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A multi-disciplinary approach for building a common understanding of genetic engineering for malaria control in Burkina Faso

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Genetic engineering is a complex topic, even for scientists working in other areas, and even more so for those who lack a formal scientific training. To help gene specialists and affected communities talk with one another, international guidance documents have been published that promote dialogue and exchanges. The current paper explores collaboration among scientists of different disciplines as well as between scientists, the local communities, mediated by theatre actors to develop a conversation about Target Malaria's work on genetic technologies to modify mosquitoes for malaria elimination in Burkina Faso. It focuses on the co-construction of meaning of key scientific concepts with a view to fostering productive collaboration between scientists and the local community. The community provided feedback on what was shared with them regarding the science being developed in the lab and in the field, which in turn informed aspects of the research itself, and the nature of the collaboration between the scientists and the local community.

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Background

This paper starts from the premise that collaboration between scientists from different disciplines and community members is essential if science is to play a role in improving human welfare. We argue that the co-construction of meaning for key scientific concepts, particularly with regard to genetic engineering, is a prerequisite for such collaboration. Communities need to have a say on research activities conducted in their proximity. Achieving this necessitates an inclusive approach, which can in return change the perspectives of all participants, both scientists and community members, and improve the research process. This paper will take the example of a research project called Target Malaria that develops genetic technologies to control malaria (Burt et al., 2018), and the process adopted in Burkina Faso to establish a productive collaboration between its research team and local communities.

Target Malaria (2019) began its research programme towards the development of gene drive mosquitoes in Burkina Faso in 2012. From the beginning, there was a commitment to promote dialogue about the research with the public, specifically in the villages in the region of Hauts Bassins where the research is conducted (Target Malaria, 2017). The dialogue has aimed to create an environment for informed decision-making on specific research activities, not to elicit unconditional acceptance of the technology. This two-way dialogue echoes Kelty's definition of collaboration as a form of co-working and co-thinking (Kelty, 2020): the creation of a series of interactions and activities combining various types of knowledge underpinning a broader discussion and an informed research process. Knowledge-building as a co-construction of meaning with regards to the technology's key ideas became central to how Target Malaria operates. Existing international guidance on gene-drive research provided additional guidance to the approach of the project and its emphasis on involving communities in research activities (Burt, 2003; Esvelt et al., 2014; Wedell et al., 2019).

Expanding discussions on genetic engineering beyond a small group of experts actively involved in the research toward interested parties, on the policy or advocacy level, is challenging. The topic is extremely tricky to navigate, even for people with a scientific background, let alone those who lack formal scientific training. Engaging in a dialogue around chromosomes, DNA, genes, and other concepts related to gene engineering was not straightforward, not for the community members, nor for the project's social scientists and engagement practitioners. The first challenge was to engage in a transdisciplinary dialogue between different fields of expertise within the project to come to a mutual understanding of complex scientific processes as well as the processes needed to convey them to concerned communities, stakeholders and publics (National Academies of Sciences Engineering and Medicine, 2016). The engagement team subsequently used learning from this internal process to inform the dialogue with people outside of the research sector.

Addressing this challenge implied the acknowledgment that scientists do not hold a monopoly on knowledge or thinking about disease control (Barrotta and Montuschi, 2018; Hartley et al., 2019). Members of wider communities; broadly speaking non-scientists, possess their own knowledge rooted in their social, cultural and/or professional contexts, and can contribute to generating the common understanding needed to communicate science and influence how research is envisaged (Knols et al., 2006). The lexical field of genetics and gene drive technology conveys specialist knowledge. That said, the inheritance of physical traits is grounded in day-to-day human experience, which can form the basis for a common understanding and a dialogue between experts and non-experts.

Target Malaria's engagement team further developed this process to achieve a dialogue with the wider community on complex scientific concepts, satisfying its objective of collaborative knowledge-building. This paper details an iterative learning process that took unexpected turns and sometimes seemed headed toward a dead end, requiring an open mind and sensitivity to stakeholders' ideas and concerns. Ultimately it has come to reflect some of the ideas and principles of Art-Science theory and practice (Barry, 2001; Born and Barry, 2010). We will explore some of the commonalities between these principles and experiences gathered by the project.

The paper will focus on processes adopted by Target Malaria with the aim of developing and trialling a productive collaboration process. First, we will look at how natural scientists and social scientists came together for the co-construction of meaning, and how this was extended to bringing together the community with local professionals. Secondly, we will consider the contribution of the local community to the research process.

Study settings

Target Malaria project. Target Malaria's overall goal is to develop and share new, cost-effective and sustainable gene-based technologies to modify mosquitoes and reduce malaria transmission (Target Malaria, 2017).

The research is based on a phased approach, involving the evaluation of different *Anopheles gambiae* mosquito strains that have been genetically modified. The different phases involve the deployment of mosquitos with different persistence abilities in the environment: starting with a non-gene drive sterile male mosquito strain (Windbichler et al., 2008) with short survival and persistence in the environment (Yao et al., 2022), to ultimately a self-sustaining gene drive strain (Burt et al., 2018). As the project has not reached the latter stage, this paper will describe only the non-gene drive sterile male mosquito strain.

The Target Malaria Burkina Faso team is composed of life science as well as social science experts with diverse disciplinary backgrounds; biology, entomology, anthropology, sociology, as well as a number of stakeholder engagement and communications practitioners.

Geographical location of Target Malaria in Burkina Faso. In Burkina Faso, the consortium operates in collaboration with the western division of a national health research institute; the "Institut de Recherche en Sciences de la Santé (IRSS)", located in Bobo-Dioulasso city in the region of Hauts Bassins. All the project facilities are hosted inside IRSS buildings. Field activities currently focus on three villages in the vicinity of Bobo-Dioulasso: Bana, Souroukoudingan and Pala, situated at a distance of 23, 28 and 6 km, respectively, from Bobo-Dioulasso. This paper will describe experiences garnered in Bana and Bobo Dioulasso.

Bana village is led by a traditional chief, supported by a committee of household elders. The principal social group are the autochthonous Bobo and, to a lesser extent, other minority groups, including Mossi and Fulani. The main occupations in the village are trade, subsistence agriculture and, to a lesser extent, livestock rearing. At 15%, literacy levels are relatively low, with most having only received a primary-school education. (Unpublished data, October 2014)

The IRSS research facility is located in an old district of Bobo-Dioulasso. Its population is diverse, comprising a variety of social groups, as is the case in other urban areas across the country. Like other districts in the city, the inhabitants are chiefly employed in the public-sector, medium-sized private-sector businesses, and local trade. A deputy mayor oversees the administration of the

arrondissement. School enrolment in the district is similar to other major cities in the country, with around 20% attending primary school.

Burkina Faso boasts around 60 different languages, three of which are dominant in the northern, central, and western regions. In the west, the most common language is Dioula, which is spoken in Bobo Dioulasso and Bana village. The village inhabitants also speak their own local dialect.

In the area, Malaria is widely viewed as a common endemic disease, which most people have experienced and whose symptoms and treatment are familiar (Tiono et al., 2008; Yaya et al., 2017). Common myths exist as to the cause of malaria, like getting wet in the rain, or eating food thought of as being too sweet or fatty, though there is some level of understanding of the link with mosquito bites. Despite the connection made by some with mosquito bites, the blood-feeding process is less understood. Dirty water is recognised as a potential breeding site for malaria-transmitting mosquitos, with the interiors of houses seen as their preferred habitat. Knowledge about the differences between male and female mosquitos and biting behaviour is limited.

Collaboration method. The collaboration method consists of an interactive process involving individual and group meetings, focusing on a two-way dialogue and theatrical performances. The strategy was developed through public experiment, or reflexive encounters, within the research team itself, and between the research team and local community members. Interactions between the research team and community members were mediated by local theatre artists and actors.

The Target Malaria engagement team, made up of social scientists and engagement practitioners, initiated this collaboration, first with the life scientists, and then with the local communities, crucially bringing in local theatre artists. The latter idea arose from the challenge of establishing a dialogue on the complex topic of genetic engineering with the communities living in the research area.

The first step consisted of ensuring a comprehensive understanding of basic concepts of genetics and genetic engineering, processes and potential outcomes. This is a prerequisite to starting up a dialogue on these topics with communities. Over the course of three months, exchanges took place between the life scientists and the engagement team in several group meetings. The resulting clarity became the starting point for interactions with the wider community.

Once a clear understanding of the research had been transferred to the social scientists and engagement experts, a conversation was initiated with the communities at the village level. This was done through one-on-one exchanges and group meetings. Explaining to the community living in Bana that the aim of the exercise was to engage in a process of co-development, rather than the passive reception of external 'expertise', more common in the knowledge-deficit model (Simis et al., 2016), proved a challenge. This objective was central to the project's engagement approach, corresponding to the ethical principles informing the project's engagement model (Roberts and Thizy, 2022), particularly the idea of co-development with the most affected communities. The villagers thought that they would simply supply their agreement, without any sense of potentially playing a part in the research. A group meeting was set up with village leaders to clarify the project's objectives and approach.

Once the aim had been clarified, a working group was established. Community leaders were able to give their input on the composition of the group, which consisted of a broad range of stakeholders; members of the research team, Dioula native speakers living in the village of Bana, people educated in Dioula but not native speakers, traders travelling in the Dioula-speaking area familiar with the local dialects, elders, women and young people from the village, and community leaders. The inclusion of diverse stakeholders provided in-depth linguistic knowledge, but also a diachronic consideration of the language (elder/younger speakers) as well as gender (women/men). Multiple exchanges, averaging seven for each category of stakeholder, were carried out over 3 months. These began with informal conversations and were followed by formal working-group sessions. Three group meetings between the research team and representatives of each category of stakeholders were organised to cross-check the outcomes of the informal conversations.

Five years after the beginning of the research project, a related activity started that can be considered as a third stage. At this point, the stakeholder engagement team noticed decreasing participation in project engagement activities. Community members who were previously engaged in the overall project objectives indicated that they had enough information to give their consent and did not need further details. However, the project wanted to ensure that the community understood the phase of the small-scale release of non-gene drive sterile male mosquitoes which was a new phase involving a different activity. This release would be the first deployment of genetically modified insects in the region. It was important to the project that the community could make an informed decision based on a thorough understanding of the science. Discussions revealed that community members were saturated with information, leading the team to conclude that the mode of communication should be reconsidered. When asked to suggest ideas on how to maintain and further the dialogue, community members repeatedly mentioned theatre and cinema, suggesting that a narrative form based on images or performance could be effective.

The project decided to test the theatre format. Community members were instrumental in helping to identify regional theatre companies with which they had had previous experiences. The theatre company, working chiefly with actors, that was eventually chosen had worked in the villages before and already had experience working with themes related to disease, including malaria and HIV. The actors started working with the team to build a concept for their performance and then tried out the result in a village. After the performance a forum was organised to garner feedback on how effectively gene-related concepts had been communicated in the local terminology/wording. They also received advice on improving the clarity of their language and the delivery. The input enabled them to create subsequent versions informed by the villagers' own ideas and suggestions.

Results

Co-constructing meaning of scientific concepts. The construction of meaning was realised through synergies emerging from this collaboration. The approach was designed according to the cooperative communication model put forward by Stanley Deetz (1992). According to this model, reality is conceived of as a pool of shared meaning into which each individual has an input. Each person adds something to the pool, and each takes something from it: what is put in is not necessarily the same as what is taken out, because each individual only takes out what he or she chooses. Furthermore, what is put in is a combined with everything else, so the input is transformed over time.

Collaboration between natural and social scientists. The co-construction of meaning by scientists and non-scientists for key concepts relating to genetic engineering was broached with an exploratory exercise involving scientists from different disciplines within the team. The rationale was to bring the team towards a

common understanding of the fundamental scientific concepts. Explaining these concepts effectively to a wider audience also required experience and practice in delivering complex ideas clearly and simply. This in turn provided the entry point for a collaboration with the community and other stakeholders.

This initiative was itself not bereft of complexity. The Target Malaria team comprised a variety of specialist expertise. Sharing knowledge about genetics across disparate disciplines unused to talking to each other constituted a challenge. Social scientists habitually focus on people and cultures, whereas life science closely examines nature, resulting in different modes of thinking. With respect to genetic modification, social scientists focus on tangible outcomes in social settings, while life scientists concentrate on the way genes operate within an organism; a crucial outside/inside dichotomy. To produce an effective dialogue, these two modes of thinking need to be taken into account for there to be an effective dialogue.

With this in mind, the inter-disciplinary collaboration needed to adjust mindsets on both sides. The life scientists had to explain what seemed to them as self-evident but was often obscure to anyone outside of their field. They were obliged to provide in concrete terms, eschewing scientific jargon, the rationale for, and process of, genetic modification. The social scientists had to enter into the mode of thinking of the life scientists in order to understand the properties governing genetic phenomena. In addition, the engagement team provided information about community knowledge of living beings, which would serve as the entry point for the communication process with the community.

To facilitate this work—serving as a base for an adequate, shared body of language—several exchange sessions were organised within the team. During the discussions, instead of explaining a concept by resorting to related scientific terminology, the life scientists and the engagement team explored the characteristics, role, as well as the function of each idea, through the following questions: how can a gene be characterised? What is its role in the human body? What is its overall function?

Through this process of asking questions and exploring answers, the life scientists tried to explain the details as clearly as possible from a scientific perspective. The social scientists responded by looking for ways to relate these core scientific ideas to things that are familiar to most. A gene, therefore, was defined as relating to physical traits and resemblances that run in families. This way, the concept of DNA and visible inherited physical characteristics could be brought together to express the principles of genetic modification in accessible terms.

Collaboration between the research team and the local community in the construction of meaning. This interaction has already been partially described by Chemonges et al. (Wanyama Chemonges et al., 2021), which gives an account of the elaboration of the glossary of technical terms used in Target Malaria's research. The present paper focuses on the process of co-constructing meaning. The technique was chosen in light of the overall challenge of communicating effectively on genetic engineering, and vagueness in the terminology among community members when discussing scientific concepts. For instance, some were found to use the expression *"seg- seg ni'* (try and see) to refer to the research, and others used *"fèrè yala*" (look for a solution). This called for a deeper discussion around the meaning of the concepts involved in genetic science.

The discussion started with the research team sharing information about the mosquito, proceeding from simple to more complex concepts, moving from the role of mosquitoes in malaria transmission to biting and feeding behaviour. Next came more detailed information about mosquito biology, focusing on a range of topics: the diversity of mosquito species, their role in disease transmission and, specifically, malaria transmission. Also prominent in the discussions was malaria vector behaviour, specifically the typical season and time when biting occurs, differences between males and females, feeding habits, blood-feeding and egg maturation, breeding sites, the mosquito life cycle (egg, larva, pupa and adult), the malaria-parasite transmission cycle, and the mosquito lifespan. Finally, more complex knowledge was shared about key concepts relating to the genetic modification of mosquitoes, such as chromosomes, enzymes, DNA, research, laboratory, sterile male.

At this stage, the informal conversation fed into the discussion by bringing in various ideas the research team was attempting to explain. For example, with regard to genetic modification some individuals proposed: "*yelemi do na a sia la, yelemani do na a cogo là*". (There is a change in the species of something. There is a change in the normal condition of something.) These words were frequently used by traders or Dioula native speakers. Younger people, however, put it differently: "*Ka fea yeleman ka bo cogo koro là*" (Change the old condition for a new one). These different ideas were used by the working groups in their process of coming up with terminology that most adequately expressed the scientific understanding of the core concepts.

A theatre performance on genetic modification: combining theoretical and practical thinking. The third stage of collaboration between the research team and the communities on the construction of meaning of key genetic concepts was done through theatre performances.

Discussions with the actors started by sharing with them relevant background knowledge on Target Malaria's research. A script (in French) with a detailed scientific explanation aimed to provide a comprehensive scientific description to the actors. The initial glossary developed with the community was also shared. However, insights provided by the actors significantly influenced the project's perception and approach. Receiving a ready-made script was unusual for them, but they accepted that there were core details that needed to be widely shared. They maintained that the provided script was not workable, saying it was too linear, and too emotionally detached. It also lacked points of conflict to draw the interest of an audience, and was seen as too passive and too scientific. They did not know how to make it work as a performance or even how the information—lacking a narrative—could be made into something as interesting and dynamic as a performance.

The lead actor asked his colleagues to read the script and provide their suggestions on how to turn it into something more captivating. He asked them to put forward their own comprehension of, and terminology for, the different featured concepts, using their own experience and perspectives, hence moving away completely from the scientific language and ideas. The group's artistic method consisted of exploring the meaning of the concepts without starting from existing work, such as the one done by the team and communities in the elaboration of the common glossary (Wanyama Chemonges et al., 2021). This way, the actors could own the concepts by exploring their meaning and potential representation through an artistic process rather than as a result of a linguistic or scientific process. This approach was not without challenges. After their individual exploration, the actors appeared unconvinced by each other's ideas. They seemed to have come to a dead end, expressing the wish to exit the project altogether. Their leader, however, was determined to keep going, and had them work together to identify a solution, still following the same process and not sharing the existing glossary with them.

At this stage they looked for other outside help, for example by buying a French dictionary to check the understanding of words such as 'genetic modification'. They also brought in local language speakers to help them come up with a more precise and effective vocabulary, in addition to setting up additional meetings with the research team to obtain a better understanding of the project and of the technical language used.

Considerable discussion centred on ways to adequately deal with the scientific terminology. Identifying language that could convey to local people the nature of the genetic modification that the project would implement took time. The process was similar to the one that had taken place between the project and the communities to establish a common glossary (Wanyama Chemonges et al., 2021). The actors, concentrating on the outcome of genetic modification of the mosquito, arrived at four different possibilities for conveying this meaning based on the word *soso*, 'mosquito' in Dioula): (i) *soso PD* 'homosexual mosquito', (ii) *soso koboni* 'castrated mosquito', (iii) *soso grue* 'barren mosquito' or (iv) *soso mi ti ce ka de ke* 'which is unable to produce offspring'.

The first idea, *soso PD* (homosexual mosquito) was proposed because of the view that homosexuals are unable to have offspring, a convenient analogy with the male mosquitoes that would be made sterile through a scientific process. Yet after further discussion, they felt that this was not a good solution due to ethical considerations surrounding prejudice and scientific inaccuracy. *Soso koboni* (castrated mosquito) was also rejected because it offered a misleading understanding in the local language: *koboni* connotes the physical act of castration, rather than the idea of sterility itself. *Soso grue* (barren mosquito) designates a natural inability to reproduce, which was in fact pre-selected, but with the important added detail that science created this barrenness by changing the body of the mosquito internally. A further decision to use an expanded phrase; 'a mosquito which is unable to produce offspring', provides a useful way of simply and clearly explaining the outcome of the scientific intervention. This was also chosen as opposed to using a single term on the grounds that the concept was in itself too complicated for a single word to embody.

All of these terms were then discussed with the research team in terms of their accuracy. The research team then provided their experience of communicating genetic modification and their awareness of the risk of misunderstandings. The final decision was to choose the third and fourth option: *soso grue* and 'the mosquito that is unable to produce offspring'. The reasons were that *soso grue* had already been heard by the engagement team in the field, and that the extended phrase was felt to clearly express the final outcome of genetic modification of the non-gene drive sterile male. This validated the process that had been carried out with the communities and showed that different stakeholders, through a slightly different process would conclude on the use of similar terminology.

As the actors continued developing their thoughts, they introduced the researchers to their ideas. These entailed focussing on certain elements of the scientific process and shedding others. They advised concentrating first on core aspects of genetics and genetic modification, and as a second step on the outcomes of genetic modification in the context of the proposed research. Subsequently, they produced their own version of the script, in the local language and informed by their own extensive experience with the community, checking and verifying various elements with project staff where they felt the need.

For example, they pruned away some of the scientific details to concentrate on what they perceived as essential. For instance, the non-gene drive sterile male was described as follows in the script provided by the Target Malaria team:

> "The sterile male mosquito is a genetically modified mosquito, whose reproductive capacity has been de-activated, and when the sterile male mates with a female mosquito the eggs are not viable."

The actors whittled this down to:

> "If a male mosquito that has been transformed mates with a female mosquito, there is no offspring."

The example is typical of their simplifying approach, and it defined the way the collaborative construction of meaning of the science proceeded.

The actors also suggested working directly with key local people like the local 'griot' or story teller, and the beer-seller. They also recommended that the performance be held in the 'cabaret', a local performance space. This prepared the ground for the creation of a setting connected directly with the local people's experience, lending the performance a familiar energy and accessibility. The play that was prepared was connected to the local traditions and customs, using humour as a channel to mobilise the community and create a dialogue. The griot, the usual conduit of information for the village, composed a song that contained the key message of the research. It was sung at every performance in the theatre, which was appreciated by the villagers as it helped them remember the information.

After the performance, at the initiative of the actors, the interactive process continued. The villagers were invited to give feedback on their performance and on the reception of its core message. This forum offered a chance for the villagers to ask questions as well as share criticism and suggestions. It also provided the research team with an opportunity to supply further details and clarifications about the science.

The two modes of communication; the actors' striking conceptualisation focusing on outcome and effect, and the scientists' explanations focusing on precise details of the process, complemented each other. The team supplemented the account supplied by the actors of the general outcome (mosquito barrenness) with explanations on how the sterility would manifest in practice in the bodies of the mosquitos. While the actors said that the male mosquito would be modified with the purpose of making it sterile, and therefore unable to have offspring, the engagement team offered a supporting description: that the genetic modification targets the male sexual gene, that mating between a sterile male and a female mosquito would still produce eggs, but that these eggs would not be viable. Both approaches contributed to a readily understandable picture of the science involved.

The actors continued to refine the performance for subsequent shows, taking into account the comments of the villagers. An example of a point of criticism raised by the villagers centred on a character that was critical of genetic modification. It was suggested that the character's disapproval would be better understood by the audience if more basic information was supplied before he voiced his objections.

Impact of community feedback on the research process. The collaboration established between the research team, the villagers and the theatre actors generated awareness of the research activities, in turn generating questions or suggestions as to the way the research was being conducted.

Questions relating to mosquito biology and entomological research led to an increase in lab visits by a broader section of the community. In the past, only community leaders (such as members of the village development council or representatives of the chief) had expressed an interest in visits to the research facilities in Bobo Dioulasso organised early on (Pare Toe et al., 2021). The theatre

performance created a renewed interest and led to the organisation of subsequent visits to the research facilities, including the insectary where the contained studies are taking place.

On this occasion, community members were shown all the key stages of mosquito development (from egg to larva and into maturity) and crucial behaviour characteristics such as around feeding and mating. They were shown how the research could be carried out on such minuscule insects. Also demonstrated were the oversight mechanisms in place for research facilities working with genetically modified organisms: how the space in the lab is organised, all aspects of 'containment' such as how the physical infrastructure of the lab reflects biosafety considerations. Villagers were able to see how risks were carefully monitored and managed, how errors could be avoided, and their potential impact mitigated. By being inside the lab, they could experience first-hand the level of rigour adopted.

The extensive sharing of understanding enabled the community to comprehend important aspects of the research: for instance that it would be a lengthy process and involve uncertainty in terms of the potential knowledge gained. Community members were content to participate in the research process, but also raised several practical issues regarding its management and their involvement in it. They were flexible and readily accepted changes at the level of the research. For instance, at one point the mosquito species under investigation could no longer be identified in field sampling, which required mosquito collection to be stopped in the village in consultation with the population. Thanks to extensive sharing, the project was able to harness local knowledge of the seasonal dynamic of mosquitoes in the village to improve place, timing and techniques for collecting insects. Local knowledge proved to be extensive and highly specialised. Their suggestions contributed to a successful collection process (Finda et al., 2019).

All the research activities, including stakeholder engagement activities, were explored through a mutually respectful two-way dialogue along the knowledge-building process. These discussions were always continued to a point where agreement about all processes and techniques was established. Nothing was done without the prior agreement of any group that would be directly affected. For each research activity, the relevant group was invited to present their knowledge, questions and suggestions, so that they could contribute creatively and positively to the scientific process. In terms of stakeholder engagement, this was consistently designed to be a two-way dialogue and to highlight any concerns from the community. All questions were addressed through extended interaction, enabling the community to achieve a good understanding of the topic, at the same time building their knowledge and dealing with any concerns.

Discussion

This paper highlights critical experience gained from collaboration between scientists of different disciplines and community members through the co-construction of meaning of key genetic science concepts. The objective was to create a shared understanding of the research relating to genetic modification among all stakeholders, which constituted an opportunity for the community hosting Target Malaria's research to impact both the research thinking and processes.

The collaboration was initiated by the Target Malaria engagement team and included life scientists, the community (in this context to be understood as individuals living in the locality of the fieldwork), and theatre actors. The collaboration renewed an old debate regarding collaboration between scientists and non-scientists under the auspices of art-science and the particular ideas associated with public-experiment thinking (Barry, 2001; Born and Barry, 2010). This conceptualisation put forward the logic of ontology defined as an orientation in interdisciplinary practice towards effecting ontological change in both the object(s) of research, and the relations between research subjects and objects (Born and Barry, 2010).

The synergising operating on the construction of meaning of key genetic science concepts was made possible through an adjustment of the mindset on the part of each of the stakeholders and their receptivity to the knowledge-sharing process. The collaboration was informed by input hailing from various skills, each with a different logic of thinking. Alejandro Valencia-Tobon, inspired by the concept of public experiment in art-science, describes a similar process of co-creating knowledge in connection with a peace-building initiative in Columbia (Valencia-Tobon, 2022). That collaboration connected the distinct worlds of individuals from very different backgrounds, facilitating an exchange of experiences through participatory art and promoting conversations on Anorí's ecological knowledge. He identifies the experience of growth in terms of the various stakeholders:

> "For the biological scientists, participation meant acknowledging that ex-combatants could help them advance their scientific work. For community leaders, it meant being willing to talk with people who were symbols of violence, and for ex-combatants, it meant acknowledging that the war they had taken part in had affected many civilians. The dialogic methods had peace-building functions, helping participants to approach the idea of co-existence in social, biological and aesthetic ways."

In the same way, in the Target Malaria experience of collaboration, different and distinct approaches came together to combine knowledge, which involved an opening up of pre-existing mindsets. While the scientists provided their expert knowledge of genetics, the theatre actors and the community brought to the table a highly localised, subtle, and detailed level of experience. Its members were able to share a very practical awareness built up over many years. Broadly speaking, the scientists operated through the consideration and articulation of details, whereas the actors grasped the value of streamlining what was being communicated with a particular focus on the outcome of chosen elements of the scientific process. These differences needed to be worked through until some form of synthesis could be achieved that was acceptable to both sides. This took time and effort. Interestingly, in the context of the forum discussion that took place after the performance, the scientists were comfortable intervening to insert more detail into the discourse once the essentials (as identified by the actors) had been delivered. In short, the manner in which the collaboration took place continued to evolve.

The experience shows that the local stakeholders actively engaged in the discussion on genetic engineering and offered useful input. Their contribution was linked to non-gene drive technology, but the experience is likely applicable to gene drive projects as well, a technology based on similar concepts.

Arguably, interactions between scientists and stakeholders in the construction of meaning regarding the science of genetic engineering should become an integral part of how genetic engineering technology is researched and implemented. Particularly, with foresight and planning, it could be integrated into the research pathways.

Co-working, as described in this paper, would create a balance of power that would make self-determination and sovereignty of the communities participating in the research process an implicit aspect of the decision-making process (Kolopack and Lavery, 2017; Lyons et al. 2017; Molyneux et al. 2004; Singh, 2019) and

the implementation of the findings. The fundamental principle behind this approach is to make sure that community members involved in the construction of meaning engage in an active, meaningful, and autonomous manner. The undertaking was explicitly not an attempt to secure unquestioning acceptance, nor to perpetuate a knowledge deficit (Hartley et al. 2019), but an opportunity to invite non-scientific stakeholders into the genetic engineering discussion and acknowledge their ability to be part of it (Roberts and Thizy, 2022). This process supports the confidence-building of the stakeholders and allows for an incremental dialogue, in which stakeholders become more confident to express their perspective as trust between the different partners is built in the process, and the perception of a knowledge and expertise asymmetry that can have hindered collaboration in the onset.

Conclusion

The process described here was implemented as part of the preparation for field studies (Pare Toe et al., 2021) of non-gene drive sterile male mosquitoes, to ensure that life scientists, social scientists and community members collaborate to establish a unique joint process to approach these research activities. It is envisaged as an iterative process that can in return nourish the research process for subsequent phases. This work with early strains that do not contain gene drive is envisaged as a foundation for the next phase, involving non-gene drive but fertile strain, and then ultimately a gene drive phase. This phased approach to engagement echoes the scientific phased approach and aims at integrating the learning into the next phase. The engagement is based on a shared understanding that developing and evaluating gene drive mosquitoes for malaria control is the final objective of the project, but that the research progresses slowly through phases.

The authors believe that the experience of co-working with a diversity of stakeholders can also serves as the foundation for other aspects of the research process. For instance, it can help respond to the needs of a host community; to design an appropriate agreement model for gene drive research; identify appropriate legitimate representatives who can express the decision of the community regarding proposed research activities (King et al., 2014; MacQueen et al., 2015; Resnik, 2018, 2014); or design an evaluation process for the engagement process (Brunton et al., 2017; King et al., 2014; Kokotovich et al., 2020; Kolopack et al., 2015; Lavery et al., 2010; MacQueen et al., 2015; Resnik, 2018, 2014).

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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References

Barrotta P, Montuschi E (2018) Expertise, relevance and types of knowledge. Soc Epistemol 32:387–396. https://doi.org/10.1080/02691728.2018.1546345
Barry A (2001) Political machines: governing a technological society. https://doi.org/10.5040/9781474213110
Born G, Barry A (2010) Art-science: from public understanding to public experiment. J Cult Econ 3:103–119
Brunton G, Thomas J, O'Mara-Eves A et al. (2017) Narratives of community engagement: a systematic review-derived conceptual framework for public health interventions. BMC Public Health 17:1–15.
Burt A (2003) Site-specific selfish genes as tools for the control and genetic engineering of natural populations. Proc R Soc B: Biol Sci 270:921–928.
Burt A, Coulibaly M, Crisanti A et al. (2018) Gene drive to reduce malaria transmission in sub-Saharan Africa. J Responsible Innov 5:S66–S80. https://doi.org/10.1080/23299460.2017.1419410
Deetz AS (1992) Democracy in an age of corporate colonization: developments in communication and the politics of everyday life. State University of New York Press.
Esvelt KM, Smidler AL, Catteruccia F et al. (2014) Emerging technology: concerning RNA-guided gene drives for the alteration of wild populations. Elife 3:e03401
Finda MF, Kaindoa EW, Nyoni AP et al. (2019) 'The mosquitoes are preparing to attack us': knowledge and perceptions of communities in south-eastern Tanzania regarding mosquito swarms. Malar J 18:56
Hartley S, Thizy D, Ledingham K et al. (2019) Knowledge engagement in gene drive research for malaria control. PLoS Negl Trop Dis 13:e0007233. https://doi.org/10.1371/journal.pntd.0007233
Kelty CM (2020) The participant: a century of participation in four stories. University of Chicago Press.
King KF, Kolopack P, Merritt MW et al. (2014) Community engagement and the human infrastructure of global health research. BMC Med Ethics 15:84. https://doi.org/10.1186/1472-6939-15-84
Knols BGJ, Hood-Nowotny RC, Bossin H et al. (2006) GM sterile mosquitoes—a cautionary note. Nat Biotechnol 24:1067–1068
Kokotovich AE, Delborne JA, Elsensohn J et al. (2020) Emerging technologies for invasive insects: the role of engagement. Ann Entomol Soc Am 113:266–279
Kolopack PA, Lavery JV (2017) Informed consent in field trials of gene-drive mosquitoes. Gates Open Res. 1:14. https://doi.org/10.12688/gatesopenres.12771.1.
Kolopack PA, Parsons JA, Lavery JV (2015) What makes community engagement effective?: Lessons from the Eliminate Dengue Program in Queensland Australia. PLoS Negl Trop Dis 9:e0003713
Lavery JV, Tinadana PO, Scott TW et al. (2010) Towards a framework for community engagement in global health research. Trends Parasitol 26:279–283. https://doi.org/10.1016/j.pt.2010.02.009
Lyons K, Parreñas JS, Tamarkin N et al. (2017) Engagements with decolonization and decoloniality in and at the interfaces of STS. Catal Fem Theory Technosci 3:1–47
MacQueen KM, Bhan A, Frohlich J et al. (2015) Evaluating community engagement in global health research: the need for metrics. BMC Med Ethics 16:44. https://doi.org/10.1186/s12910-015-0033-9
Molyneux CS, Peshu N, Marsh K (2004) Understanding of informed consent in a low-income setting: three case studies from the Kenyan coast. Soc Sci Med 59:2547–2559. https://doi.org/10.1016/j.socscimed.2004.03.037
National Academies of Sciences Engineering and Medicine (2016) Gene drives on the horizon. https://doi.org/10.17226/23405
Pare Toe L, Barry N, Ky AD et al. (2021) Small-scale release of non-gene drive mosquitoes in Burkina Faso: from engagement implementation to assessment, a learning journey. Malar J 20:1–18.
Resnik DB (2018) Ethics of community engagement in field trials of genetically modified mosquitoes. Dev World Bioeth 18:135–143
Resnik DB (2014) Ethical issues in field trials of genetically modified disease-resistant mosquitoes. Dev World Bioeth 14:37–46
Roberts AJ, Thizy D (2022) Articulating ethical principles guiding Target Malaria's engagement strategy. Malar J 21:35. https://doi.org/10.1186/s12936-022-04062-4
Simis MJ, Madden H, Cacciatore MA et al. (2016) The lure of rationality: why does the deficit model persist in science communication? Public Underst Sci 25:400–414. https://doi.org/10.1177/0963662516629749
Singh JA (2019) Informed consent and community engagement in open field research: lessons for gene drive science. BMC Med Ethics 20:54
Target Malaria (2017) Mission vision value statement [WWW Document].
Target Malaria (2019) Target malaria: our work [WWW Document]. https://targetmalaria.org/our-work/
Tiono AB, Kaboré Y, Traoré A et al. (2008) Implementation of home based management of malaria in children reduces the work load for peripheral health facilities in a rural district of Burkina Faso. Malar J 7. https://doi.org/10.1186/1475-2875-7-201
Valencia-Tobon A (2022) Art, science and anthropology: co-creating knowledge and building peace in Colombia. Leonardo, 55:34–38. https://doi.org/10.1162/leon_a_02060.
Wanyama Chemonges E, Pare Toe L, Dicko B et al. (2021) Co-developing a common glossary with stakeholders for engagement on new genetic approaches for malaria control in a local African setting. Malar J 20:1–11
Wedell N, Price TAR, Lindholm AK (2019) Gene drive: progress and prospects. Proc R Soc B Biol Sci 286:20192709
Windbichler N, Papathanos PA, Crisanti A (2008) Targeting the X chromosome during spermatogenesis induces Y chromosome transmission ratio distortion and early dominant embryo lethality in *Anopheles gambiae*. PLoS Genet 4:e1000291
Yao FA, Millogo AA, Epopa PS et al. (2022) Mark-release-recapture experiment in Burkina Faso demonstrates reduced fitness and dispersal of genetically-modified

sterile malaria mosquitoes. Nat Commun 13:796. https://doi.org/10.1038/s41467-022-28419-0
Yaya S, Udenigwe O, Bishwajit G et al. (2017) Knowledge of prevention, cause, symptom and practices of malaria among women in Burkina Faso. PLoS ONE 12:e0180508. https://doi.org/10.1371/journal.pone.0180508

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Author contributions

LPT conceived and designed the collaboration model for genetic communication, formulated the approach initiated, and submitted the text for publication. NB and ADK contributed to the model design and the writing-up of the research; WIM and KB contributed to fieldwork; DT contributed to the design of the stakeholder engagement strategy and communication model; SK, OM and IC contributed to the design of the communication tools; MD, PSE, MN, RKD and AD contributed to the conception of the model and reviewing the paper.

Competing interests

The lead-author LPT is stakeholder-engagement lead for Target Malaria (Burkina), and played a substantial role in formulating this paper's approach, designing the fieldwork, and preparing and submitting the manuscript for publication. All the co-authors are involved in the Target Malaria consortium in different respects. Authors report receiving funding through the Target Malaria project. The funders had no role in the model design, nor in the fieldwork, the decision to publish the research, nor in the preparation of this text.

Ethical approval

The project received ethical approval from the Institutional Ethical Committee of Institut de Recherche en Sciences de la Santé under the Ministry of High Education, Research and Innovation, no. 2018-005/MESRSI/SG/CNRST/IRSS/CEIRES. The research was performed in accordance with ethical guidelines.

Informed consent

Informed consent was obtained from all participants to the study.

Additional information

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