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Sustainable development as successful technology transfer: Empowerment through teaching, learning, and using digital participatory mapping techniques in Mazvihwa, Zimbabwe

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A R T I C L E I N F O

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A B S T R A C T

In development engineering, practitioners often strive to empower local communities through technology. Empowerment, however, is typically not well-defined and rarely assessed, leading to an erosion of its meaning. In this study, we define empowerment as capacity building through technology transfer, which we evaluate by assessing skill transfer, skill application, increased individual confidence, and community support. We test the usefulness of these assessments for participatory mapping as a form of technology transfer, using a Participatory Action Research approach. Our case is a digital mapping team embedded in the long-term community-based participatory research agenda of The Muonde Trust in Mazvihwa, Zimbabwe. We taught and evaluated mapping by conducting workshops and engaging in a variety of mapping projects (including measuring access to basic services, land-use planning, and cultural and historical preservation projects), demonstrating dramatically increased mapping skills and individual confidence, and the creation of a community of practice able to teach the skills. Our peer-based learning techniques used adult education principles and could be applied in creating other local communities of practice to support the use of medium-tech mapping methods (basic GPS units and computer mapping software). In poverty reduction and sustainability initiatives, participatory mapping can be complementary to cutting-edge big data approaches and necessary for true improvements in the well-being of the most vulnerable populations on our planet. Development engineers would benefit from incorporating participatory action research principles into their work, learning to co-labor with communities to define and solve problems.

1. Introduction

A key component of sustainable development is the ability of local people to discover, define and prioritize their own problems, and to access the support to develop and apply appropriate solutions (Reynante et al., 2017). Development engineering distinguishes itself from earlier humanitarian engineering efforts in its insistence on ensuring that technological solutions are appropriate for the low-resource context and constraints they are intended for, emphasizing iteration with communities on the ground (Nilsson et al., 2014; Levine et al., 2017). However, even well-intentioned outsiders' user-focused design approaches still run the paradoxical risk of neocolonialism: continuing to control other societies through informal economic or political means (Janzer and Weinstein, 2014). Viewing developing communities as "needing help" from outsiders can work against humanitarian goals of positive community impact (Kramer, 2015). This paradox of reduced or even negative impact despite good intentions can arise due to narrow ideas of benefits as products or services without parallel empowerment of the community (Reynante et al., 2017). Even where empowerment is included as an intended benefit, it is typically ill-defined (Herman, 2014), and this often-rhetorical and imprecise use has "eroded the meaningfulness of the concept" (Corbett et al., 2016). Empowerment is also problematic and potentially neocolonial when it implies that power is something outsiders give to communities rather than something that

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already resides with those communities, which Freire would call “false generosity” (1970) that maintains rather than deconstructs oppression.

Despite these problems, empowerment can still be a useful concept if it is well-defined, ideally in a way that emphasizes existing community capabilities and capacity-building (Hennink et al., 2012). One specific definition of empowerment as capacity-building is successful technology transfer that builds on existing community competencies. The United Nations’ 2030 Sustainability Development Goals include “the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries” (UN, 2015). This definition of empowerment as technology transfer is uniquely suited to development engineering with its focus on appropriate technology (Levine et al., 2016). Assessments of successful technology transfer include: 1) The acquisition and retention of technology-based skills (including assessing whether skills were retained some time after the initial technology transfer); 2) The ability of the community to define, measure, and solve their own problems using the technology, without further input from outsiders; 3) Individual and collective changes in identity including increased confidence around the technology (Young and Gilmore, 2013) and successful creation of a local community to support the maintenance and further spreading of the associated skills.

Mapping provides a useful context to apply this complex set of ideas and values around empowerment to the context of development engineering, due to its extremely colonial history (Pickles, 1995) and the many contemporary approaches for mitigating that history, including “counter-mapping” and Participatory Geographic Information Systems (PGIS) (Peluso, 1995; Radil and Anderson, 2018). Particularly for Indigenous and rural peoples, participatory geospatial techniques can represent an important avenue for environmental justice and can be a tool for culturally appropriate management of local ecosystems (Chapin et al., 2005; Chambers, 2006), especially when these techniques are carefully placed in their historical, political, and socio-economic context (Harris and Weiner, 1998). PGIS has the potential to empower community members who learn these methods (Laituri, 2002); however, most PGIS projects do not define empowerment and even fewer actually assess it (Corbett et al., 2016). Without critical attention to empowerment concerns, PGIS work runs the risk of paradoxical neocolonialism through extraction of community knowledge (Stewart et al., 2008). PGIS can also distort community knowledge by reinforcing colonial structures, concepts of territory and property rights or particular kinds of data representations (Pearce and Louis, 2008; Wainwright and Bryan, 2009; Sletto, 2009), or perpetuating unjust political structures (Young and Gilmore, 2017; Radil and Anderson, 2018). PGIS initiatives may avoid colonial outcomes by supporting increased self-determination at meaningful scales and ensuring data sovereignty, or ownership and control over the data produced by PGIS techniques (Rainie et al., 2017).

In order to avoid reinforcing neocolonial power structures and relationships, some scholars have taken a Participatory Action Research (PAR) approach (McTaggart, 1991; Cornwall and Jewkes, 1995; Minkler and Wallerstein, 2003; Kindon et al., 2008). PAR has several principles parallel to those of development engineering: it is problem-focused, iterative, and works directly with communities (Merriam, 2015). Action research fundamentally involves changing aspects of the study system during the process of the study. In order to rigorously understand the system as it changes, the method entails a cycle of planning an intervention, implementing that plan, observing the plan in action, and reflecting on the results (Kuhne and Quigley, 1997). Often the reflective phase leads naturally into the planning phase for the next loop (Merriam, 2015). This adaptive cycle means that working hypotheses, strategies, and study design will shift and emerge as researchers learn and iterate through the process (Herr and Anderson, 2015). This principle is similar to the development engineering design cycle (Levine et al., 2016), which like PAR also deeply involves local people (‘users’). However, both approaches can range in the level of community or user participation actually realized in the project, based on the level of authority the community has over the process (Arnstein, 1969) or the stages of the research that involve communities (e.g. problem definition, data collection, analysis, communication of results; Cooper et al., 2007, Wiggins and Crowston, 2011).

While many projects aspire to the community-controlled end of this spectrum, community leadership in participatory research is not actually the norm (Sarna-Wojcicki et al., 2017). In this study, we assess technology transfer according to the definitions above, seeking through capacity-building to avoid neocolonial outcomes. We ask: What are the key conditions and mechanisms that lead to effective community empowerment with PGIS? Can we avoid the potential neocolonial pitfalls of PGIS? We specifically apply PAR methods in rural Zimbabwe to test whether highly participatory, medium-tech mapping (using basic GPS units and computer mapping software) can increase community empowerment through peer-driven technology transfer. We argue that for this kind of empowerment, both development engineering and PAR need to focus more on the collaborative (or co-laboring) end of the PAR spectrum. We suggest that this requires a focus on building new or supporting existing communities of practice (Wenger, 2000) which can sustain the knowledge and skill transfer.

2. Material and methods

We describe our case study system, the mapping activities we engaged in, and our PAR approach. We use a grounded theory framework to connect our case findings to larger bodies of theory regarding community empowerment, adult learning, and communities of practice.

2.1. Case selection: The Muonde Trust in Mazvihwa Communal Area, Zimbabwe

Our project takes place in Mazvihwa Communal Area in Midlands Province, Zimbabwe (Fig. 1). This work is a case study, with data originating from a bounded source: Our project was conducted with and by the Muonde Trust, a Zimbabwean Non-Governmental Organization which supports Indigenous innovation in Mazvihwa and beyond. In Muonde, we have chosen a case that is at the community-created end of the participation spectrum. This choice gave us the opportunity to study whether deeply participatory community-based research would achieve the goal of empowerment through technology transfer.

One underlying problem that The Muonde Trust seeks to address is the prevalence of ‘donor syndrome,’ a kind of learned helplessness where people wait for handouts or for others to try (and likely fail) to solve their problems for them, an outcome which can be common in situations with persistent outside aid. (The local slang term is *kumbiraitisi,* derived from *kukumbira*, “to ask,” meaning “how people are addicted to begging always.”) This goal is aligned with the points raised by Kramer (2015) and Reynante et al. (2017) regarding the difference between aid strategies of charity versus empowerment, and Freire's exhortation that the oppressed do not benefit from false generosity and must “liberate themselves” (1970).

At any given time, Muonde's core group includes about 30 highly motivated local people, both salaried and volunteer, some of whom have been conducting community-based research on a variety of agricultural and cultural innovations for more than 30 years. Muonde supports several teams who develop and apply solutions to specific community problems. These include rainwater harvesting to retain moisture and prevent soil erosion, innovative domestic architecture which separates kitchen smoke from sleeping areas, dry-stone walling and live hedge fencing to prevent deforestation, the study of drought-resistant small grain varieties, and many cultural preservation and education initiatives (see Appendix A).

Within a capacity-building framework, outside mentors are encouraged to visit and teach useful skills to the Muonde research team. Muonde is a particularly excellent choice for studying empowerment

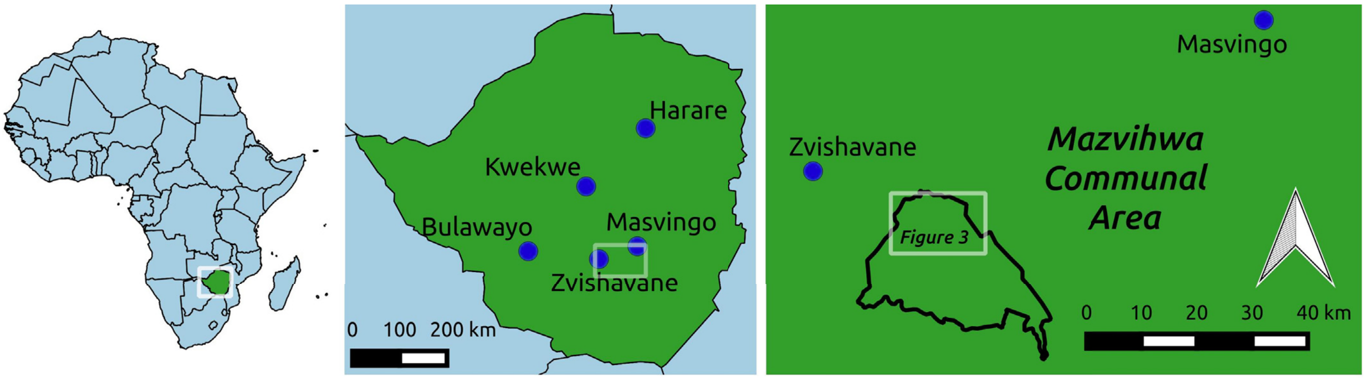

Fig. 1. Geographic context: Zimbabwe is located in southern Africa (left); location of cities within Zimbabwe where Muonde's mapping projects take place (middle); location of Mazvihwa Communal Area (black-outlined area) relative to the two nearest cities, Zvishavane and Masvingo, with the extent of Fig. 3 shown in a light outline (right).

through skill transfer, whether skill transfer is from visiting mentors to Muonde or from Muonde to the community in Mazvihwa and beyond. Muonde's teaching programs and requests for instruction from visitors align with their goal of reducing donor syndrome. Our digital mapping instruction is one of these initiatives.

2.2. Sampling within the case: mapping activities

Our focus is on the effectiveness of participatory GIS, within the Muonde Trust. Our study primarily follows teaching and mapping activities running from March 2015 through March 2016. Our author team includes two visiting mentors[1] and nine members of Muonde, all of whom were involved in the digital mapping teaching, learning, and community building between 2015 and 2016 as well as the writing and analysis in 2016–2018. The digital mapping technology we used included relatively simple GPS units (Garmin eTrex 10) and open-source, freely-available mapping software (QGIS); see Appendix B for details. We describe this as "medium-tech" to distinguish it from "low-tech" mapping tools like paper maps and drawings and from "high-tech" mapping tools including remote sensing and machine learning. Our teaching methods included "How-To" sheets with screenshots, photos, and instructions on how to do a variety of common mapping tasks such as marking waypoints and displaying them on a map. We taught GIS to a small group of 10–11 people, using the how-to sheets and hands-on exercises with the GPS units and mapping software. Later, this 10-person local "GPS team" led workshops to train the rest of the Muonde team in digital mapping techniques. See Fig. 2 for some examples of teaching, learning, and practicing mapping techniques, and Appendix B.

2.3. PAR approach to learning goals, hypotheses, and authorship

Following the principles of PAR, our learning goals and hypotheses were driven by community input and needs, and these were iterated over the course of the study. In a pedagogical context like skill transfer, Freire's classic approach of learner-led education is essential to empowerment: recognizing that the learners should drive the agenda (Freire, 1970). Because of this, our initial learning goal was simply that the community could demonstrate their mapping skills. Over time, these goals evolved to include mapping concepts that were essential for the tasks the community was choosing to use the mapping skills for. Therefore, at the beginning of the PAR cycle our learning goals were for the community to (individually or collectively) record points and tracks from the GPS, conduct basic operations on the computer including downloading the GPS data, display the data in QGIS to see the results, join the mapping data with additional field data, and make maps, all without the international mentors' help. In later rounds of the research, learning goals expanded to include understanding mapping uncertainty, map projections, spatial representation choices (points, lines, and polygons), understanding how the GPS works, and also creating more sophisticated exportable maps. Each of these goals were supported by a set of related How-To sheets, many of which were created at the community's request in an iterative fashion (see supplemental materials).

Because we adapted our strategies and questions throughout the study, our hypotheses emerged from various cycles of our research. 1) Our initial hypothesis was that we can achieve empowerment through technology transfer, defined as skill transfer, skill application, and confidence and community building. 2) As we engaged in teaching, we further hypothesized that using medium-tech mapping techniques played a key role in the success of our open-ended, peer-driven teaching, and subsequent technology transfer. 3) As we analyzed and evaluated our success, our additional hypothesis (which we leave open for future work to test) was that building on an existing community of practice at Muonde was an additional factor in our success.

Following our ethical commitment to deeply participatory work, this paper originated from a co-writing process. The initial drafts of the paper were more descriptive of the people and place, with extensive writing by our rural Zimbabwean authors. However, in successive revisions for editors and peer reviewers, much of this material has been moved to the Appendices in favor of a more analytical approach engaged with scholarly literature. We have chosen this strategy to facilitate communication with development engineering audiences and to generalize our results. Community coauthors have continued to review drafts of the paper and still feel that it is their paper because all the parts they wanted are included (even if mainly in the appendices), but the form of the main article is quite different from our initial collective writing. This process raises important questions for critical development engineers about what happens to knowledge when it is forced into a certain form, whether in a map (Pearce and Louis, 2008) or in a scientific journal article – especially if the desire is to engage directly with developing communities.

[1] Note that in our descriptions of teaching, we deliberately use the terms "mentor" and "learner" rather than "teacher" and "student" for two reasons: first, to avoid falling easily into the hierarchical roles learned from formal educational institutions in both the US and Zimbabwe, instead emphasizing that the mentor was there to guide and advise but keep the focus on the learners and their needs; and second, to acknowledge that the mentors had a lot to learn from the learners – these roles were therefore very fluid even from moment to moment, as well as over a longer timeframe.

Fig. 2. Muonde GPS team learning to map and teaching mapping. Clockwise from top left: small group instruction in the field with GPS team (initial learners in 2015) explaining how to use Garmin units for recording points to villagers from Madzoke Valley (new learners; also see Table 1); field practice at Great Zimbabwe with two GPS team members doing a practical exam of making points and tracks (in 2015); GPS team member (s) explaining maps to the larger Muonde research team during first visit in 2015; GPS team learning about map projections by drawing points on and then peeling oranges to see how flattening a sphere can distort distances (during second visit in 2016) – eating the oranges was a special treat and an incentive to participate; GPS team practicing making maps with QGIS on Acer computer during second visit in 2016 – specifically ensuring that all members were learning the new concepts regarding calculating areas and uncertainties; whole-group instruction with the entire Muonde research team on how satellites work, A Changarara explaining in Shona what MV Eitzel has just said in English (in 2016).

2.4. Data collection and analysis

To test the hypotheses listed above, we took notes through participant observation during teaching activities and workshops, gathered semi-structured group-based interview responses during those workshops, undertook self-reflection on the part of the participant-authors and others, and developed ideas further through digital communications. These notes and exchanges were reviewed periodically and memoed, giving rise to themes which were later validated by participants. Multiple rounds of writing and revision of this paper helped us refine our analysis. We give a detailed account of these activities in Appendix C, including a high-level audit trail listing which members of the author team were involved in which parts of the data gathering and analysis.

We first report a baseline assessment of our participants' familiarity with spatial reasoning, mapping technology, and computer use. We established this through discussion with the directors of The Muonde Trust who have been observing and working with the community research team for more than three decades. Skills assessments were conducted initially in 2015 by asking each of the mapping team members to perform mapping tasks themselves (with verbal help from the rest of the team because technology transfer here was defined as the group's ability to collectively do these tasks once the initial mapping mentor had left) and observing and assessing their success. Skills were further assessed a year later in 2016, during a second visit, by reviewing and synthesizing all the mapping projects conducted by the mapping team in the intervening year (see Table 1), along with observing the mapping team and other Muonde research team members while practicing the mapping skills. We also assessed the success of skill transfer and implications for empowerment by ranking the scope of each mapping project listed in Table 1 and categorizing whether the idea for the project originated from outside mentors or from community members. The leaders of the Muonde Trust verified our ratings of the scopes of each project (See Appendix A and supplementary materials.).

To gauge changes in attitudes about the mapping tools via self-assessment, we asked the discussion questions "How have we changed? How have our relationships changed?" (see Table 2), assessing whether confidence had increased around the technology and skills. This is effectively a set of pre-post retrospective questions in a semi-structured group interview. We assessed the success of different teaching methods by analyzing notes from early rounds of workshops and focus groups and then bringing the themes that emerged into a larger group setting, getting feedback and then collectively describing and refining them in our writing workshops (see Table 3), so these themes are generated through participant observation and participant validation through workshops. The Muonde members of the author team have repeatedly reviewed the resulting tables for accuracy.

2.5. Grounded theory analysis via writing

As a final note on methodology, we took a Grounded Theory (Glaser and Strauss, 1967; Charmaz, 2014) approach to our analysis. We began with a goal to transfer the mapping technology using PAR methodology. This process generated additional questions and working hypotheses based on our participatory mapping experiences. We then formulated theories about what worked and why with respect to PGIS technology transfer and empowerment, and then connected these ideas with larger bodies of theory on adult learning and communities of practice (see Discussion).

3. Results

The open-ended, peer-driven teaching methods we collectively and iteratively developed were highly successful in transferring medium-tech digital mapping skills and technology to Muonde researchers. This success is shown both by demonstration of the skills a year later (technology transfer assessment 1: basic skills), and by the variety and quantity of mapping projects undertaken by the mapping team (technology transfer assessment 2: skill application). In addition to these technology transfer assessments, we also found that the Muonde research team had considerably improved their self-confidence around mapping technology, including the ability to teach new learners (technology transfer assessment 3: confidence-building and community-building), and had increased political agency and self-determination in a number of arenas. We give examples of each finding in the following sections.

3.1. Basic skills assessment (technology transfer goal 1)

We first report our participants' baseline spatial knowledge and skills. The people in Mazvihwa have a strong sense of territory and its boundedness in space and time, and were acutely aware that in order to deal with contemporary community issues they would need to be able to represent that territoriality in digital spatial representation frameworks. The leadership originally requested computer and mapping training and equipment for these reasons. Community interests in these technologies also originated from local youth. However, most members of the community were not initially accustomed to spatial representations of their reality or to "spatial reasoning" (National Research Council, 2006). When giving directions, people would typically use a narrative method relying on landmarks (especially trees), and their typical concept of distance to a place was determined by the desire to send a person to that place (i.e. "near" simply means the speaker wanted the person to go there). If pressed to give quantification, community members would use units of time rather than distance.

Although existing familiarity with geospatial technology and computers varied throughout Mazvihwa, within Muonde's research team, and in our author team, the overall initial level of technology exposure was low. One of our authors had seen a GPS unit while working with a local mining company but had not used it himself. One author with post-secondary schooling was taught GPS use as part of his degree program but he remembered very little of what he had learned, partly due to a lack of hands-on practice, and he was also not present during the initial instruction in 2015. No other Muonde team members had prior exposure to GPS units. Most members of the initial mapping team had not used computers: the first computer was brought to Mazvihwa in 2010, and the first computer intended for Muonde's sole use was given to them in 2013. Several of our authors with post-secondary schooling were familiar with computers but these individuals were not present during the initial mapping instruction. Many members of Muonde had seen aerial photographs (particularly historical photographs from 1939 to 1985 brought by an earlier researcher) but few had seen a map.

Despite their limited baseline experience, the mapping team's uptake and retention of basic mapping skills was excellent. At the end of the first teaching period for two weeks in March 2015, all members of the initial mapping team demonstrated the ability to record points and tracks with the Garmin eTrex 10 units, download the points to the computer using DNRGPS, and add them to a map in QGIS (some team members needed verbal support from their peers during the process, but this was consistent with our target learning goals). When the international mentors returned in March 2016, the mapping team still demonstrated the ability to conduct all these tasks (though again, some members needed peer assistance), as well as having demonstrated the ability to teach additional Muonde research team members how to do mapping tasks.

3.2. Applied skills assessment (technology transfer goal 2)

The Muonde research team engaged in over 20 different mapping projects on a variety of topics during and after our teaching (from March 2015 through October 2017). These projects were assessed via looking at the data collected and maps produced, listening to the mapping team describing them to the larger Muonde research team, and discussing them with the author team during writing workshops. Broadly, the team used digital mapping to identify, discuss, and act on new community needs; to assist with land-use planning and monitor Muonde innovation projects; to tell important historical and cultural stories; and to create opportunities and connections for Muonde. The projects conceived of by the community tended to be larger in scope (in terms of how many people benefit or how large an area was mapped) than those suggested by international mentors (Table 1). We give four examples below, with benefits ranging from village level up through the entire communal area.

First, the Muonde team mapped the road from Mudhomori village to "nearby" Mhototi primary school and learned that small children (under the age of 10) typically walk 4.5 km each way. The Muonde research team gathered and discussed the issue and decided that it was too long a distance for young children to walk along dusty roads in the heat or rain on a daily basis. They then shared this information with the community who unanimously agreed to establish a preschool in Mudhomori itself – and they proceeded to do so. This entire sequence occurred in the intervening year between March 2015 and March 2016.

Second, the team mapped the borehole wells in Mhototi Ward[2] (Fig. 3), noting which were functioning and which were not. The map identified a number of non-functioning wells, and also illuminated the

[2] "Ward" is an organizational level larger than a village (usually containing several villages), but smaller than the entire Communal Area which contains several wards.

Table 1
Description of The Muonde Trust GPS team mapping projects conducted between March 2015 and October 2017. The rows of the table are ordered by scope/scale (in terms of area mapped, number of individuals who may benefit, and/or the reach of Muonde's work), in ascending order: projects for "Individuals" have the smallest scope, followed by projects in a single "Village," then multiple villages which constitute all or part of a governmental "Ward" (mostly via projects which benefit more than one village), followed by the whole of Mazvihwa "Communal Area," then projects with connections to "Regional and National" resources and communities. More than half of these mapping projects originated with the Muonde team and not from outsiders' suggestions, the vast majority took place without direct outsider participation, and the projects originating with Muonde and the community consistently have larger scopes/scales than those suggested by visitors/outsiders.

Scale	Project Ideas Suggested by Outsiders	Project Ideas Generated by Muonde/Community
Individual	**Individual homes (*bindu*)** The areas of and points of interest within the homes of several individuals affiliated with The Muonde Trust.	**Distance for Electrification**[b] One nearby individual in Mazvihwa asked the GPS team to measure the distance from Gwavachemai school to his home in order to ask ZESA to provide electrical power from the school to his home.
Village	**Chinguo Village Sample Households**[b] As part of the 35-year community-based research in Mazvihwa, several households from each village are regularly interviewed. These are the physical locations of the sample households in Chinguo village which includes the Zhou and Ngwenya people. The GPS team has since mapped the locations of the remainder of sample households in all of Mazvihwa. **Distance to Services**[b] Distances between Mudhomori village children and the closest schools (Mhototi and Gwavachemai schools) and also the distance from Mudhomori village to the nearby town of Zvishavane. **Zoza Garden** A nutrition garden for women's projects, found near Chinguo village. The GPS team measured its area to help a UC Berkeley-crowdfunded project, "Pump It Up,"[c] to determine what equipment would be needed to pump water from the river to the garden to make the women's work easier.	**Mudhomori Village grazing land** Found between Mudhomori village's homesteads and the Lundi river, this area is communally managed for livestock grazing and a variety of other uses. **Mudhomori Locations and Roads**[b] The GPS team mapped locations of interest in Mudhomori village (including hills, trees, dams, boreholes, and homes) as well as the main roads.
Ward	**Higgs quadrat resurvey**[b] Bryn Higgs did a vegetation survey in the 1980s as a part of his undergraduate thesis at St. Catherine's College, Oxford; the Muonde Trust GPS team re-surveyed these quadrats to gain insights on the changes in vegetation types and density over the last 35 years.	**Madzoke Valley Stone Wall Projects**[b] Madzoke is a hilly area surrounded by mountains with wetlands which has good results in terms of crop production and includes a number of Muonde Trust collaborators. GPS team members have mapped dry stone wall projects throughout the valley. **Utaya Irrigation Project**[b] A small land area near the Lundi river in Mudhomori village where Muonde proposes to launch an irrigation project; the GPS team calculated the area of the proposed project. **Mhototi Ward Borehole Wells**[b] Mhototi is the biggest ward in Mazvihwa Communal Area; the team mapped all the locations of the borehole wells (sources of clean water) and whether they were working or not (See Fig. 3).
Communal Area (multiple wards)	**Great Zimbabwe**[a] The world-renowned historical site where great houses of stones were built without using mortar; the site after which Zimbabwe is named. **Matobo National Park**[a] Matobo National Park forms the core of the Matopos hills, an area of granite kopjes and wooded valleys commencing some 35 km south of Bulawayo, southern Zimbabwe. **Lake Kyle (Mutirikwi) Recreational Park**[a] A park near Masvingo town which specializes in wildlife management and where Lake Kyle (Mutirikwe) is found.	**Proposed Muonde Trust Center**[b] The Muonde Trust proposes to create a Center for both operations of the organization throughout Mazvihwa, and also for visitors to stay. The GPS team measured the proposed area of the Center. **War Bases**[b] The locations where the Zimbabwean freedom fighters met with the parents and other war collaborators (*chibwido,* females; *mujibha,* males) during the liberation war. It was a place for war education and entertainment *pungwes* (meaning the whole night). **Sacred Forest (*Rambotemwa*) Mapping**[b] The Muonde mapping team located the current and former boundaries of sacred forests in one region of the communal area, as well as locations of the villages which had grown up within the sacred forest. They used this map to initiate work with local leaders in the communal area to design a bio-cultural restoration protocol to protect these forests throughout Mazvihwa.
Regional/ National		**Zvishavane Town (old and new)**[b] The GPS team mapped sites throughout nearby Zvishavane town, including both sites which give evidence of what the town was like since 1916 when it was established, as well as what Zvishavane is like today. These records could be shared with students at nearby Midlands State University. **ZESA Electrical Lines**[b] For the Zimbabwe Electrical Supply Authority (ZESA), the GPS team mapped the length of electrical lines which were cleared of vegetation and other obstacles, in order to determine how much to pay the workers. **Mlezu Agricultural College**[b] An educational institution in Kwekwe (a city in central Zimbabwe) where different students, including Agritex (agricultural extension) officers, are taught agricultural techniques. The Muonde GPS team gave the students lessons on GPS and digital mapping. **Kufunda Village**[b] A center for permaculture training and learning, 25 km east of Harare (Zimbabwe's capital) along Mutare road. The GPS team demonstrated water harvesting techniques and digital mapping to the permaculturalists.

[a] The Muonde Trust and visitors took trips to see and map the historical places, so though the trip was regional, the impact was for the benefit of Muonde and those it serves.
[b] These were projects conducted between visits in March 2015 and March 2016 with no direct assistance from visiting mapping mentors.
[c] https://crowdfund.berkeley.edu/project/1699.

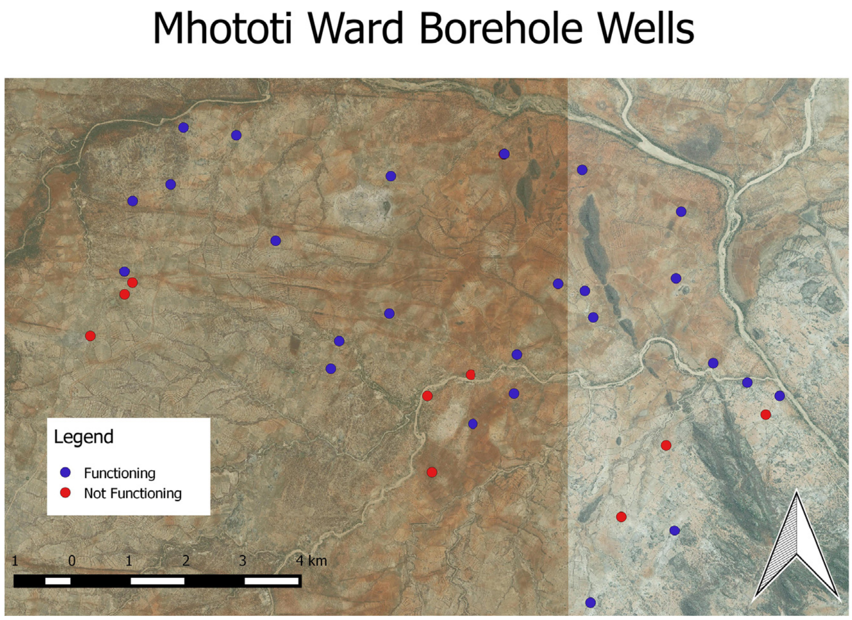

Fig. 3. Map of borehole wells in Mhototi Ward of Mazvihwa Communal Area, created by the mapping team. An example of a mapping project which illuminated an emerging problem: there are fewer borehole wells in the western side of the ward, and many of them are not currently functioning. The mapping project both shows where boreholes need to be fixed and also where new ones might be built. Having a map like this allows The Muonde Trust to advocate for services in Mazvihwa. Satellite imagery courtesy of DigitalGlobe Foundation (www.digitalglobefoundation.org, copyright DigitalGlobe, Inc. All Rights Reserved.) We note that the symbology of this map is better for color reproduction, so the intended audience would be government or aid agencies. To share this map with farmers, different symbology would be needed (e.g. different shapes for functioning/nonfunctioning wells), in case color copies are not an option. Understanding and designing maps for cartographic subtleties like these is a future goal of the mapping team. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Attitudes about digital mapping and relationships with others both before and after mapping instruction and skill application.

	Before	After
Attitudes about themselves	- Intimidated by the technology - Doubted themselves - Only for educated people, big companies (in Mazvihwa, typically mining companies), young people, or white people - Hard for mentors to teach new learners about the computer and the mapping software	- Confident in themselves (higher self-esteem) - Now much faster at mapping, everyone has something to add - Anyone can learn it if they're interested, have courage to learn something new, and can work hard
Attitudes about the technology	- Digital mapping didn't seem useful, relevant, or believable - Maps are only used to show the whole world or maybe all of Zimbabwe	- Confident in the technology - Everyone can benefit from this technology - Maps can be made of their own places, including their villages and all of Mazvihwa Communal Area
Attitudes of and relationships with local authority	- Potentially suspicious of Muonde's work - Muonde's innovation projects could be a way to get around their authority - Mapping could be seen as colonialism all over again - Could be an example of Muonde having resources and not sharing	- Muonde asking permission to map keeps the team in frequent contact with local authorities and shows respect - The local chief (*vashe*) was pleased with the maps the team showed him during the 2016 workshops - Authorities now want Muonde to help them to map areas
Attitudes of and relationships with local people	- Muonde's projects might reduce aid - Maps could have the same problem of discouraging charitable assistance	- They see the value of mapping, because it gives them a sense of ownership when seeing maps of their own homes for the first time
Relationships with other regional or national groups	- Heavily involved in the Phiri Award honoring farming and water harvesting innovations (within the District)	- Shared the Zvishavane historical maps with students at nearby Midlands State University - Taught digital mapping skills at Mlezu Agricultural College - Mapped brush cleared from electrical supply lines for ZESA - Presented water harvesting and mapping to Kufunda, a permaculture organization

unequal distribution of boreholes in the ward. Many wells are found in the east, with a disadvantage on the western side where a single borehole supplies seven villages containing 80 households, or about 500 people. Using this digital mapping data and information, Muonde can seek assistance from the relevant local government ministry and from outside supporters to repair these boreholes and install new ones in a more balanced fashion.

Third, the Muonde team have used digital mapping for vital historical studies. One project mapped all the military bases in Mazvihwa Communal Area from the war of independence. For those who were a

Table 3
Successful teaching/learning methods. See Appendix B for details and examples of each method.

Principle	Method
Relevant, hands-on teaching	- Examples, exercises, and analogies were based in the local culture - Practical exercises on relevant topics motivated by real needs - Explanations in English were translated into Shona by several of the learners so that others for whom English was more challenging could still understand
Multimodal teaching	- Auditory teaching through lecturing, verbal explanations, and discussions among learners - Visual teaching through how-to sheets and markerboards - Tactile/kinesthetic teaching through doing hands-on exercises with the technology, role-plays acting out how we taught and learned as well as how GPS satellites work, and through songs
Modifying familiar teaching methods	- Written assignments to rehearse and reflect on the material - Verbal tests to explain understanding or present results to larger group - Practical exams to prove skill acquisition - Asking questions during instruction and taking notes in a notebook - Mnemonics to remember acronyms and other concepts
Attending to interpersonal aspects of learning	- Fostering an informal and encouraging atmosphere - Individual attention to ensure everyone was following the lesson and to build mentor-learner relationship - Working in small groups helped provide both accountability and support - Setting collaborative goals (collectively decided on, and achieved as a group) - Paired learners who had quickly picked up the mapping skills with those who hadn't yet - Friendly competition and fun incentives - Initial learners presented their work to the larger Muonde research team - Humor!
Fostering positive attitudes in mentors and learners	- Patience and perseverance: participants were encouraged to be tolerant of making mistakes – learning from them and trying again; as well as repetition necessary to retain skills and ideas. *Sango rinopa waneta* ("the bush yields to the hunter who perseveres") - Generosity and compassion: generous with both their own time and in sharing scarce mapping equipment (especially the computer), compassionate when others were having trouble learning - Humility and respect: acknowledging that we can all learn something from each other and at the same time respecting authority where appropriate - Industriousness and commitment to work hard: willing to travel long distances and respond at odd times of the day/night - Openness and curiosity: courage, even when you are afraid of the new technology or of being asked to teach one another - Flexibility: being willing to adapt the curriculum for what the learners need instructionally, socially, emotionally, physically

part of the war, it is a way to see where they operated, and for the younger generation, it can be a teaching tool to make them aware of this part of their history. In addition, the bases pose a potential safety hazard, largely unnoticeable to the community, because they may be home to unused artillery and land mines. One of our authors has had a bullet explode on his property when he was making a fire. Knowing where the bases are located could either allow people to avoid settling there or to do a military weapons survey first.

Fourth, in another historical mapping project, the team recorded the neighborhoods of Zvishavane (the nearest town to Mazvihwa). The map of the old neighborhoods captured many important memories of people and events, and also demonstrates some of the historical injustices during the colonial era, for example most black workers' compounds were found in a direction where mining gases were emitted, and the mining wastes were deposited. In contrast, the low-density suburbs for the whites were located at scenic southern and eastern sides of the asbestos mine. These maps can be useful tools for community members to conduct historical lectures, presentations, and writing.

We also note that all mapping data has remained with the community, and the visiting mentors make use of their copy of the data and maps only with permission from the community (for example the map of borehole wells in Fig. 3). This is consistent with the empowerment goal of respecting the data sovereignty of the research team (Rainie et al., 2017).

3.3. Changes in attitudes and relationships (technology transfer goal 3)

Through our collaborative teaching methods, Muonde research team members increased their confidence in using the technology and their role as teachers. The team has also improved existing relationships and built new relationships with the local community and authority figures, as well as other organizations throughout the country. We summarize these changes in Table 2 and give several detailed examples, below.

The GPS team in particular and Muonde as a whole has built their confidence in the usefulness of the technology to serve their needs as well as their confidence in themselves in using the technology. One author when working at Murowa diamond mine as an assistant engineer had asked what GPS stood for and was only told that the mine uses GPS to track their vehicles; he now knows far more than those mine workers about how GPS works and can not only use it himself but teach it to others. Teaching gave him a chance to learn and a chance to be patient; in learning how to teach, he imitated his mentor, and he gained additional confidence in his teaching and mapping ability.

Despite initial suspicion about mapping from some local community members, when the mapping team filmed themselves performing the GPS songs and dances in the Runde riverbed, people from both sides of the river in different provinces were intrigued and wanted to learn more about their activities. Through songs like *gps yauya ndachembera*, a song that plays with the complaint "oh why did GPS have to come only once I'd already grown old," Muonde communicates to others that patient mentoring can help anyone learn how to use GPS. For local people, hearing the songs and seeing the dances, combined with seeing maps of their own villages, showing roads, homes, fields, grazing land, and borehole wells, builds their friendship with Muonde while also demonstrating the value of mapping.

Finally, after learning digital mapping skills, Muonde has made connections with other institutions within the country. The Muonde team has shared the historical maps with students at the nearby Midlands State University, Zvishavane campus, helping to teach them about the history of the town. Institutions like Mlezu Agricultural College now wish to join hands with Muonde so Muonde can help them teach them mapping skills in a truly "bush-to-office" effort. The ward councilor facilitated Muonde's connection with the Zimbabwe Electrical

Supply Authority (ZESA) to measure brush cleared away from their electrical lines by ZESA workers in order to pay their workers according to the kilometers cleared. Kufunda, a permaculture non-governmental organization near Harare, asked Muonde to visit so they could exchange knowledge (including digital mapping), thereby building a new friendship with Muonde.

We note here that many of the mapping projects represent an increase in self-determination for Muonde, including their generally improved relationships with local leaders as well as several specific situations at multiple political scales. First, the early childhood development facility for Mudhomori children represents a village-level solution achievable without needing outside resources; in the case of the Utaya irrigation district (Table 1), the mapping team was able to verify the area of land that the local leaders had promised, including making slight corrections as appropriate; in addition, mapping sacred forests (*rambotemwa*) allowed Muonde to take part in a regional planning process for bio-cultural restoration; and finally, the teaching at Mlezu Agricultural College represents a complete reversal of the usual flow of knowledge between farmers and government officials, hence the term “bush-to-office.” This teaching also represents an opportunity to encourage agricultural extension officers-in-training to develop an interest in technology transfer for local farmers' empowerment.

3.4. Effective teaching methods

Our technology transfer was successful in part because of our teaching methods, which emphasized a relevant, multimodal, and interpersonal approach. This approach was highly open-ended and flexible, and instruction became naturally peer-driven as we tapped into Muonde's strengths in teaching practical skills to their communities and we turned challenges into assets. We summarize our teaching methods in Table 3, give an example below (the importance of humor in our teaching) and make a comment about unusual learning modalities. We describe our methods in detail in Appendix B.

Humor was an important part of making the learning fun, engaging, and low-stress. For example, we often turned mistakes into jokes which also helped learners remember: at one point, a learner left her finger on an arrow key for several minutes because the mentor forgot to tell her to stop pressing it; it was referred to as “Mai Chikudo's arrow” from then on (e.g. “hold down Mai Chikudo's arrow while you move the pointer across the screen,” was a reminder frequently accompanied by laughter). Learners also invented funny mnemonics to remember the acronym “GPS,” for example, *gunduru piii sedanda* which refers to a way of sleeping where a person just throws themselves on the floor or ground without blankets or a bed, like a log or stick that is falling to the ground.

The role-plays and songs were a particularly important, creative kind of modality which allowed for wider participation, and songs are a key method Muonde uses for teaching and spreading Indigenous innovations on many topics; as of the time of this writing the team had created three different GPS songs. We highlight this point because a part of empowerment is recognizing that teaching methods themselves need to be responsive to what is strong and effective in a culture (Freire, 1970).

4. Discussion

By focusing on peer-based learning of medium-tech mapping tools, we achieved our goal of empowerment through technology transfer for Muonde's mapping team. Community members reported significant improvements in confidence and applied the mapping technology to a wide variety of activities at scopes larger than outsiders had thought of. We have avoided some of the potential neocolonial pitfalls of PGIS by emphasizing the community's skills, interests, and knowledge. (We have not addressed the potential distortion of Indigenous knowledge by using colonial concepts and data structures, however. This was beyond the scope of the project and will be discussed in the future by the community team.) We reflect on the reasons for the success of these strategies below. Key conditions enabling our success included our emphasis on adult education principles, building new and working with existing communities of practice, and pairing medium-tech solutions with community capacity.

4.1. Flexible, relevant teaching and adult education principles

What aspects of our teaching methods facilitated effective technology transfer and empowerment, given the limited mapping and computer experience the team began with? Based on our analysis and community discussions, we believe our success is due to our emphasis on a flexible, relevant, multimodal, and interpersonal approach. These features align with principles of effective adult education, which hold that teaching should be relevant and problem-centered, and should build on learners' prior experiences (Knowles, 1973; Cooper and Richards, 2017). Relevance is key for adult learning (Sackey et al., 2015; Pinto and Cooper, 2016), and particularly important for participatory work. GIS technologies lend themselves to problem-based learning, which is consistent with constructivist learning theory in which learners work through authentic, real-world problems (Kinniburgh, 2010). Constructivist educational psychology also suggests that students are not blank slates: Students build on what they already know (“information processing” constructivism), and bring assets to the learning grounded in their social context (social constructivism) (Hull and Schultz, 2001; McInerney, 2013; Tate and Jarvis, 2017). Teaching that engages learners multimodally (through visual, auditory, and kinesthetic channels) employs the idea of multiple kinds of literacies, ensuring that people are not left out because they learn differently (The New London Group, 1996). Respecting literacies other than written ones is important when empowerment of local people is a goal of the teaching, particularly in cultures with extensive oral traditions like those in Mazvihwa and in many other communities. Development engineers should also note that there are strong parallels between adult education and human-centered design (Altay, 2014).

4.2. Peer-based instruction and building communities of practice

In our peer-based technology transfer, several of the challenges we faced were actually our greatest assets. Because of the language barrier between the initial mentors and the initial learners, translating English to Shona and encouraging learners to discuss together was essential and indirectly meant that we emphasized their own ability to understand and use the technology for themselves. Very quickly, the local people were teaching each other and the visitors were serving as technical advisors (Young and Gilmore, 2013). Because we had some learners who acclimated quickly to the mapping tasks, by necessity we placed them in mentoring roles early on. This had the effect of cementing these mentors' understanding of the technology, keeping the most skilled individuals invested in their community, and reducing the community's reliance on outside help to maintain the technology and skills after initial instruction. Because of this strategy, we focused on key moments of inclusion and exclusion among the team (Elwood, 2006) as well as helping them to form close relationships. These challenges did make the learning harder and required more time and patience, but we feel that our methods were ultimately better off for it.

These challenges-turned-opportunities contributed to our construction of a community of practice (Farnsworth et al., 2016) around mapping. Until recently, GIS education has not focused on the idea of communities of practice as a strategy for skill and knowledge transfer (Tate and Jarvis, 2017), and we believe that it was a critical aspect of what made our teaching so successful. Communities of practice are a form of social learning which is heavily peer-based and focused on an application of a topic or skillset of mutual interest (Wenger, 2000). In our case, the community of practice allowed us to be very open-ended in terms of the goals of mapping. Going into the situation, none of us had rigid ideas of what instruction or mapping should look like, and this helped us remain flexible to changing conditions and new ideas for instruction. This approach is unusual, as many participatory mapping projects are motivated by some particular funded issue requiring mapping rather than allowing the communities to drive more open-ended questions (Cooper et al., 2007; Wiggins and Crowston, 2011). These specific, externally-motivated projects may be empowering for that particular issue or opportunity, but do not become sustainably empowering if they have not taken the time to impart the skills to a broad group of community members. Technology transfer goes beyond assisting a community in mapping something to allowing the community to update their maps and find new uses for the tool when the researcher has left, which is not often feasible with project-driven mapping (Cullen, 2015). We also sought to impart basic familiarity with digital mapping techniques to as many people as possible (Elwood, 2006). This helped the community understand what the technology could do, enabling a critical mass where learners could have conversations with each other to discuss the possibilities. By having 30 Zimbabweans able to discuss what should be mapped and how, rather than just a few (and by encouraging those conversations to happen), we greatly increased the possibilities of community-generated discussion leading to community-generated applications by encouraging the formation of a community of practice.

One of the benefits of this community of practice was the rapidly expanding scope of the mapping projects the community undertook. The types of projects the team mapped while the visitors were present tended, unsurprisingly, to be limited in scope because they were associated with what we could map in a short time. However, even when those of us in the international mentor (outsider) group made suggestions of what to map after the training, we were not thinking as broadly as the Muonde-based team (contrast, for example, the Zoza garden with the Mhototi Ward borehole map). And where the scope of the project suggested by an international mentor was at the village level, the Muonde team proceeded to move from mapping a problem to solving it (for example, tracking the distances to nearby schools, resulting in creating an early childhood development center in Mudhomori village). Similarly, the fact that many of the projects that the mapping team mapped had scopes that tended towards village, ward, and communal area is aligned with The Muonde Trust's mission and existing strengths. However, with the transfer of this technological toolkit, the team also turned their attention to a wider set of connections both regionally and nationally (for example, the Zvishavane history project, which is a part of reaching out to the history students at the local University).

4.3. Scaling up from a pre-existing community of practice

Our extremely open-ended approach was successful, in part, because Muonde's team already has familiarity with research, self-confidence in solving their own problems by asking and answering questions, and their own existing communities of practice. Even when they do receive outside help in the form of funds or training, Muonde's researchers maintain a positive, self-reliant attitude. This attitude emerges from decades of being supported in their own knowledge of what works and their inherent skills in addressing their own problems, exemplified in one of their songs: *Muonde wedu unoenda mberi haudzokeri shure* ("Our Muonde, always going forward, never backwards!"). Muonde's skill transfer methods share this emotional empowerment with the communities around it, as well as practically empowering people with solutions to the thorny problems they face on a daily basis. Not only do they have significant confidence in themselves to begin with, but they also have an established mechanism for mentors to come teach them new skills, making it easy for the mapping instruction to fit into their pre-existing structure. In addition, Muonde's role as a community organization meant that the team was in a good position to bring together stakeholders to engage in a constructive discussion with the community, and with the digital mapping data, effective actions regarding development issues could then be proposed and taken (e.g. with the children of Mudhomori walking long distances to school). Muonde is also well-positioned to work with local government, making their mapping products even more practically empowering for local decision-making, which is often a challenge for participatory approaches (Smith et al., 2017).

Building on Muonde's pre-existing communities of practice and training Muonde's researchers in mapping has a much larger, cascading, networked effect, in the "train-the-trainer" sense. Muonde is able to teach many others in their region and beyond. Their researchers are well positioned in the knowledge networks of Mazvihwa Communal area to be 'supernodes' and have a deep knowledge of what kinds of language and approaches will influence local farmers (Elwood, 2006). Logistically, the team feels that many of the existing mapping applications can be scaled up within Mazvihwa Communal Area with few additional resources (mainly food for workshop participants, electricity, and batteries). Muonde would need further resources to scale up outside Mazvihwa, including transportation resources (fuel for vehicles and financial allowances for the mapping mentors) as well as a projector. These resources would allow the team to travel outside Mazvihwa to teach workshops to communities elsewhere, as well as in tertiary institutions like Mlezu or other universities. Key will be the capacity in these other locations to absorb and use training; these communities and institutions would eventually need to be able to develop a mapping team and purchase their own GPS units and computers, in order to scale up further, but the cost of this equipment is low relative to the number of people who can benefit from the mapping projects. See Appendix A for further thoughts about scaling up Muonde's mentoring and mapping strategies within Zimbabwe via their own direct teaching.

What accounts for Muonde's successful pre-existing community of practice and strong network? First, there have been several key individuals throughout the group's history who have worked together to consistently practice research, generate and answer questions, and recruit financial and intellectual resources, and we honor them for their work: Dr. K.B. Wilson, Mr. Abraham Mawere Ndlovu, and Dr. B.B. Mukamuri. The importance of individuals is key even in the mapping team – several of the authors learned the mapping skills particularly well and do the majority of the mapping at this point (in 2017–2018). Future work with this community and others could focus on how to find and involve these key individuals, and how to ensure continuity in the community of practice if they aren't able to remain engaged. Also key to Muonde's success is their emphasis on self-reliance and their goal to reduce donor syndrome, paired with long-running research projects which reinforce the ideas that the community can solve its own problems. Finally, Muonde trains a variety of people from different villages and clans throughout Mazvihwa, and emphasizes teaching women as well as men, ensuring that there is a broad base of people throughout the area trained in and enthusiastic about their Indigenous innovation projects. Our success with the mapping instruction also makes use of this strategy: we kept the emphasis on teaching everyone.

4.4. Medium-tech solutions paired with community capacity

Another aspect of our success was our choice of medium-tech mapping techniques to bring to the Muonde team. Participatory mapping can be done with a range of technologies, e.g. low-tech solutions like paper maps, medium-tech solutions like basic GPS units and digital mapping software, or higher-tech solutions like drones (Rambaldi et al., 2006). Participatory mapping need not use the most cutting-edge computational tools, and for on-the-ground solutions, cutting-edge tools might not be readily available or appropriate (e.g. opaque and complicated software, continuous and fast internet access, or expensive equipment). Participatory mapping solutions must balance between the applications and solutions that they enable and the resources required for each technology (e.g. reliable power grid, internet access, ability to repair, time required to learn, use, and maintain). Our deliberately medium-tech choices were within our learners' abilities to grasp, feel ownership over, and maintain (therefore becoming potentially sustainable over the long term), and have the advantage of generating products that may be easier to share with other audiences than lower-tech techniques like paper maps.

This medium-tech choice is important in an age of big data where the tendency to favor problem discovery or definition by a remote observer can be particularly tempting, especially with cutting-edge geospatial technologies. As satellite imagery becomes more common and finer-grained and algorithms become faster and more automatic, the pull is strong to focus on detecting development challenges from space. This strategy can be a legitimate way for the big data movement to make a significant contribution to development engineering, for example monitoring rural electrification in Africa based on nighttime lights (Min et al., 2013) or reservoir use in Syria during the recent refugee crisis (Müller et al., 2016). We argue, however, that remote problem detection can be problematic should not be the only way for geospatial technologies to serve sustainable development (Acolin and Kim, 2017). As we have demonstrated them in this study, participatory mapping methods are equally as important and can indeed be complementary to satellite-based methods (which, in Mazvihwa, would not have addressed the development concerns of the community; see Appendix A).

In fact, participatory mapping can be especially effective in accurately detecting problems in real time that are not visible remotely (Aynekulu et al., 2006; Shrestha, 2006; Livengood and Kunte, 2012). In addition, local people are more likely to understand the social context of a problem and to be able to communicate effectively with other stakeholders about it (Elwood, 2006). Community engagement also makes solutions to development problems more effective because solutions are better attuned to the situation (Mapedza et al., 2003) and valued by the community who is empowered by shaping them (Grobler and de Villiers, 2017). These techniques not only ensure that remote interpretations of systems are properly ground-truthed with local expert knowledge, legitimizing that knowledge and contributing to better governance and land-use planning, but also provide opportunities for training and investment in sustainability solutions for the people on the ground (McCall and Minang, 2005, Tomaszewski et al., 2017). Participatory mapping can increase self-esteem and pride for individuals and groups (Rambaldi et al., 2006; Young and Gilmore, 2013), imparting significant emotional benefits along with the recording of knowledge. They can also provide an opportunity for the integration of wisdom from other knowledge systems and worldviews (Reed et al., 2008), empowering local people to feel that their knowledge has value, their experiences are valid, and that they are capable of solving their own problems (Friere, 1970). In these ways, participatory mapping can contribute more clearly to not just detecting but also solving problems in ways that promote sustainable development.

To place the benefits of participatory mapping in perspective, the projects that the team mapped address several of the UN's Sustainable Development Goals (UN, 2015). These include: eliminating hunger (via mapping of prospective irrigation areas, community gardens, and Muonde's innovations such as stone walls which increase the efficiency of crop production), achieving universal primary education (via tracking the distances to schools and establishing closer schools for very young children), providing clean water (via mapping which borehole wells are not functioning and where there are no wells in parts of the district), supporting life on land (via mapping the sacred forests/*rambotemwa* and the change in woodland trees by resurveying quadrats), and promoting peace, justice, and strong institutions (via mapping the area for Muonde's new center, which was a first step in getting the land to establish Muonde's permanent presence in the Communal Area). There is clearly great potential to combine participatory mapping with remote and automated technologies to address sustainability goals.

4.5. Technology transfer assessments revisited

We began with criticisms regarding the overuse and poor definition of empowerment in development contexts. What have we gained by defining empowerment as technology transfer? Common sense indicates that making ideas measurable makes them more useful, but did our specific assessments gain us anything? We believe so.

First, in the case of our community, we could check whether the community really was benefiting from the technology that was brought to them. They showed excellent uptake, application, and retention of the skills, and clearly felt more confident about the technology before and after the teaching and community-building. They claimed the technology as their own and made use of it for their own purposes. That said, we note that now, three years later, fewer of the team members can create maps than we might have hoped. Mainly one or two individuals (notably, men) are the ones retaining the skills to map, and when they are busy, no one is available to teach the others. We believe that with more in-person international instruction (perhaps once a year), more computers, and more funds for applying the technology, the community's retention would remain higher for a longer period. This implies that the community of practice needs ongoing investment to maintain the high level of function that the team exhibited in the first year of the project. We still believe our results show great promise for other applications, however. Even if the community has not continued to map as much in the last year, the mapping they are doing (*rambotemwa* mapping for the bio-cultural restoration protocol) is extremely important and significant to them, and they are still benefiting from what they have already mapped. So our project did achieve positive results for technology transfer in the short and medium term, and might need more input for the longevity of the project to move into the longer term. Carefully defining empowerment through technology transfer allowed us to see this.

Second, by assessing these carefully defined technology transfer goals in an extremely community-driven participatory context, we were able to see that open-ended teaching that follows adult education principles helps to create or enhance communities of practice. In our case with Muonde, this allowed us to understand that the pre-existing community of practice was a key condition for the success of our project. This points to the importance of building and supporting communities of practice along with developing technological interventions. So defining empowerment has not only social justice impact (meaning we assess real benefits to communities of technological interventions) but also helps us understand the key conditions for our success more completely. This understanding allows us to scale up to other situations, which in this case points to using adult education principles and building communities of practice.

5. Conclusions

Empowerment as capacity-building is an essential part of sustainable development, and we have seen in our participatory mapping project that medium-tech mapping transfer to rural Zimbabweans is a feasible capacity-building project. Participatory mapping is a powerful tool to complement remote approaches to poverty detection and alleviation. Satellite-based remote sensing approaches for classifying land-use/land-cover change can identify areas for governments, international aid agencies, and non-governmental organizations to focus efforts. However, Muonde's sustainability concerns (many of which are represented in Table 1) would not have been easily identified by these kinds of approaches, and their ability to work locally on solutions is grounded in their community-based work.

Development engineering, in aiming to improve sustainability for the most vulnerable people in our global community, should engage wherever possible with radically co-created participatory projects, incorporating the principles of PAR into the engineering design cycle. These principles can guide engineers from simply devising solutions to true collaboration in defining and solving problems – that is, co-laboring with the people they intend to serve. Participatory mapping researchers should also put the focus of their projects on technology transfer in addition to generating mapping products, building in time and funding that allows the creation of communities of practice around medium-tech mapping solutions. Participatory research teams should be prepared to both provide the technology to communities as well as ongoing support as the community builds its practice. Adult education principles and flexible teaching methods should be a part of the training for development engineers and participatory mapping researchers in order to realize these goals. In the future, established principles of GIS pedagogy drawn from the primary school formal education literature could inform these trainings, and trained cartographers willing to conduct PAR projects could enhance the kinds of maps produced by these developing communities of practice.

Where collaborations with pre-existing community-based organizations like Muonde are possible, technology transfer and empowerment is enabled by long-standing community-based research, teaching, and co-laboring. In these cases, teaching and learning can be extremely open-ended and still succeed. However, in communities where these assets do not yet exist, a more structured approach is likely to be more useful. We believe that relevant future work needs to investigate what it takes to build communities of practice that can support open-ended, community-driven inquiry, regardless of a community's initial capacity for the technology. That said, the perennial principles of PAR still apply, and researchers should come prepared to find out what the community wants to learn, what they care about, and what skills and abilities they already bring to the table. After all, there was a time in Mazvihwa before Muonde, and through consistent steady capacity-building, they have achieved important gains in well-being for their community. There is room for others to do the same.

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.deveng.2018.07.001.

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