach on the participants, which helps to keep heterogeneous groups in line with the process, and it worked nicely in our case despite the participants' diverse backgrounds. Second, even though the overall structure is set, within the different steps, facilitators are free to try various tools (see tools used, Table 2). Third, the approach balances rigidity and flexibility, thus remaining adaptable to a range of settings and groups of participants.

Similar to other participatory approaches, its dependence on adequate participation of stakeholders is a major limitation of the DT approach. The application of flare and focus elements needs to be clearly guided to avoid participant distraction. Heterogeneity and group dynamics can also impede the DT process: hierarchies, societal norms, prejudice, and differing levels of mental ability and courage need to be addressed by the facilitators and resolved where possible, in our case through ice breakers and an informal setting including coffee breaks and use of first names. Even so, neither long-lasting learning nor a shift towards more responsible pesticide management are guaranteed by this process. A full cycle of knowledge exchange leading to the implementation of the interventions proposed in workshops depends on the willingness and ability of participants and local communities to act on the outputs of such workshops (Bovaird and Loeffler, 2012; Sufi et al., 2018). Nevertheless, the application of such knowledge exchanges as standard tools can support the formulation of research questions.

5. Conclusions

Our expectations of the knowledge gaps were confirmed in all three knowledge types. A major finding of this research was that not all research represents the practitioners' perceptions of the problem or their needs. Some links, such as between actors and targets only became evident in the workshop and through the successful integration of knowledge (e.g. extension officers need money for fuel to reach farmers and educate them about safe pesticide use). Research may fail to incorporate and reflect the reality of people living within a studied system. Whereas previous studies have investigated farmers' attitudes and risk perception, this workshop has shown that, to achieve a transformation towards safe pesticide use, research needs to broaden its scope away from farmers to other stakeholders such as agro-input dealers and decision-makers. Studying diverse stakeholders, from local farmers to international manufacturers, can provide research with a systemic understanding of the problem situation, thus leading to better-informed decisions. Closing the knowledge gaps requires strong bridges to be built between research and practice through participatory approaches, fostering exchanges, and enhancing understanding. However, doing so requires two essentials that seem difficult to find in research: first, establishing long-term relationships, which are not always compatible with funding schemes; and second, maintaining long-term relationships, which conflicts with the time researchers need for writing publications and applying for funding. Even more, conducting similar studies across national and cultural borders entails strong relationships between collaborators, these collaborations are challenged by short-term nature of project-based research and the long-term nature of academic output production (e.g., development of publication after project termination and peer review processes).

Closing the gap between non-academic and academic knowledge, and thus between practice and research, contributes in various ways to a sustainability transformation. For practice, closing the gap can foster ownership and acceptability of identified pathways forward. The more that various stakeholder groups participate in knowledge production, the more they feel that they are part of the solutions (Fischer, 2015). Closing the gap also allows research to escape the pitfalls of disciplinary silos and oversimplification of complex issues (Francis et al., 2008) and instead use innovative, integrative approaches to understand complex real-world problems (Söderbaum, 2006). For policy, closing the gap is fundamental, as decision-makers need evidence to design targeted public policies, select policy instruments for behavioral change, and implement these to reach desirable societal outcomes. By including stakeholders' perspectives prior to decision-making, issues related to compliance as well as differences between decision-makers and target groups can be addressed and solved upfront (Turnpenny et al., 2009; Podestá et al., 2013; Daviter, 2019). Participatory approaches are therefore valuable to policy analysts to "focus carefully and reflexively on the nature of the policy problems, their evolution, the experience and knowledge of relevant stakeholders and the prospects of effective action in different situations" (Head, 2019, 192).

Lastly, we briefly address potential avenues of research. First, this single case study provided contextual insights related to smallholder pesticide management; we thus refrain from generalizing the results. However, participatory approaches are necessary to value non-academic knowledge and enhance target groups' acceptance of proposed interventions. To foster safe pesticide management it is crucial to further integrate and co-produce knowledge, also related to other wicked problems in similar regional contexts (e.g., sub-Saharan Africa) to test the applicability of our results. Future research could benefit from drawing conclusions from comparative case studies and larger populations. Second, the process of participatory workshops could be reported more systematically to allow for quantitative comparisons between academic and non-academic knowledge, making the gaps between them measurable. Third, future research should investigate the effect of these workshop formats on participants. More precisely, the suggestion is for a long-term evaluation of the degree to which researchers include non-academic knowledge in their projects and to which practitioners further develop interventions as proposed in participatory processes.

Author's statement

Ruth Wiedemann co-designed and co-implemented the workshop, co-wrote the first draft of the manuscript and took the lead in writing the final manuscript with inputs of all authors. **Christian Stamm** contributed to the interpretation of the results and supervised the entire process of writing. **Philipp Staudacher** provided the idea to conduct a design thinking workshop, co-designed and co-implemented the workshop, and co-wrote the first draft of the manuscript. All authors provided critical feedback and helped shape the research, and manuscript.

Funding

Data gathering and the implementation of the workshop was funded by the Swiss Network for International Studies (SNIS, Switzerland) and the Eawag Discretionary Fund (Switzerland).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank all workshop participants for their time and patience, and particularly Dr. Jonathan Lilje for his support in organizing and implementing the workshop. The authors would also like to acknowledge the support of Aggrey Atuhaire and Peter Ssekkadde from the Uganda National Association for Community and Occupational Health (UNACOH) in planning and implementing the workshop. Finally, the authors are grateful to Prof. Dr. Karin Ingold, Dr. Sabine Hoffmann and the three anonymous reviewers for their advice and comments on earlier versions of this manuscript.

The icons used in Fig. 1 are obtained under creative commons license from thenounproject.com ("regulation" by Martin Markstein, “importers" by priyanka, “chemical" by DinosoftLab, “distribution" by monkik, “training" by Creative Mania, “Farmer market" by Becris, “PESTICIDE" #2208129, “garbage dumb" by Eucalyp, “sustainable development" by Vectors Point).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2021.11.012.

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