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Co-Designing a Mobile-Based Game to Improve Misinformation Resistance and Vaccine Knowledge in Uganda, Kenya, and Rwanda

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Misinformation can decrease public confidence in vaccines, and reduce vaccination intent and uptake. One strategy for countering these negative impacts comes from inoculation theory. Similar to biological vaccination, inoculation theory posits that exposure to a weakened form of misinformation can develop cognitive immunity, reducing the likelihood of being misled. Online games offer an interactive, technology-driven, and scalable solution using an active form of inoculation that engages and incentivizes players to build resilience against misinformation. We document the development of the critical thinking game *Cranky Uncle Vaccine*. The game applies research findings from inoculation theory, critical thinking, humor in science communication, and serious games. The game content was iterated through a series of co-design workshops in Kampala (Uganda), Kitale (Kenya), and Kigali (Rwanda). Workshop participants offered feedback on cartoon character design, gameplay experience, and the game's content, helping to make the game more culturally relevant and avoid unintended consequences in East African countries. Our co-design methodology offers an approach for further adaptation of the *Cranky Uncle Vaccine* game to other regions, as well as a template for developing locally relevant interventions to counter future infodemics.

Misinformation and disinformation–false information which may be spread either unintentionally or intentionally, respectively–about vaccines is prevalent and popular on social media platforms (Broniatowski et al., 2018). This is a self-reinforcing problem with prior exposure to misinformation increasing misinformation promotion (MacFarlane, Tay, Hurlstone, & Ecker, 2021). The prominence of vaccine-related misinformation has been heightened by the COVID-19 pandemic and the resulting overabundance of information, or "infodemic." Almost every type of vaccine has been the target of misinformation, including the Human Papilloma Virus (HPV) vaccine (Turiho, Okello, Muhwezi, & Katahoire, 2017) and the measles, mumps, and rubella (MMR) vaccine (Rao & Andrade, 2011). Vaccine misinformation can have a serious negative impact on vaccination uptake (Loomba, de Figueiredo, Piatek, de Graaf, & Larson, 2021). COVID-19 misinformation belief has been associated with lower willingness to get vaccinated and recommend the COVID-19 vaccine to others (Roozenbeek et al., 2020), as well as reduced perceived threat of COVID-19 and less confidence in governmental and scientific institutions (Pickles et al., 2021).

Lower vaccine confidence–trust in the safety and efficacy of vaccines and the health system and immunization professionals that deliver it (MacDonald, 2015)–is a key barrier toward vaccine acceptance and demand. Evidence has shown that simply providing factual information is not enough (Larson & Broniatowski, 2021). Misinformation can be persistent and resistant to correction

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(Chan, Jones, Hall Jamieson, & Albarracín, 2017; Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012; Paynter et al., 2019), which has shifted the focus of much contemporary research toward preemptive interventions in an attempt to reduce misinformation impacts (e.g., Lewandowsky & van der Linden, 2021). Inoculation in the form of explaining the misleading techniques used in misinformation provides broad-spectrum resilience against multiple types of mis- and disinformation narratives, as opposed to simply debunking singular pieces of misinformation.

Misinformation disproportionately affects marginalized populations within low- and middle-income countries (LMICs), which often have lower trust in and exposure to official health information sources (Dash et al., 2021). Different communities have diverse and unique characteristics and concerns, and thus require bespoke solutions to reduce the barriers they face around vaccine access and acceptance. Human-centered design (HCD, an approach to the design process that puts humans at the heart of the process) and community-based participatory research (CBPR, an approach where researchers and community member collaborate as equals in the research process) are two people-centered approaches used often by both private and public sectors to design interventions informed by and/or responsive to the local context and community needs (Chen, Leos, Kowitt, & Moracco, 2020). Social listening—the process of identifying what is being discussed within a community—is one known method for understanding people's health-related concerns, queries and information gaps (Chanely, Benjamin, & Mechae, 2021; Johnson, Das, & Tyler, 2021). The Generative Communication Paradigm (Toschi, Davini, Pandolfini, & Sbardella, 2021) considers using communication between researchers and members of society as a tool to co-design projects or interventions across various fields, including health, in response to the needs of that society.

The objective of this paper is trifold: a) provide background on different evidence-based theories and strategies to combat misinformation, including logic-based inoculation, critical thinking, humor-based corrections, active inoculation, and gamification; b) describe the original evidence-based, mobile-based game to combat science denialism, *Cranky Uncle* (here we adopt a pragmatic definition of science denial: the use of rhetorical arguments to give the appearance of legitimate debate on topics where there is scientific consensus; Diethelm & McKee, 2009); and c) document the development of the vaccination-related Cranky Uncle version and its co-design process for the East African setting. The recent development of *Cranky Uncle Vaccine* has provided the opportunity to document an approach for further adaptation of the game to other global regions, while also accounting lessons learnt that might be applied in other contexts, and share a template for developing locally relevant interventions to counter future infodemics.

Evidence-Based Theories and Strategies to Combat Misinformation

Inoculation Theory

Inoculation theory is a branch of psychological research that applies the biological metaphor of vaccination, where exposing people to a weakened form of a virus develops resistance to the real virus (Compton, 2013; Ivanov, Parker, & Dillingham, 2020; McGuire & Papageorgis, 1961). In similar fashion, exposing people to a weakened form of misinformation has been found to help develop immunity to real-world misinformation. Two common inoculation approaches are fact-based and logic-based (Banas & Miller, 2013). Fact-based inoculations expose how the misinformation is wrong through factual explanations. While this is the most common form of inoculation, one limitation to this approach is that each fact-based inoculation is limited in effectiveness to a specific myth (Schmid & Betsch, 2019). In contrast, logic-based inoculations are more generalizable because they explain the misleading rhetorical techniques or logical fallacies used in misinformation (Kim, Vraga, & Cook, 2020; Tay, Hurlstone, Kurz, & Ecker, 2021; van der Linden, Leiserowitz, Rosenthal, & Maibach, 2017). By explaining the rhetorical technique used in one topic, this approach can convey immunity against that technique used in another topic, thus acting as a kind of universal vaccine against misinformation (Lewandowsky & Yesilada, 2021).

Leveraging the Logic-Based FLICC Framework to Identify Vaccine-Related Misinformation Fallacies

The FLICC taxonomy offers a useful framework for understanding and explaining the techniques used in misinformation, generally (Cook, 2021). The acronym represents five categories of misleading rhetorical techniques: Fake experts (F), Logical fallacies (L), Impossible expectations (I), Cherry picking (C), and Conspiracy theories (C) (Hoofnagle, 2007). Table S1 in the Supplementary Material summarizes the FLICC taxonomy. Applying the FLICC framework to vaccine-related misinformation enables the identification of the key misleading techniques used to confuse the public about vaccination.

Parallel Argumentation and Humor in Science Communication

The numerous techniques used to mislead presents the educational challenge of developing effective strategies to inoculate the public against each misleading technique. One promising technique is parallel argumentation which involves transplanting the false logic from misinformation into a parallel or analogous example (Juthe, 2009). Logic-based approaches may demonstrate how an argument is false without lengthy explanations of complex information. It is also an accessible pedagogical approach because it explains abstract logic using concrete, everyday examples (Juthe, 2009). Lastly, this approach is well suited to humor using absurd, extreme examples (Cook, 2020b).

The use of humorous parallel arguments to explain the logical fallacies in misinformation has been effective in neutralizing misinformation about vaccines (Kim, Vraga, & Cook, 2020; Vraga, Kim, & Cook, 2019) and climate change (Vraga, Kim, Cook, & Bode, 2020). A factor in the effectiveness of humorous cartoons adopting the logic-based approach has been the extra time spent paying attention to the cartoons (Kim, Vraga, & Cook, 2020). Humorous corrections are also more likely to be remembered and discussed afterward relative to non-humorous corrections (Compton, 2018).

More generally, humor has been shown to be effective for communicating information about health, science, and social issues to the general public, albeit with much of the humor research focused on U.S. audiences (Becker & Bode, 2017; Borum Chattoo & Feldman, 2017; Nabi, Moyer-Gusé, & Byrne, 2007). People respond to humorous messages on difficult topics by showing less counterarguments (Nabi, Moyer-Gusé, & Byrne, 2007). Humor also makes serious or intimidating subjects more accessible, such as the plight of Syrian refugees (Feldman & Borum Chattoo, 2019) and climate change (Brewer & McKnight, 2015). Political humor has been effective in increasing knowledge and engagement, particularly among disengaged audiences (Baek & Wojcieszak, 2009; Cao, 2008; Xenos & Becker, 2009). A humorous message about the importance of the MMR vaccine was found to outperform a serious message by reducing reactance and increasing parents' vaccine acceptance (Moyer-Gusé, Robinson, & Mcknight, 2018).

Humor can take many forms, such as wordplay, anthropomorphism, and satire (Yeo & McKasy, 2021). Satire is particularly of interest in the context of countering misinformation as it can combine both positive and negative emotions. Specifically, it combines the positive emotion of amusement with hostile feelings toward the satirical target, using humor to "attack ideas [and] behaviors [. . .] by encouraging us to laugh at them" (Bore & Reid, 2014).

Logic-based inoculations convey immunity against misinformation and humorous parallel arguments are an engaging and attention-grabbing way to implement the logic-based approach. However, one limitation of the logic-based approach is that it is essentially an attempt to boost critical thinking abilities, which is cognitively effortful. Most thinking is effortless and instantaneous (i.e., fast-thinking) in contrast to effortful, critical thinking (i.e., slow-thinking). However, a third type of thinking—expert heuristics—occurs when a person practices a difficult task repeatedly until the slow thinking processes develop into fast-thinking responses (Kahneman, 2011). Games are one tool that can potentially incentivize people to repeat slow-thinking processes.

Games as an Educational Tool

Serious games combine learning strategies, knowledge and structures, and game elements to teach specific skills, knowledge and attitudes (Laning, 2019); and are designed to be both fun and educational (Girard, Ecalle, & Magnan, 2013). Narrative games, which focus on story structure and core emotional elements (e.g., theme, plot, character, and dialogue, Lionbridge Games, 2020), have been shown to be effective in changing health-related knowledge and behaviors (Zhou, Occa, Kim, & Morgan, 2020). Mobile-based games—which more broadly reach audiences compared to in-person (non-gamified) health promotion activities, thus increasing user accessibility—have used gamification to promote improved health behavior for improved health outcomes (Chib & Lin, 2018).

A subset of digital serious games have the particular educational goal of building players' resilience against misinformation (Roozenbeek & van der Linden, 2018). Past misinformation-focused games have targeted general fake news (Roozenbeek & van der Linden, 2019), misinformation designed to undermine democracy (Roozenbeek & van der Linden, 2020), and health misinformation (Basol et al., 2021; van der Linden, 2021). The framework that these games are based on is active inoculation. Most inoculation messages involve one-way communication, where recipients passively receive the message. In active inoculation games, players learn the techniques of science denial by interactively learning to use the misleading techniques themselves in an ironic fashion. Games can combine the interactive inoculation approach with other gameplay elements, such as being made to repeatedly practice identifying misinformation.

Development of the Original Cranky Uncle

In December 2020, the digital game *Cranky Uncle* was released on iPhone (sks.to/crankyiphone), Android (sks.to/crankyandroid), and browser (app.crankyuncle.info). The game combined previous research on logic-based inoculation, critical thinking, humor-based corrections, and active inoculation and gamification to psychologically inoculate players against science denialism, particularly surrounding climate change. Using adapted cartoons and characters from the cartoon book *Cranky Uncle vs. Climate Change* (Cook, 2020a), the game features an archetypal science-denying "Cranky Uncle" character. He explains how to apply the techniques of science denial, and in so doing, teaches players how to become a science-denying Cranky Uncle themselves. To date, *Cranky Uncle* has been translated into Dutch, German, Spanish, Portuguese, Swedish, French, and Italian, with the game being adopted in over 600 classrooms from 28 countries Cook et al. 2022.

Humor is a key feature of the game, designed to help make the serious game more entertaining (Dormann & Biddle, 2009), as well as incentivize players to continue playing the game (Imbellone, Botte, & Medaglia, 2015). As characters are a strong source of humor in games (Dormann & Boutet, 2013), the character of Cranky Uncle is a central component, delivering deadpan explanations of how he denies overwhelming scientific evidence with fallacious reasoning. As players progress through the game, they collect "cranky points" and regularly graduate to new levels, each of which equate to a crankier mood for Cranky Uncle (e.g., from "tolerable" at the start of the game to crankier moods such as "peevish" and "irate"). The purpose of these gameplay elements is to motivate the player to get further into the game, with the outcome of greater resilience against vaccine misinformation.

As well as fallacy explanations, the game features quiz questions where players identify the denial technique in misinformation examples. The quizzes allow players to collect additional cranky points, motivating them to repeatedly practice spotting denial techniques. The cartoon quizzes are also cartoon parallel arguments, which have been found to attract attention, provoke information seeking, stick in memory longer, and explain logical fallacies in a concrete, accessible form (Compton, 2018; Kim, Vraga, & Cook, 2020).

Development of Cranky Uncle Vaccine

In 2022, a new collaboration between UNICEF, the Sabin Vaccine Institute (Sabin), and Irimi Company enabled the development of the *Cranky Uncle Vaccine*. This new version focused on reducing the influence of vaccine misinformation and, as a secondary goal, fostering trust in vaccines, at both the individual- and community-

level. To enable global roll-out of this intervention, this collaboration aims to create and launch regionalized versions of the game featuring appropriately localized content adapted through co-design workshops with local implementation partners and UNICEF Country Offices. A co-design process was conducted with workshops run in Kampala, Uganda; Kitale, Kenya; and Kigali, Rwanda; to inform the design of the first regional version for East Africa. This section describes the full co-design methodology, inclusive of content and gameplay adaptations informed by the co-design process.

Game Prototype Content Design

Identification of Vaccination Denial Techniques

To prioritize which vaccination denial techniques should be included in the game, an evidence-based literature review was derived from searches within Google Scholar (over an open time period), to curate studies highlighting fallacies in vaccine misinformation. Search terms utilized included "vaccine misinformation" and "fallacies." The literature review provided in-depth depictions of each identified fallacy. As a proxy for the prevalence of each fallacy, the frequency of each denial technique appearing in the literature was tabulated. The 10 most prominent denial techniques were selected to be included in the game. The literature review led to adaptation of the FLICC framework, as two newly identified fallacies were additions to the original FLICC framework fallacies (see Figure 1). Table 1 depicts the 10 most common fallacies as identified by the literature review, as well as the frequency each appeared in the literature and a short description (see Section S2 in the Supplementary Material for more detailed descriptions of the 10 fallacies).

Drafted Game Script and Initial Character Design

Ten script explanations were drafted–one per fallacy–to introduce each denial technique with examples and quiz questions. The script was first written as monologues spoken by the main cartoon character, Cranky Uncle. The drafted script in text form was then shared with our identified East African in-country implementation partners–Sabin social and behavioral research partners affiliated with Makerere University in Uganda, and the University of Nairobi and the Kenya Medical Research Institute (KEMRI) in Kenya; as well as representatives of UNICEF's global Demand for Immunization team and UNICEF Rwanda Country Office and their implementing partners including the Rwandan Ministry of Health. Feedback was obtained, and each fallacy script was updated. Five of the fallacy names were also updated following feedback from in-country partners that some fallacy names were not easily understood. Post Hoc was updated to "False Cause;" Cherry Picking was updated to "Pick and Choose," Anecdote was updated to "Personal Stories;" Appeal to Nature was updated to "Natural is Best;" and Ad Hominem was updated to "Personal Attack." At this stage of development, it was realized that the hybrid approach of fact-based and logic-based inoculation necessitated the introduction of a new character–the health worker (HW). The script was amended so that a doctor character provided the fact-based content and Cranky Uncle provided the logic-based explanations of denial techniques.

Initial sketches of the East African Cranky Uncle were provided to the East African in-country implementation partners through the Focus Group Discussions (FGDs) with potential target groups for their review and feedback. From there, a color digital version of Cranky Uncle was created, featuring the character in a suit jacket, which enabled adaptation of the final scripts into visual mockups used as design probes during the co-design workshops. This blueprint served to guide the embedding of the script and digital version of Cranky Uncle and doctor characters into the game prototype. See Supplementary section S3 for description of the technical set-up of the game.

Several quiz questions in the game required Cranky Uncle to express misinforming statements to other characters. To keep production manageable, the initial number of characters–in addition to Cranky Uncle and the HW–was restricted to just three others–an older woman, a younger man, and a younger woman. In preparation for the in-country co-design workshops, up to three initial sketches per character were drafted.

Co-Design Workshops with East African Partners

Through discussion and collaboration with in-country implementation partners, a three-hour long co-design workshop was planned for four key community member groups across three locations: Kampala, Uganda; Kitale, Kenya; and Kigali, Rwanda. The cadres of participants–identified by implementation partners as potential target users–were i) youth aged 16 to 24 years, ii) parents and child caregivers, iii) medical students,

Figure 1. Vaccine denial techniques within the FLICC framework.

Table 1. Frequency and description of vaccine-related fallacies from literature review (bracketed text is terminology for each fallacy used in the game)

Fallacy/Trick	Frequency	Description
Appeal to nature (Natural is best) 	10	The view that something natural is inherently good while unnatural things are inherently bad (Howard & Reiss, 2018; Kata, 2012; Wawrzuta, Jaworski, Gotlib, & Panczyk, 2021). In the context of vaccines, this fallacy takes the form of assuming that because vaccines are man-made, they are unnatural and therefore potentially dangerous or inferior to natural immunity (Fasce et al., 2021; Stolle et al., 2020).
Post hoc (False cause) 	10	Latin for "after this, therefore because of this," this fallacy confuses correlation with causation. It involves incorrectly identifying two things as being causally associated without enough evidence to do so (CHOP, 2018; Stolle et al., 2020; Zimmerman et al., 2005). A common example is the claimed link between autism and the MMR vaccine (Stolle et al., 2020).
Evil intent 	9	Suspicion about individuals, organizations, corporations, or overarching belief systems (e.g., doctors, the government, pharmaceutical companies, "Western medicine") are an integral feature of anti-vaxxers and conspiracy theorists (Moran, Lucas, Everhart, Morgan, & Prickett, 2016). Conspiracy theorists consider healthcare and government systems untrustworthy because they believe they are corrupt and colluding with pharmaceutical companies, have conflicts of interest, and are deceiving the people (Fasce et al., 2021).
Anecdote (Personal stories) 	7	This fallacy prioritizes personal experiences over scientific evidence, referring to first-hand "testimonies" and personal "narratives" as "evidence" that vaccines are injurious and harmful (Fasce et al., 2021). An example is a heart-breaking story from a mother about her child being hospitalized shortly after a vaccination (Moran, Lucas, Everhart, Morgan, & Prickett, 2016).
Ad Hominem (Personal attack) 	5	Translated from Latin for "to the person," ad hominems attempt to discredit a person's arguments or science by personally attacking them (Cook, 2021). One type of ad hominem is genetic fallacy, where arguments are dismissed by their source of origin. For example, the fact that vaccines are made by pharmaceutical companies is enough to discredit them (Howard & Reiss, 2018).
Misrepresentation 	6	Generally, the misrepresentation fallacy involves misrepresenting a situation or system in such a way as to distort scientific understanding. For example, the claim that vaccines can cause the diseases they are meant to prevent, or that vaccines contain active viruses (Fasce et al., 2021).
Cherry picking (Pick and choose) 	5	This fallacy involves focusing on individual cases or data that seem to confirm a particular position, while ignoring a significant portion of related cases or data that may contradict that position (Howard & Reiss, 2018).
Conspiracy theories 	5	Vaccine conspiracy theories involve governments, pharmaceutical companies, doctors, CDC/WHO, or the media, conspiring to deceive the public about vaccine dangers/adverse side effects from the public (Fasce et al., 2021). Conspiracy theories are an integral feature of the anti-vaccine movement (Howard & Reiss, 2018).
Impossible expectations 	6	Unrealistic standards of safety or efficacy are often demanded when it comes to vaccine safety (Stolle et al., 2020). This involves the demand that vaccination should be 100% safe, and because absolute safety cannot be promised, vaccines are flawed and dangerous. (Fasce et al., 2021).
Fake experts 	5	People are more likely to rely on ideas offered by expert sources but often lack the resources, knowledge, or time to resolve whether someone is an expert or not. This makes them vulnerable to the influence of "fake" experts, who represent themselves as possessing relevant knowledge and expertise when they have none (Lewandowsky et al., 2021). Appealing to fake expertise is also known as an argument from false authority (Howard & Reiss, 2018).

and iv) HWs. In-country partners recruited workshop participants using flyers and by leveraging existing research study cohorts and other health programming networks. Criteria for participation were for individuals to be able to transport themselves to the workshop location, have the use of a smartphone device (i.e., mobile phone, tablet, or laptop), and have English literacy. Co-design workshop participants were provided refreshments and reimbursed for their time and transportation costs to the venue through receipt of the local currency equivalent of US$8.

All four, three-hour focus groups per country setting occurred on the same day–two groups running concurrently during the morning, followed by the last two in the afternoon. Each group was co-facilitated in English (with local language translation into Kiswahili, French, and Kinyarwanda, where needed) by one Cranky Uncle program team representative traveling to the country and one representative from the local implementing partner institution (Makerere University, University of Nairobi, or UNICEF Rwanda). Workshops ran in Kampala, Uganda (36 participants); Kitale, Kenya (37 participants); and Kigali, Rwanda (61 participants); on June 28, July 5, and July 12, 2022, respectively. Rwanda was the only setting within which there was not a subgroup of medical students; however, there was a second session amongst youth. Table S2 in the Supplemental Material further depicts the number of participants per setting and community member sub-group.

During these sessions, participants spent up to 45-minutes playing a prototype of the *Cranky Uncle Vaccine* game without any prior prompting. Participants completed a pre- and post-gameplay survey using a five-point Likert scale to assess the game's effectiveness in increasing misinformation resiliency (as ethics approval wasn't obtained for publication of survey data, this data remains unpublished). Kitale, Kenya, was the only setting in which gameplay was conducted using participants' own cellular data with provided airtime from the preferred service provider. This served to both test game functionality across different mobile network providers in a rural setting and mitigate challenges with venue wi-fi. Ugandan and Rwandan participants connected to the Wi-Fi made available at the workshop venue. During gameplay, participants were provided notepads to capture any likes, dislikes, or other thoughts regarding their experience. To better assess game usability, co-facilitators did not interfere with any participant during gameplay, and simply observed the participants. Post-gameplay, a semi-structured co-facilitated discussion amongst the participants investigated their gameplay experience and understanding of the character constructs. Specially designed and interactive group activities elicited detailed feedback on character sketches and script.

Groupings of printed and laminated cartoon character sketches (i.e., Cranky Uncle, older woman, younger woman, younger man, HW) were taped to the venue walls, giving participants the opportunity to clearly view the drafts. Participants were provided with stickers and asked to use them to vote on their preferred character sketch. An in-depth discussion followed for each character grouping to understand motivations behind participant selection and discuss any additional change requests (to hairstyle, items of clothing etc). Figure S1 shows the co-design activity outcome for the Cranky Uncle character.

To ensure the game script was understood culturally, each group was divided into two smaller groups to facilitate discussions on up to half of the game's fallacy scripts, which were also printed and laminated. Alongside the co-facilitator, participants read the scripts line-by-line, pausing to discuss any needed simplification, further explanation, or cultural translation of words, phrases or examples in the game (e.g., conspiracy theories) that might potentially cause confusion to users, and offer suggested revisions to the script. Participants were also asked to paraphrase their understanding of each denial technique to the co-facilitator, to ensure the true meaning of the fallacy was understood and conveyed appropriately. The same scripts were utilized across settings.

Lessons Learned from Co-Design and Adaptation of Game Elements

Game Construct and Script Revision

The majority of participants had the required digital literacy to play the game, found the game to be interesting and educational, and understood the Cranky Uncle construct. However, in both Kenya and Uganda, it was recommended that there be additional text included to ensure better understanding of the role of Cranky Uncle. Participants in all three countries also requested an in-game introduction to the goals and structure of the game. Following the Kenyan co-design workshop, an "onboarding" script of dialogue between the antagonist (Cranky Uncle) and the protagonist (HW) was developed as a primer to the game (Figure 2) and included in subsequent co-design workshops in Rwanda to eliminate any confusion surrounding Cranky Uncle's role and intentions. There were no other adaptations to the co-design workshops.

One common theme in feedback across countries was the need to simplify the language and add culturally relevant examples. After all workshop feedback across settings was integrated, the Flesch Kincaid reading level of the script was reduced from grade 7.5 before the workshops to grade 6.9. Certain words or phrases, such as "big pharmaceutical companies" or "eating fish gives you gills," did not translate as envisioned and were changed to, "big drug companies" and "eating goat will make you grow a beard," respectively. Text based on U.S. culture, a legacy from the classic version of the game, was removed or replaced with more general or regional interpretations (e.g., the fallacy category "cherry picking" was changed to "pick and choose" to resonate in regions where cherries were uncommon). Additionally, any text related to culturally or politically sensitive issues was removed and replaced with other topics, including any questions that used religion as an example of a fallacy.

The Appeal to Nature fallacy needed to be treated with more nuance, in response to strong cultural beliefs and practices surrounding "traditional" or natural medicine. Traditional healers are influential community members in African culture. Participants–particularly youth and parents and child caregivers in Kenya and Rwanda–felt the original script would be interpreted negatively by communities due to a conflict of choice between Western medicine and traditional medicine. Accordingly, the entire Appeal to Nature section was moved to appear later on in the game so as not to deter players who encountered it early on during gameplay. The fallacy itself was renamed to "Natural Is Best," and the script revised to clearly

Figure 2. Onboarding script.

state that traditional medicine can still be utilized, just not as a substitute for vaccination (Figure S2).

Lastly, participants in Uganda and Rwanda requested to learn more about vaccination within the game, and therefore facts regarding safety, efficacy, and the importance of vaccines were written into fallacy scripts following the co-design workshops.

Cartoon Character Adaptation

Across all three countries, the Cranky Uncle's suit jacket was considered too formal, conveying a degree of credibility and trust that could confuse interpretation of the Cranky Uncle construct. The final version of the Cranky Uncle character design was instead dressed in a long-sleeve shirt, with glasses, receding hair, pocket pens, and a watch. In-country implementation partners helped to choose the appropriate skin tone.

It was advised that the portrayal of the HW character should be a nurse or community health worker, as they are closer to the community than facility-based doctors, and are thus a more trusted source of health and vaccination information. Participants suggested all-blue attire underneath the white coat, removing the stethoscope, and adding a pocket holding a thermometer. Table 2 shows the various renditions of each character design, as well as the final version incorporating workshop recommendations.

Table 2. Initial sketches through to final, amalgamated design of East African Cranky Uncle cartoon characters

	Selected Option	Option 2	Option 3	Final Design	Suggested Revisions
Cranky Uncle					He needed to appear more balding with gray hair Add a shirt pocket with pens Have him wear spectacles and a watch
Older woman					Head scarf style to change from West African to East African Add large shoulder handbag Change heeled shoes to flat slide sandals
Younger woman					Change hairstyle to braided hair in a bun with two hanging braids More form-fitted black vest top Change shoes to high heels Add make-up and earrings, small shoulder handbag, and mobile phone
Younger man					Make pants into distressed jeans Change shoes to sneakers Add cap and headphones
Health Worker					Have all-blue attire under white coat Remove stethoscope Add pocket holding thermometer Change hair from bun to tied up in a braid

The digitized Cranky Uncle and HW within the "option" columns were the characters included in the prototype of the game played during the co-design workshops.

Discussions around the additional characters confirmed that while they were to be a minor part of the game, only appearing within quiz questions, their inclusion was considered important. Local players could see themselves in the game by relating to the characters. Participants also suggested introduction of additional characters (e.g. a pregnant woman, a child, a person with disabilities) in order to better reflect the diversity of their societies. The introduction of a religious figure–such as an imam or priest–was also discussed, but ultimately rejected as too potentially divisive. Certain colors (yellow and red) and character poses were also identified as potentially problematic and removed from the game, such as the thumbs-up gesture, which may be politicized or viewed as offensive in some African countries. A party whistleblower animation shown when players level up was deemed irrelevant to African culture and was replaced with a more general image.

Gameplay Elements

Workshop participants also provided feedback on structural gameplay elements, and young people, in particular, had many ideas on how to make it more entertaining. Common feedback across all participant groups and settings was that the game would be more dynamic and engaging if players were given audio notification or a visual reward for leveling up. In response, confetti animation will be added to a future iteration of the game to celebrate level completion. This is consistent with research finding that games show the greatest player outcomes when they combine a variety of achievement notifications (Blair et al., 2016). Other examples of suggested gameplay edits that were adopted included deducting points if a player answered a quiz question incorrectly and locking future denial technique "levels" until earlier levels were mastered and completed.

Discussion

Development of *Cranky Uncle Vaccine* combined an evidence-based content design drawing on inoculation theory, critical thinking, research into humorous corrections, and evidence on vaccine trust, with a co-design process that resulted in a more culturally relevant intervention, as informed by the community. If the co-designed game is found effective through a subsequent pilot study validation, this methodology provides a blueprint for further adaptation of the Cranky Uncle Vaccine to other regions, as well as replication of locally relevant intervention development to counter future infodemics.

Inoculation theory proposed a theoretical method of building resistance against misinformation, by explaining the rhetorical techniques used to mislead. By combining explanations of misleading tricks with real-world examples, misinformation is delivered in weakened form, thus conveying cognitive immunity against other examples of misinformation using the same techniques. Research into humorous misinformation correction and development of serious games offered an approach for presenting inoculating content in an engaging format that incentivized players to practice critical thinking, thus reinforcing the resilience induced by the inoculation explanations. The co-design process was used to adapt the game content into a format intended to resonate with local audiences which is a critical process often lacking in such tools affecting game effectiveness or sustainability.

Concurrent with the co-design workshops, stakeholder meetings were conducted in Uganda, Kenya, and Rwanda to lay the groundwork for a nation-wide promotional plan to disseminate the game in each country once validated through pilot studies. Stakeholder groups included government department representatives (e.g., Essential Program on Immunization [EPI] managers and expanded partners); leaders of youth and student organizations; and members of the health professional association. Discussions included identifying a) the target audiences of the game (primarily youth and health workers); b) how can the target audience be reached; and c) public and/or private organizations that should be engaged in strategic promotional planning to assist with scale-up. Integral to these conversations was exploration of how the *Cranky Uncle Vaccine* game could be integrated within broader, existing immunization, communication or education programs or services, such as educational curriculum within schools or health promotion outreach activities.

Pilot studies were planned at this time to be conducted in Uganda and Kenya in collaboration with research partners at Makerere University, University of Nairobi and KEMRI, for assessment of game efficacy. In-game surveys conducted at the start and end of the game will measure changes in trust in vaccines, using psychometrically validated items from the vaccination trust indicator, and the ability to discern between vaccine facts and misinformation, using a standard approach to measuring perceived reliability of information (Ellingson, Omer, Sevdalis, Thomson, & Wagner, 2023). Partner organizations were consulted on strategies to recruit research participants.

A limitation of these case studies is that they were conducted in only three countries in East Africa. We deliberately targeted English-speaking countries, and it remains to be seen how the co-design process will work in other languages. Other challenges that may vary across different regions are cultural differences between urban and rural areas, religious sensitivities, literacy levels in some regions, and internet connectivity.

In conclusion, we have documented the development process of the *Cranky Uncle Vaccine* game. We adopted an interdisciplinary approach, which is necessary to address complex societal issues such as misinformation (Ecker, 2017; Ecker et al., 2022; Lazer et al., 2018; Lewandowsky, Ecker, & Cook, 2017). The development of the *Cranky Uncle Vaccine* combined science, technology, psychology, education, and the arts, then iterated the content directly with community members, through the co-design process. This resulted in a game that is more locally relevant and resonant, with the goal of maximizing its effectiveness in increasing vaccine acceptance and resistance to misinformation.

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No potential conflict of interest was reported by the author(s).

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Supplementary Material

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