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A community-based One Health education program for disease risk mitigation at the human-animal interface

Amanda M. Berrian[a], Martin H. Smith[b,*], Jacques van Rooyen[c,d], Beatriz Martínez-López[e], Monica N. Plank[b], Woutrina A. Smith[f], Patricia A. Conrad[a]

[a] Department of Pathology, Microbiology and Immunology, School of Veterinary Medicine, University of California, Davis, CA, USA
[b] Department of Human Ecology/Department of Population Health and Reproduction, School of Veterinary Medicine, University of California, Davis, CA, USA
[c] Department of Veterinary Tropical Diseases, Faculty of Veterinary Science, University of Pretoria, Onderstepoort, South Africa
[d] Centre for Veterinary Wildlife Studies, Faculty of Veterinary Science, University of Pretoria, Hans Hoheisen Wildlife Research Station, Orpen Gate, Kruger National Park, South Africa
[e] Center for Animal Disease Modeling and Surveillance, Department of Medicine and Epidemiology, School of Veterinary Medicine, University of California, Davis, CA, USA
[f] Department of Medicine and Epidemiology, School of Veterinary Medicine, University of California, Davis, CA, USA

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ABSTRACT

The interface between humans, domestic animals, and wildlife has been implicated in the emergence of infectious diseases and the persistence of endemic human and animal diseases. For individuals who reside at this interface, particularly those in low-resource settings, the development of disease risk assessment and mitigation skills must be prioritized. Using a community engagement-One Health approach, we implemented a training program aimed at advancing these skills among agro-pastoralists living adjacent to conservation areas in South Africa. The program included professional development of local facilitators who then conducted workshops with community members. Workshops used a series of experiential, inquiry-based activities to teach participants the concepts of pathogen transmission and disease risk assessment and mitigation. The program was implemented over four weeks with 10 facilitators and 78 workshop participants. We conducted a within-subjects experimental study using a mixed methods design to evaluate the program in terms of facilitator and participant One Health knowledge and practices. Quantitative data included pre/post written assessments; qualitative data included focus group discussions, semi-structured interviews, and pre/post photographs. Mean post-test scores of facilitators increased by 17% ($p = 0.0078$). For workshop participants, improvements in knowledge were more likely for females than males (OR = 7.315, 95% CI = 2.258–23.705, $p = 0.0009$) and participants with a higher versus lower education level, albeit borderline non-significant (OR = 4.781, 95% CI = 0.942–24.264, $p = 0.0590$). Qualitative analysis revealed the implementation of risk mitigation strategies by 98% (60/61) of workshop participants during the three-month follow-up and included improved personal and domestic hygiene practices and enhanced animal housing. Although further evaluation is recommended, this program may be appropriate for consideration as a scalable approach by which to mitigate human and animal infectious disease risk in high-risk/low-resource communities.

1. Introduction

The interface between humans, domestic animals, and wildlife has been implicated in the emergence of infectious diseases and the persistence of endemic zoonoses [1–3]. While these diseases are of global concern, their impact is disproportionately high in developing countries due to a combination of factors, including a high proportion of people with compromised immunity due to co-morbidities such as HIV/AIDS; lifestyles in which daily life depends on animals; and low resources [2,4]. In recent history, most disease outbreaks were driven by a breakdown of public health measures, including sanitation and hygiene, immunization, and vector-borne and zoonotic disease control [5]. Thus, health promotion in these high-risk/low-resource settings must be prioritized and, by utilizing a One Health (OH) approach, should target pathogen dynamics at the human, animal, and environmental level.

Abbreviations: CE, Community Engagement; EM, Environmental Monitor; FGD, Focus Group Discussion; MCP, Mnisi Community Programme; OH, One Health; OHTL, One Health Training and Leadership; PD, Professional Development; TFCA, Transfrontier Conservation Area

* Corresponding author at: 3213 Vet Med 3B, Davis, CA 95616, USA.
E-mail address: mhsmith@ucdavis.edu (M.H. Smith).

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Community engagement (CE), the process of working with and through groups of people to address issues affecting their well-being [6], has been advocated as a useful strategy for health promotion in low-resource groups [7,8]. Successful infectious disease control programs require both CE and educational outreach to disseminate information to the public; however, these components are often neglected [9]. For example, surveys focusing on rabies prevention have repeatedly identified gaps in knowledge of risks, modes of transmission, and preventive measures [10–12]. When implemented, CE and educational outreach can be cost-effective risk mitigation strategies in high-risk/low-resource areas [13].

In Mpumalanga Province, South Africa, where agro-pastoralist communities live adjacent to several conservation areas, most of which form part of a transfrontier conservation area (TFCA) [14], nearly 20% of people are infected with HIV and poverty rates exceed 60% [15,16]. Prior research identified high-risk behaviors for pathogen transmission and gaps in health knowledge, particularly among animal owners [17]. These findings provided the foundation for *One Health Training and Leadership* (*OHTL*), a community-based human and animal infectious disease risk mitigation program. With a CE-OH approach, the *OHTL* program used a sequence of hands-on activities to teach participants infection control concepts. To build local capacity and promote community acceptance, program facilitators were members of the community who had received professional development (PD).

For *OHTL* facilitators, we hypothesized the program would improve their professional skills and OH knowledge. For *OHTL* participants, our hypothesis was that the program would improve their OH knowledge and skills through the implementation of human, animal, and environmental risk mitigation strategies. This study aimed to address these hypotheses by evaluating facilitator and participant outcomes before and after the intervention. Additionally, we aimed to identify participant factors related to program outcomes. Results can help inform the development of future community-based programs that strive to reduce disease risk among vulnerable human and animal populations.

2. Methods

2.1. OHTL curriculum development and pilot testing

The first step in developing the *OHTL* curriculum was to adapt hands-on, inquiry-based activities and tools (e.g., Risk Assessment Tool) from a biosecurity project for livestock producers in the 4-H Youth Development Program [18]. Activities were supported by the theoretical underpinnings of Social Cognitive Theory (SCT), the interactions between people, their behavior, and their environments [19], as well as constructivist learning theory, whereby learners construct knowledge and meaning through experience [20]. For example, learning activities emphasized reciprocal determinism, such that participants learned how environmental factors influence pathogen transmission, but also how they can influence their environment to mitigate transmission risk [19]. Constructivist-based activities were sequenced and divided into four modules: (1) pathogen transmission in humans and animals; (2) OH risk assessment; (3) OH risk mitigation; and (4) OH in action (Appendix A). Modules were designed to be implemented over two workshops which provided opportunities for participants to build knowledge and skills over time and complete authentic assessments to gauge learning and help them apply concepts.

The *OHTL* curriculum was pilot-tested with adult livestock owners in rural California, USA. This step allowed for the trial of activities among similar-aged learners and the determination of whether the proposed assessment tools measured the intended construct (i.e., face validity) [21]. Observational data were collected for formative purposes and reviewed by investigators to identify modifications to the curriculum and facilitator training manual. Changes in the curriculum included revision of learning assessments to improve validity; and changes in the training manual aimed at improving implementation fidelity (i.e., how well the intervention was executed as planned) [22], such as recommendations for activity set-up and facilitator preparation.

2.2. OHTL program evaluation

2.2.1. Study area and village selection

The study area, located in the Bushbuckridge Local Municipality, Mpumalanga Province, South Africa, is the core engagement area of the Mnisi Community Programme (MCP), University of Pretoria (UP). More than 75% of the study area borders conservation areas, including the Great Limpopo TFCA. The total population is approximately 50,000 individuals in 8500 households, with an estimated two-thirds of households owning livestock [17]. We selected three villages from the area to conduct our study. Village selection was based on their involvement in prior research to further build the relationship between researchers and community members.

2.2.2. Study population

The study had two populations: *OHTL* facilitators (“facilitators”) and *OHTL* participants (“participants”). Facilitators were selected from MCP Environmental Monitors (EM), residents of the study area who are hosted by UP and employed by the Kruger to Canyons Biosphere Reserve with funding from the Expanded Public Works Programme of the Department of Environmental Affairs [23]. All EMs have a minimum of a Grade 12 (high school) education, experience with animal handling, and English language proficiency.

Participants were residents of the study area who were recruited through selected villages' Community Development Forum (CDF), an internal leadership group that generally represents individuals of all village factions, including traditional leaders, cattle owners, traditional healers, health care workers, and teachers. For two of the selected villages, participants included CDF members and village residents. For the third village, participants included CDF members, village residents, and residents of two other villages over which the CDF had governance. Additional eligibility criteria included age (≥ 18 years) and availability. To detect a difference of 20% between pre/post assessments with $\alpha = 0.05$ and 80% power, a total sample size of 82 individuals was desired, which accounted for 15% attrition [24].

2.2.3. Intervention

We implemented the *OHTL* program over four weeks in March 2016, alternating between PD workshops of facilitators, led by study investigators, and curriculum implementation with participants, led by the facilitators. The first PD workshops for facilitators occurred during weeks 1 and 2 of the intervention and included pedagogical strategies (e.g., guided inquiry, experiential learning, and effective questioning) [25] and curriculum content for modules 1 and 2. During week 3, teams of facilitators conducted the first participant workshops which included the first two curriculum modules. Within-workshop facilitator support strategies included the provision of written manuals and monitoring/feedback by study investigators. After completion of these modules, participants applied their knowledge and skills by completing a OH risk assessment (Appendix B) of their home premises which allowed participants to observe and compare high-risk to low-risk factors, such as free range vs. confined livestock (animal risk), infrequent vs. frequent hand washing (human risk), and standing water near home vs. no standing water near home (environmental risk); facilitators provided technical assistance as needed. The next PD workshops for facilitators focused on curriculum modules 3 and 4 and were completed by the end of week 3. During week 4, the same facilitator teams conducted the second participant workshops which guided them through curriculum modules 3 and 4 and included the development of a risk mitigation plan by each participant. Risk mitigation plans comprised practical strategies to reduce risks identified by participants using the OH risk assessment tool.

2.2.4. Study design

We conducted a within-subjects experimental study using a mixed methods design. Quantitative and qualitative data were collected and analyzed to evaluate the program in terms of facilitator and participant knowledge, skills, and practices. Qualitative data were used to further explain the quantitative outcomes [26].

2.2.5. Data collection

2.2.5.1. Knowledge and skills acquisition by facilitators. An objective written pre-/post-test was used to evaluate knowledge quantitatively; questions were based on learning objectives (Appendix A) and included a combination of 12 multiple-choice (single answer) and true/false questions. A self-report of knowledge and skills, administered after the intervention, was used to compare facilitators' perception of their own understanding and abilities related to *OHTL* modules before and after the program. Self-reports also evaluated pedagogical knowledge and leadership skills, specifically effective workshop facilitation and understanding of constructivist-based learning [20]. Self-reports included six paired questions each with four response categories ranging from "Poor" to "Excellent." This retrospective format was chosen to reduce response-shift bias [27] and has been used previously to demonstrate change in conceptual understanding by learners [18]. Components of the self-report (e.g., ability to facilitate a training workshop) were grounded in the self-efficacy construct of SCT [19]. Content validity by subject experts, including those from the health and social sciences, was used to develop quantitative learning assessments [21].

2.2.5.2. Knowledge and skills acquisition by participants. For participants, acquisition of knowledge and skills pertaining to *OHTL* modules was assessed quantitatively using the objective pre-/post-test and the retrospective self-report questionnaire. Similarly, components of the self-report (e.g., ability to assess environment) were grounded in the self-efficacy construct of SCT [19]. Qualitative assessment included a post-intervention audio-recorded focus group discussion (FGD) with randomly selected participants from each group. Focus group discussions were conducted by a trained moderator (study investigator) and two assistant moderators (facilitators). The purpose of the FGDs was to assess knowledge acquisition by participants and triangulate results with the pre/post assessments [26,28].

2.2.5.3. Knowledge application by participants. Data were generated by participants during the intervention in the forms of a personalized OH risk assessment with accompanying photographs and OH risk mitigation plan. Photographs provided evidence of the application of learned concepts and allowed for within-workshop discussion of these concepts in a personalized context. Three months later, semi-structured interviews were performed at participants' households to determine the extent of their risk mitigation plan implementation, as well as self-perceived effort, associated costs, and barriers to implementation. Additional photographic data were collected to document risk mitigation strategies implemented.

For all participants, demographic data were collected pre-intervention using a written questionnaire. All program documents were written in English and translated into the local language (Shangaan). During FGDs and interviews, investigators asked questions in English, and facilitators translated to/from Shangaan.

2.2.6. Data analysis

Descriptive statistics were used to summarize quantitative data. Normality was assessed for each variable; the appropriate test was selected to assess association between variables and/or groups. Objective pre-/post-tests were scored by calculating the percentage of correct responses and compared by calculating the percent difference. Analysis was performed on subjects with complete data.

To address the second objective, a change score was calculated for participants by subtracting objective pre-test from post-test scores. A binary variable was created for improvement or not in participant knowledge, coded as 1/0, respectively. Improvement was defined as a positive change score (i.e., 1); no improvement was defined as a negative or neutral change score (i.e., 0). A logistic regression model was used to identify factors contributing to knowledge improvement. The model was expressed as follows:

$$y_i \sim Bernoulli\ (\pi_i);\ \text{logit}\ (\pi_i) = \beta_0 + \beta_1 \times {}_{1i} + \beta_2 \times {}_{2i} + ... + \beta_k X_{ki}$$

where y_i was the binary dependent variable—improvement on post-test yes/no—for individual i; π_i was the expected probability of improvement; β_0 was the intercept; and β_{1i}, β_{2i}, …, β_{ki} were the slopes. Model construction was initiated with a univariate analysis of hypothesized risk factors using a $p < 0.2$. Significant variables were included in a multivariable model. The best-fitting multivariable model was assumed to be the one with the lower Akaike information criterion (AIC) and containing significant predictors ($p < 0.05$) and confounders. Analyses were performed in SAS v9.4 (SAS Institute, Cary, NC, USA).

Qualitative data, including semi-structured interviews, were analyzed inductively by two investigators using the constant comparison method [29], with emphasis placed on the frequency of themes/subthemes [30]. If intercoder agreement was not reached, a third investigator was used to aid in interpretation and achieve consensus [26]. Microsoft Excel (Redmond, WA, USA) was used for data management and descriptive statistics. Study investigators compared pre/post photographic data and selected those for inclusion based on their representativeness of risk mitigation strategies.

2.2.7. Ethics

Ethics approval was sought from the UP Faculty of Health Sciences Research Ethics Committee and the UC Davis Institutional Review Board. Permissions were granted by the Mnisi Traditional Council and village leaders. All enrolled participants provided written consent. Facilitators and participants were assigned an identification number to maintain anonymity. Written materials and workshops were in English for facilitators and Shangaan for participants. When needed, facilitators read written materials aloud to facilitate comprehension by participants.

3. Results

3.1. Study participants

All MCP EMs participated in the study as facilitators, which included seven males and three females. Median age of facilitators was 30.5 years (interquartile range = 28–40).

Seventy-eight participants were enrolled. Participants with a higher education level (≥ grade 12) were younger than those who were less educated (median age = 34 vs. 63 years; Kolmogorov-Smirnov test, $p < 0.0001$). There was no evidence that education level varied by gender (Fisher's exact test, $p = 0.1407$). Of the participants who did not complete the training and follow-up, 94% (15/16) were males. A description of participants by group is provided in Table 1.

3.2. Knowledge and skills acquisition

3.2.1. Facilitators

Eight facilitators (80%) had improved objective post-test scores; two had no change. Overall mean score improved by 17% (signed rank test, $p = 0.0078$). On self-reports, facilitators' understanding of pathogen transmission in humans, risk mitigation, and effective pedagogy improved significantly (Wilcoxon signed rank test, $p = 0.0156$, 0.0020, and 0.0020, respectively). Self-reports also indicated a significant improvement in skills, specifically their abilities to conduct a risk assessment and facilitate a workshop (Wilcoxon signed rank test, $p = 0.0078$ and 0.0020, respectively).

Table 1
Description of *One Health Training and Leadership* participants, by village group.

	Athol	Gottenburg	Utha	Total	*p*[a]
Participants at enrollment, *n*	31	38	9	78	
Male, *n* (%)	22 (71)	21 (55)	1 (11)	44 (56)	0.0061[1)]
Female, *n* (%)	9 (29)	17 (45)	8 (89)	34 (44)	
Age, median (IQR)[b], in years	62 (45–73)	37 (27–45)	34 (25–40)	43 (29–60)	< 0.0001[2)]
Highest education level completed					0.0001[3)]
None, *n* (%)					
Primary, *n* (%)	11 (35)	1 (3)	1 (11)	13 (17)	
Grade 8–11, *n* (%)	9 (29)	3 (8)	1 (11)	13 (17)	
Grade 12 or higher, *n* (%)	3 (10)	5 (13)	1 (11)	10 (13)	
	8 (26)	29 (76)	6 (67)	43 (55)	
Animal ownership, *n* (%)	28 (90)	31 (82)	9 (100)	68 (87)	0.4408[3)]
Participants who completed training, *n* (%)	28 (90)	33 (87)	9 (100)	70 (90)	0.6717[3)]
Participants who completed 3-month follow-up, *n* (%)[c]	26 (93)	29 (88)	7 (78)	62 (89)	0.7251[3)]

[a] Frequencies between village groups were compared by: [1)] chi-square test, [2)] Kruskal-Wallis test, or [3)] Fisher's exact test.
[b] Interquartile range.
[c] Of participants who completed training.

3.2.2. Participants

Thirty-three *OHTL* participants (48%) had improved post-test scores; 11 had no change. For all modules, the mean percent difference between pre-/post-tests was positive for females and those with a higher education level (≥ grade 12); males had a negative mean percent difference for all modules (Fig. 1). Female participants were over seven times more likely than males to have improved post-test scores; more educated participants were nearly five times more likely than participants with less education (Table 2).

Overall, participants reported improved understanding of concepts; however, females were more likely than males to report improved understanding of disease prevention and OH. Participants with a higher education level were more likely to report improved understanding of pathogen transmission in animals and OH than participants with less education (Table 3).

Three FGDs were conducted, each with 5–6 male and female participants. During FGDs, males ($n = 6$) and females ($n = 10$) could accurately describe program concepts. For example, a male participant described poultry quarantine procedures: "*One chicken is sick then I have just to separate it. I have to take it out from the healthy ones.*" A female participant described indirect pathogen transmission: "*You can touch the door handle coming from the toilet, you didn't wash your hands…somebody comes and then touch the same door handle.*"

3.3. Knowledge application: risk assessment and mitigation

Each participant identified 3–5 household, environmental, and/or community health risks as part of their OH risk assessment. Risks are summarized by themes and sub-themes in Table 4 (abridged) and Appendix C (unabridged) and classified according to whether they were considered a risk to human (H), animal (A), or environmental health (E). A selection of photographs documenting these risks, along with photographs depicting mitigation strategies implemented three months later, are presented in Fig. 2.

Sixty-two participants (79%) could be reached for follow-up interviews. Comparing risk mitigation plans to follow-up interview responses revealed the implementation of 70% (174/247) of proposed mitigation strategies by participants; proportions were similar for males and females (Appendix C). Representative responses from participants included: "*Always wash hands after using the toilet to prevent diseases*" (hygiene-H); "*Vaccinations are important to keep cattle healthy. Before [I] thought it was giving it disease, now [I] know it is preventing disease*" (medical/disease prevention-A); *"We must clean our environment. We should not throw rubbish all over"* (garbage/sanitation-E). Ninety-eight percent (60/61) of participants had implemented ≥ 1 risk mitigation strategies. The median self-perceived effort for strategies implemented was 2 (1 = no effort, 5 = maximum effort). The mean cost of strategies implemented was 79 ZAR (~$5.50 USD), with most being no cost (e.g., hand-washing). For plans not yet implemented, the greatest barriers were lack of money, time, and supplies. Ninety-five percent of participants (58/61) had shared their knowledge with other community members.

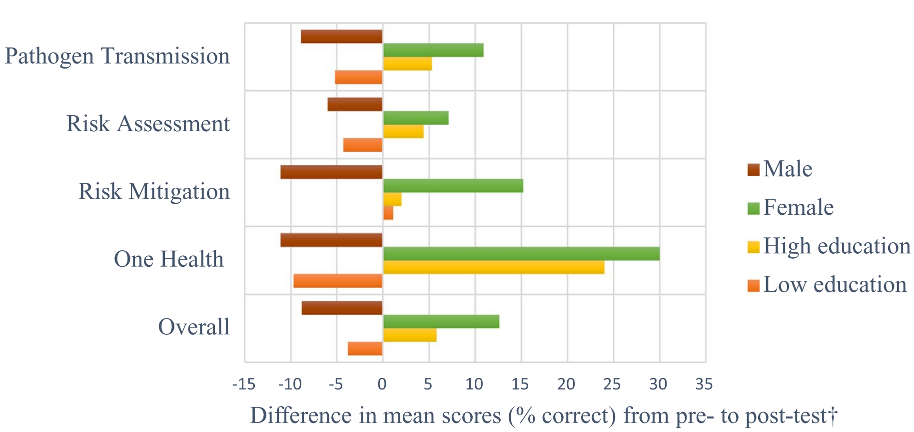

Fig. 1. Change in *One Health Training and Leadership* participant ($n = 69$) knowledge by gender and education level.
†12 questions (multiple choice, true/false).

Table 2
Change in knowledge – Independent predictors, beta coefficients, odds ratios (OR) and 95% confidence intervals (CI) obtained for univariable and multivariable logistic regression model of improvement in knowledge (yes/no) of *One Health Training and Leadership* participants ($n = 69$) using an objective pre-/post-test.

Predictors (n)	β	Univariable OR	95% CI	p[a]	β	Multivariable OR	95% CI	p
X_1. Gender coded as 1—female (33), 0—male (36)	1.7884	5.980	2.112–16.931	0.0008	1.9900	7.315	2.258–23.705	0.0009
X_2. Education level coded as 1—high (38), 0—low (31)	0.9163	2.5	0.940–6.646	0.0663	1.5647	4.781	0.942–24.264	0.0590
X_3. Age[b] (continuous)	− 0.0123	0.988	0.961–1.016	0.3834	0.0371	1.038	0.989–1.089	0.1288
Fit statistics for multivariable model								
AUC (ROC)						0.796		
AIC						84.535		

Model fit statistics: AUC = area under curve; ROC = receiver operating characteristic; AIC = Akaike information criterion.
[a] Wald test.
[b] Variable X_3 was tested both as a continuous and binomial (1 = value ≥ median; 0 = value < median) variables to determine the best model fit.

4. Discussion

Program outcomes revealed the acquisition and implementation of new knowledge by participants. Specifically, participants could identify and mitigate OH risks at their households and surrounding premises. However, differences in knowledge acquisition by gender and education level were apparent on quantitative assessments, despite controlling for age. These findings may support a growing awareness of the role of gender as a social and biological construct in determining various health outcomes [31]. In rural areas, men and women perform different activities due to gender norms. For example, men are more likely to be involved in hunting and large livestock production, while women care for small livestock and produce subsistence food [31]. Thus, activities involving livestock, crops, and natural resources are gender sensitive as is the risk to contract disease from these activities [32]. However, disaggregation and analysis by gender are rarely per-

Table 3
Change in knowledge and skills – Frequency and proportion (%) of *One Health Training and Leadership* participants ($n = 69$) who reported an improved understanding/ability regarding program concepts using a retrospective self-report (subjective) questionnaire with four response categories (1 = poor, 4 = excellent), by gender and education level.

Concept	Gender		p[a]	OR[b] (95% CI)	Education level		p	OR (95% CI)
	Male ($n = 36$)	Female $n = 33$)			High ($n = 38$)	Low ($n = 31$)		
Pathogen transmission (humans)	22 (61)	23 (70)	0.4545		25 (66)	20 (65)	0.9120	
Pathogen transmission (animals)	15 (42)	13 (39)	0.8477		20 (53)	8 (26)	0.0240	3.194 (1.145–8.912)
Risk assessment[c]	17 (47)	19 (58)	0.3898		21 (55)	15 (48)	0.5695	
Risk mitigation	10 (28)	15 (45)	0.1270		17 (45)	8 (26)	0.1037	
Disease treatment/prevention	8 (22)	16 (48)	0.0221	3.294 (1.163–9.328)	13 (34)	11 (35)	0.9120	
One Health	13 (36)	20 (61)	0.0419	2.722 (1.027–7.214)	24 (63)	9 (29)	0.0048	4.190 (1.514–11.595)

CI = confidence interval.
[a] Chi-square test.
[b] Mantel-Haenszel odds ratio (OR) calculated for significant ($p < 0.05$) independent variables.
[c] Assessed as a skill.

Table 4
Knowledge application (*abridged*) – Selection of One Health (human, animal, and environment) risks identified and mitigation strategies proposed and implemented by *One Health Training and Leadership* participants ($n = 62$), categorized by gender.

	Theme	Sub-theme	Mitigation strategy proposed (n)	No. strategies implemented/total proposed	
				Male	Female
Human	Hygiene (personal and domestic)	Touching high-use surfaces (e.g., door handle, water tap)	Wash hands (18)	5/9	9/9
			Wash surface (11)	3/3	6/8
			Cover/paint surface (2)	1/2	
	Property maintenance	Standing water	Cover/eliminate water (19)	6/9	8/10
			Spray for mosquitoes (2)	2/2	
			Move outdoor kitchen (1)	0/1	
Animal (domestic)	Housing	Inadequate housing/confinement	Build/repair/use coop/kraal (17)	4/9	3/8
			Separate animals by species/health status (4)	2/3	1/1
			Confine cat indoors (1)	1/1	
			Sell chickens (1)	1/1	
	Medical care & disease prevention	Inadequate/incomplete vaccination	Vaccinate (8)	2/4	1/4
			Build coop (1)	0/1	
Environment	Garbage/sanitation	Improper garbage disposal	Burn garbage (6)		6/6
		Fecal waste	Collect/remove garbage/waste (2)		2/2
	Food/water	Contamination by domestic/wild animals	Build enclosure (2)	1/1	1/1

(a)
(b)
(c)
(d)

Fig. 2. a–d. Photographs depicting high-risk practices or interfaces before and after risk mitigation. (a) Bucket with water is made available in the toilet area for hand-washing, (b) Standing water is removed near the house to reduce mosquitoes, (c) A water tap is covered to reduce contamination from animals, (d) Building materials and debris are removed from around the house to reduce risk of vectors and vermin.

formed in health program evaluations [33]. Results from this study highlight a need to consider gender in the design, implementation, and evaluation of community-based health promotion interventions to help optimize outcomes for men and women. Given the significance of gender as a predictor of knowledge acquisition, investigators are currently involved in a follow-up study to further evaluate roles and responsibilities of community members, as they pertain to One Health risks, by gender. While analysis is incomplete, preliminary data suggest the possibility of personal motivation as one factor for differences by gender.

Explanations for the disparity on written assessments for participants between education levels may include: unfamiliarity with assessment type, poor literacy, and translation errors. In our study, participants with a low education level were older, which is likely due to the apartheid legacy (1948–1994) that restricted educational access to black South Africans. However, despite lacking written language skills, the identification of OH risks and the broad implementation of mitigation strategies indicated comprehension and application of concepts by participants. Thus, our outcomes provide merit to the use of a mixed methods design for program evaluation, whereby the qualitative data provided a more comprehensive account of the inquiry. Relying exclusively on quantitative indicators would have underestimated participant outcomes, particularly among males.

Program impacts were seen despite linkages between CE and health behaviors being historically difficult to identify [34,35]. By the end of the three-month follow-up period, strategies to mitigate disease risk were implemented at the human, animal, and environmental level. Additionally, most participants had shared their knowledge with others, extending the reach of the program beyond those enrolled. While we did not assess health outcomes directly, the strategies implemented could decrease the risk of infectious disease in individuals and their animals [36]. Improved livestock health can also impact household poverty, food security, and gender equality [32]. Furthermore, through the *OHTL* program, community leaders have a greater understanding of the dependence of health on many factors which is critical to upstream, multi-sectoral health policy.

Program outcomes were also supportive of improved OH knowledge and skills of facilitators. Additionally, by using community-based facilitators, our program developed specific leadership skills of selected community members. Facilitators indicated an improved ability to facilitate a training workshop. On a larger scale, this program could be used to build OH capacity in low-resource communities. Community health workers play an important role in disadvantaged communities where health services and education may be lacking [37]. Using a similar program to expand their knowledge and skillset to include OH leadership could have wide-ranging impacts on human and animal health.

One limitation of our study was selective reporting bias (i.e., suppressing unfavorable information), which we reduced by using photography to document implemented risk mitigation strategies, rather than relying on self-report. Our training approach also had limitations, including loss of implementation fidelity. To minimize this, we used facilitation support strategies including the provision of manuals, monitoring, and feedback [22]. In addition, facilitators worked in pairs or small groups to allow for team teaching. Other limitations included the selection of pilot test participants from outside the study area and potential issues regarding assessment reliability. Recommendations for future *OHTL* program implementation include the selection of a more representative pilot test audience to maximize relevancy of the curriculum, and the evaluation of quantitative learning assessments by reliability measures to enhance data interpretation. Additionally, future iterations of the intervention would benefit from further grounding in health behavior theory.

Much of the literature on community-based disease prevention interventions endorses a model of evidence whereby replication of earlier trials is prioritized over attention to unique features of the current setting [38,39]. In contrast, the *OHTL* program emphasized local context which may have contributed to its efficacy and community acceptance [7,39]. The use of community-based facilitators for program delivery could have also contributed to the high involvement and retention of participants [7].

Recent research highlighted the lack of systematic evaluations of OH interventions [40]. This study adds to the literature by providing a formal evaluation of a OH program using both quantitative and qualitative metrics. While results of the study are promising, further evaluation of the *OHTL* program would be recommended prior to broad implementation and may include comparing our curriculum and pedagogical methods to more traditional community education interventions. Additionally, comparing human and animal disease prevalence before and after the intervention and/or between participants and nonparticipants would be recommended to validate our results.

5. Conclusion

Our community-based One Health education program may have implications for endemic and emerging infectious diseases, particularly when implemented in high-risk/low-resource settings. We suggest similar programs be considered for such areas globally as part of a long-term development strategy. The curriculum should be contextualized, as well as gender sensitive. These programs should use a CE-OH approach utilizing local facilitators and contemporary pedagogy, giving ownership of the solutions to those most affected.

Conflict of interest statement

The authors declare no personal or financial conflict of interest.

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Appendix A. ***One Health Training and Leadership*** **modules**

	Module 1: Pathogen transmission in humans and animals	Module 2: One Health risk assessment	Module 3: One Health risk mitigation	Module 4: One Health in action
Learning objectives	1) Describe “health” 2) Describe what it means to be “sick” 3) Identify modes of transmission of infectious pathogens 4) Compare disease (presentation, modes of transmission) in people vs. animals 5) Identify role of environment (indoor/outdoor) in health	1) Define risk 2) Describe risky behaviors/situations in terms of health 3) Understand what factors make disease more/less likely in people/animals (i.e., disease risk) 4) Understand that risk cannot be eliminated	1) Identify methods to mitigate disease risk in people/animals 2) Describe practices/behaviors in people/animals that support health 3) Describe benefits of risk mitigation in terms of greater community/environment 4) Understand basic principles of financial risk (cost vs. benefit)	1) Communicate learned health messages to another audience 2) Understand how/why promoting health at the individual level is important to community/environmental health 3) Describe benefits/challenges of your community's environment/location
Evidence of Learning	1) Group discussion 2) Observations of activity	1) Group discussion 2) One Health Risk Assessment of home environment	1) Group discussion 2) Risk Mitigation Plan for home environment	Individual One Health Action Plan
Activity/experience	Glitter activity (3 scenarios to represent modes of pathogen transmission in humans/animals/environment)	3 scenarios in pictures – identify risks using One Health Risk Assessment Tool	1) Probability Exercise (dice game) 2) Risk Mitigation Plan using personal pictures	Create a personal action plan to put program lessons into practice; plan a public presentation for new audience
Application	Identify potential modes of pathogen transmission and critical control points in home environment	Use One Health Risk Assessment Tool in home environment/community (photo-documentation)	Implement Risk Mitigation Plan of home environment/community	Implement One Health Action Plan

Appendix B. *One Health Training and Leadership* One Health Risk Assessment Tool

Risk factors	Low Risk	✓	Moderate Risk	✓	High Risk	✓
ANIMAL (DOMESTIC)						
Animal ownership	0-1 species		2 species		More than 2 species	
Animal contact with domestic species outside home environment	Never/seldom		Occasionally		Frequently	
Animal contact with wild animals	Never/seldom		Occasionally		Frequently	
Vaccinations	All recommended vaccinations		Some recommended vaccinations		No recommended vaccinations	
Vaccination status	All current		Some current		None	
Cattle dipping	Frequently		Occasionally		Never/seldom	
Housing	Animals confined individually or in single species groups		Animals allowed to free range occasionally and otherwise confined in single or multi-species groups		Animals are always able to free range	
History of illness	No illness of any kind among animals		Few or minor illnesses		Frequent or severe (e.g., death) illnesses	
Isolation of newly introduced animals	Always		Occasionally		Never/seldom	
Isolation of ill animals	Always		Occasionally		Never/seldom	
HUMAN						
History of flea/tick bites	None		Some		Many	
Consume fresh (unboiled) milk from cattle/goats	Never		Occasionally		Frequently	
Slaughter/handle uncooked meat from household livestock / poultry	Never		Occasionally		Frequently	
Vaccination status	All current		Some current		None	
Hand-washing	Before contact with animal / animal products *and* after contact with animal / animal products *and* before preparing/eating food *and* after using toilet		Before contact with animal / animal products *or* after contact with animal / animal products *or* before preparing/eating food *or* after using toilet		Never/seldom	
Household size	1-2 persons		3-4 persons		More than 4 persons	
ENVIRONMENT/WILDLIFE						
Observe rodents in/around home/crops	Never		Occasionally		Frequently	
Source of household / drinking water	Taps for all household use		Taps for drinking water; surface water for other household uses		Surface water for drinking and other household uses	
Use cattle manure for fire or fertilizer	Never		Occasionally		Frequently	
Wash clothes where animals drink water	Never		Occasionally		Frequently	
Slaughter / handle wildlife	Never		Occasionally		Frequently	
Consume meat from wildlife	Never		Occasionally		Frequently	
Allow standing water to accumulate near home / garden	Never		Occasionally		Frequently	

Appendix C. Knowledge application (*unabridged*) – One Health (human, animal, and environment) risks identified and mitigation strategies proposed and implemented by *One Health Training and Leadership* participants (n = 62), categorized by gender.

Theme	Sub-theme	Mechanism of disease transmission/ Injury	Mitigation strategy proposed (n)	No. strategies implemented/ Total proposed	
				Male	Female
A. Human health					
Hygiene (personal and domestic)	Touching other people (e.g., hand-shaking)	Direct (human-human)	Wash hands (2)	1/1	1/1
			Use clinic (1)		1/1
	Touching/contact with animals	Direct	Vaccinate animals (19)	9/9	10/10
		Vector	Improve animal housing/confinement (8)	2/3	2/5
		Indirect (animal-human)	Vector control (3)	0/1	0/2
		Unspecified	Cover food/dishes (2)	1/1	1/1
	Touching high-use surfaces (e.g., door handle, water tap)	Indirect	Wash hands (18)	5/9	9/9
		Unspecified	Wash surface (11)	3/3	6/8
			Cover/paint surface (2)	1/2	
Property maintenance	Standing water	Vector	Cover/eliminate water (19)	6/9	8/10
		Injury	Spray for mosquitoes (2)	2/2	
		Unspecified	Move outdoor kitchen (1)	0/1	
	Excess building materials (wood, bricks, iron)	Injury	Remove/use material (7)	0/1	4/6
		Vermin	Trap/poison vermin (1)		1/1
	Toilet	Indirect	Clean toilet (12)	4/5	5/7
		Vector	Repair/replace/modify toilet (10)	1/3	3/7
		Injury	Spray for mosquitoes (4)	3/3	0/1
		Airborne			
		Unspecified			
	Housing/infrastructure	Vector	Fill holes (1)		0/1
		Unspecified	Treat for termites (1)	1/1	
			Build fence (1)		0/1
Garbage	Improper garbage disposal	Vector	Burn (18)	5/7	10/11
		Injury	Collect/remove (8)	4/4	4/4
		Indirect	Build/replace pit (4)	1/2	0/2
		Airborne	Bury/cover (3)	1/1	1/2
		Unspecified	Crush cans (1)		1/1
Food/water	Cooking/eating	Vector	Improve food/water storage (10)		
		Vermin		5/5	5/5
		Unspecified	Clean dishes (1)		0/1
Total				55/73	72/97

B. Domestic animal health					
Housing	Inadequate housing/confinement	Unspecified	Build/repair/use coop/kraal (17)	4/9	3/8
		Direct (animal-animal)	Separate animals by species/health status (4)	2/3	1/1
		Vector	Confine cat indoors (1)	1/1	
		Vermin	Sell chickens (1)	1/1	
	Sanitation	Airborne	Clean coop (2)	2/2	
		Unspecified	Spray for fleas (1)		1/1
		Vector			
Property maintenance	Excess building materials (wood, bricks, iron)	Injury	Remove material (4)		3/4
		Vermin			
	Standing water (fish pond)	Injury	Build enclosure (1)		0/1
	Termites	Vermin	Remove termite mound (1)		0/1
	Toilet	Injury	Remove/replace old toilet (1)		0/1
Medical care & disease prevention	Inadequate/incomplete vaccination	Unspecified	Vaccinate (8)	2/4	1/4
		Direct	Build coop (1)	0/1	
	Vector control	Vector	Spray for flea/ticks (7)	3/6	0/1
			Clean kraal (1)	1/1	
			Use vet clinic (1)	1/1	
			Castrate dog (1)		0/1
	Medical care	Direct (animal-animal)	Seek medical care for sick animals (1)	0/1	
Garbage	Improper garbage disposal	Intoxication	Burn (6)	1/1	5/5
		Injury	Collect/remove (2)	1/1	1/1
		Unspecified	Bury (1)	1/1	
			Build enclosure (1)		0/1
			Build/replace pit (1)		0/1
Total				20/33	15/31
C. Environmental health					
Garbage/sanitation	Improper garbage disposal	Environmental contamination/litter	Burn garbage (6)		6/6
	Fecal waste	Unspecified	Collect/remove garbage/waste (2)		2/2
Food/water	Standing water (natural)	Vector	Level ground (2)	2/2	
			Cut grass (1)	0/1	
	Contamination by domestic/wild animals	Indirect	Build enclosure (2)	1/1	1/1
		Unspecified			
Total				3/4	9/9
Total (all sections)				78/110	96/137

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