Sustainable Development as Successful Technology Transfer: Empowerment Through Teaching, Learning, and Using Digital Participatory Mapping Techniques in Mazvihwa, Zimbabwe

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Appendix A – Case Study System Details

To give context to our digital mapping projects we first describe Mazvihwa Communal Area in Zimbabwe where the work is based, the Muonde Trust which supports the digital mapping work, and our authors' experiences of the Zimbabwean formal education system. We describe the formal education in Zimbabwe as experienced by our author team in order to compare the mentoring methods we used with the learning environment most of our learners had experience with. We then give some information about the author team who wrote this paper in order to partially situate our knowledge (Haraway 1988).

1 Mazvihwa Communal Area

Mazvihwa has a population just under 20,000 (in 2012) in an area approximately 518 km^2 in size, and is located in south-central Zimbabwe, 45 km southeast of the city of Zvishavane (population just over 45,000 in 2012). Zimbabwe classifies its farmland as Agro-Ecological Region 1 (very productive) through 5 (poor); Mazvihwa is located in one of the driest parts of Region 5. In colonial times, agriculture was thought impossible in Mazvihwa, and it was considered poor even as ranch land. While there are services in the Communal Area, including schools, health clinics, some solar and transmitted electricity, and borehole wells, Mazvihwa is a good target for development engineering to ensure better and expanded access to these services. In addition, for Mazvihwa, standard remote sensing products are completely inaccurate, inadequate, or inaccessible, making participatory mapping particularly important (see section 2 of this appendix).

Lying between the Runde, Sabi, and Ngezi rivers, Mazvihwa Communal Area is divided into two distinct areas, a mountainous area (*kumakomo*) and a non-mountainous area (*kudeve*). Although the colonial administration had displaced indigenous farmers in 1914 in order to reserve the land for whites, no commercial farmers were interested in such dry land, and in the 1960s and 70s the government eventually reverted to allowing local farmers to live and farm there. While farming conditions have been historically marginal at best and rainfall always highly variable, the limited data are consistent with local views that in recent decades rainfall first became more variable and then less predictable and concentrated. The last bumper harvest before 2016-17 was in 1999-2000, and local observers report that since 1998-99 the rainfall has tended to come in sudden erosion-generating downpours.

Driving to Zvishavane requires 45-60 minutes in each direction, 30 USD in fuel in 2016 (only 4-wheel drive vehicles can handle the rough roads in Mazvihwa), and passing through many police roadblocks where motorists are frequently fined (this was true in 2015-2016 when the international mentors visited; since the changes in the government in 2017, this has no longer been true, at least until 2018). While some borehole wells provide safe drinking water, overall infrastructure is lacking, and even many of the boreholes are inoperative or in need of repair (causing the functional ones to be utilized over capacity). There is no powered irrigation. Most households have some level of solar power, ranging from the ability to occasionally charge a few cell phones up through the ability to power a small computer or two and provide light at night (e.g. the Muonde Trust headquarters). Any larger appliance, such as a pump, requires a generator and fuel. Repairs usually require a trip into town (for parts or service), and even professional repairs in town are limited by availability of resources. Due to the costs of schooling and the urgent demands of farm life, many people have not completed secondary education, and university education is a formidable challenge in both time and cost.

2 Shortcomings of satellite-based geospatial analysis for Mazvihwa

Satellite imagery is too spatially coarse (MODIS products have 500-m pixels; Landsat products have 30-m pixels) to reflect Mazvihwa residents' needs for land-use planning. Where these products do identify potential issues, the significance of the situation on the ground is quite different than it appears in the top-down approach. For example, the Global Forest Change 2000-2014 dataset (based on Landsat, Hansen et al. 2013) shows considerable deforestation to the north of the Runde/Sabi Rivers. While Muonde may agree that the rate of deforestation is greater than desired, these are the villages of people reclaiming the land previously held by white ranchers and mining companies. So deforestation here is accompanied by an important re-assertion of sovereignty by black Zimbabweans. Muonde does continue to work with the people in these villages to help them develop in a sustainable way, but top-down imagery was not needed to alert them to this situation. In addition, the spatial scale is too coarse to identify issues like erosion due to excessive runoff, which is a much bigger ecological problem for the people of Mazvihwa than deforestation. Higher spatial resolution imagery such as DigitalGlobe's products might make such an analysis possible, but the imagery is prohibitively expensive, especially for change detection requiring repeat imagery. We were extremely lucky to obtain basemap data in 2015 through the University of Minnesota's connection to DigitalGlobe Foundation, and cannot rely on that kind of fortuitous chance for ongoing environmental management. Because Mazvihwa does not have consistent internet access, using Google Earth to view DigitalGlobe's imagery is not possible. Historical aerial imagery of sufficient quality for quantitative analysis is equally difficult to obtain and will only become more difficult to obtain in the future.

More importantly, Muonde's main environmental concerns are about forest type (mopane versus acacia), decline of individual species of importance in the woodland, and the growing of drought-resistant crops. Satellite-based data products use classification schemes which are too coarse for application to these needs. They do not distinguish between which kind of deciduous broadleaf forest or which kind of cereal crop is being grown. For example, MODIS' Land Cover Type data product classifies most of Mazvihwa as grass or shrub (almost completely missing crop production), and classifies the mountainous areas as "deciduous broadleaf." GLCC (based on the AVHRR satellite) has finer categories but it has pixels one kilometer in size, which is even coarser than MODIS.

Other sustainability issues identified by Muonde's mapping team that could have been addressed with large databases (rather than satellite imagery) include distances to services like schools, clinics, and borehole wells. In this case, however, the Zimbabwean government, like in most African countries, typically does not have such data. Where it does, there is little established procedure to share it with stakeholders and communities for local planning. Other entities such as NGOs and mining companies may have data on an area or phenomenon of particular interest, but this data is likely to be difficult-to-impossible to access for various reasons. All these issues point to the necessity of bottom-up mapping practices. And even when the imagery is adequate, there is always need to ground-truth classifications and examine the significance of land-use changes (e.g. the deforestation in the resettled lands).

3 The Muonde Trust

The Muonde Trust was founded by Abraham Mawere Ndlovu, based on 30 years of work with Dr. K. B. Wilson and Dr. B. B. Mukamuri. Originating as an informal group in the 1980s and increasing over time in its reach and organizational formality, Muonde was finally registered as a Zimbabwean non-profit in 2014. By documenting, revitalizing and disseminating local knowledge and also bringing in visitors to share knowledge, Muonde has been able to spread information about water harvesting techniques including dead-level contours and Phiri pits (small water infiltration ponds), improvements in domestic architecture, dry stone wall masonry, land history and environmental history, live fencing, sand traps and gully filling for erosion prevention, weather monitoring, empowerment of women, cultivation of local small grains, GPS and digital mapping, as well as outreach and documentation of their work and ongoing scientific research projects.

Muonde has no political or extra-political authority, but rather it works with local authorities such as district administrators, ward councilors, chiefs, village heads, and headmen in order to promote shared development goals. Muonde's "bush-to-office" (bottom-up) approach, in which ideas originate in rural areas and are then brought to local cities and then up through governmental channels, provides multiple benefits: it empowers rural farmers; it allows ideas to come from the people who are most directly involved in the implementation and outcome; it favors practical, inexpensive solutions; it generates approaches which are appropriate to local environmental conditions; and it automatically selects ideas which are culturally acceptable. Muonde has already seen significant success in spreading water harvesting techniques throughout the area through farmer to farmer and peer to peer trainings, service to local communities, and supporting the Phiri Award for local farm innovators.

A contributing factor to successful skill transfer is that Muonde is a group which actively works to teach others their skills, instead of hoarding the knowledge (or even just teaching a few who can take courses from them). Since the greater community knows that Muonde works to teach others and share knowledge, they have reasons to interact with Muonde already. Muonde's pre-existing "classes" earn the community's respect and goodwill, ensuring that the new "class" (e.g. digital mapping techniques) can be disseminated (transferred) to many new learners, helping to solidify a local community of practice which can become self-sustaining.

Muonde strongly fights "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. Local people refer to donor syndrome as a disease, using the slang word *kumbiraitisi* (derived from *kukumbira*) meaning "how people are addicted to begging always." Muonde's attitude of self-reliance is the context in which we tackled learning digital mapping, and part of why we could try a teaching method that required some self-confidence to begin with and which so directly contradicted learners' experiences in the formal school system.

4 Zimbabwean formal education system

Zimbabwe's education system, as experienced by our author team, evolved from colonial school systems. The Zimbabwean Government rapidly expanded service after Independence in 1980, until it was hamstrung by financial problems in the 2000s. In many ways, the current system is still weighted down by the legacy of 1960s state-of-the-art British educational thinking. The education culture tends toward formality, hierarchy, and distance. The top-down model of education elevates the status of the lecturer and diminishes the status of the learners, who are relegated to simply taking notes. Student participation and engagement are not emphasized. Class discussion is rarely employed as a pedagogical technique. Students are often intimidated or even afraid to ask questions. There is usually no opportunity for one-on-one instruction such as office hours or asking questions after class. In this sort of environment, it is hardly surprising that raising an issue regarding a teacher's facts is seen as a direct challenge to the teacher's authority and treated accordingly. The situation is slightly more flexible at the university level, but much of the hierarchy and distance remains. Questioning or doubting the professor is likely to lead to repercussions. All this said, recent reforms have been proposed at the national level to mitigate these issues, with policies encouraging early childhood development programs, more student participation and class discussion, and office hours where students are encouraged to ask questions. We may therefore expect that future formal educational experiences will be quite different from those of our author team and potentially more similar to our mapping teaching methods, described in Appendix B.

5 Author Group

This paper is a collaboration between two researchers in California (USA) and nine researchers from the Muonde Trust. Among the Muonde team, seven live in rural Mazvihwa, and two come from Mazvihwa but live in the city of Zvishavane, 45 km away. Education levels vary, with five authors having completed secondary education, four having completed tertiary (university) education, one having completed a master's degree, and one having completed a PhD. Our ages range from 24 to 50, with Muonde team members at both extremes. The team contains five women and six men. Among the Zimbabwean researchers, livelihoods include farming, raising livestock, and employment through the Muonde Trust; the US authors include a postdoctoral researcher and an engineering management consultant. M.V. Eitzel, assisted by J. Solera, was the initial mapping mentor for a group of community researchers from the Muonde team; this initial group of learners became the "GPS team," which included A. Changarara, S. Gwatipedza, and A. Chirindira. The GPS team became the next round of mapping mentors, teaching other Muonde members (including the remainder of the authors), community members,[1] and others who became in turn new mapping learners. Learning GPS and digital mapping spread outward like ripples on a pond, and the authors of this paper have played roles in all parts of the process.

[1] Other community members taught by the GPS team include primary and secondary school teachers, secretaries for bore holes, Madzoke valley people, Mudhomori village people, preschool early childhood development teachers, Mike Auto (local amateur historian in Zvishavane), war collaborators, community garden committees, Mlezu Agricultural College teachers and students, Kufunda permaculturalists, Zimbabwe Electrical Supply Authority, and local authorities who attended a meeting to discuss the proposed Utaya irrigation project; see Table 1 in the main paper for descriptions of mapping projects.

6 Characteristics of mapping learners and mentors

The Muonde team was familiar with research methods (e.g. they demonstrated mastery of consistent measurement methods and the idea of statistical sampling); however, GPS and digital mapping (GIS) were still more highly technical than much of the research they had been exposed to at the time. Among our learners, there were people with widely varying backgrounds and aptitudes and therefore quite different learning speeds. For older individuals, it had been decades since their schooling, while some younger people never completed secondary school, and still others had recently completed university-level education. In addition to this, there was significant fear and intimidation associated with learning a new skill and mastering a new technology. Some characteristics of Muonde's researchers and their visiting mentors that made the rapid uptake of the technology possible included patience, compassion, the determination to work hard, respect for each other, and a general attitude of openness and curiosity that reflects the approach of the larger community as a whole towards indigenous innovation.

Patience was a key attitude for both mentors and learners. Digital mapping is a complex task to learn and then implement. Both mentors and learners were tolerant of making mistakes and learning from them. As a group, mentors and learners were willing to repeat the ideas behind it and to continually practice the skills. The initial mapping mentor showed patience with learners despite her expertise through her PhD training, repeating instruction and waiting for individuals to try again until they succeeded at a task. When the initial mapping mentor went back to the US, the Muonde learners continued to meet to practice their skills several times a week. The initial learners then became mentors to new learners, and also brought considerable patience to their instruction methods, teaching in Shona so the material would be more accessible to more people. Peers were also generous in giving each other time to practice on the computer and with the GPS units; even in a group of ten people everyone had to take turns with the single computer and limited number of GPS units (especially in 2015 when there were only four units). Humility was key for all mentors and learners, as was a deep sense of mutual respect. Muonde models this by showing respect for local authorities and the community in Mazvihwa more generally, and by valuing all people as contributors to indigenous innovation regardless of education level.

Underlying the group's patience was a strong commitment to hard work. Muonde's research team is generally tireless in its efforts to develop, sustain, and spread indigenous innovation, often traveling through difficult conditions to help community members improve their homes and land. When the initial mapping mentor was in Mazvihwa, she was always thinking of what the next lesson would be, how to adjust it to where the learners were, and often stayed up late hours the night before a workshop to prepare. The initial learners' persistence after she left even in the face of difficulty remembering exactly what she had taught them was key in cementing what they had learned, and they showed this by continuing to ask her questions via WhatsApp. She also consistently responded to this steady stream of messages, some of them quite late at night or early in the morning (the time difference between California and Zimbabwe is 9-10 hours).

Muonde's members are also characterized by an attitude of openness and curiosity. The mapping mentor often had to work hard to stay ahead of the learners in order to instruct them and sometimes learned alongside them as they tried out different ways to use the software together. Even the older learners demonstrated their interest in technology, despite its unfamiliarity. Particularly for the initial mapping mentor, flexibility was a key attribute.

One mentor noted that initially it was a difficult task to do the translation between English and Shona on complex mapping concepts and techniques; at first it felt like false authority, because you need trust from both sides. After persevering, he discovered that everyone wants to learn and people wanted him to teach. Now he feels that it's his duty to teach – someone taught him, so he should teach others – and he enjoys doing it. He says that people make jokes and it reminds him of school. As a group, the Muonde team now has the confidence and experience to teach others, sharing their excitement about the technology.

7 Additional mapping applications envisioned by Muonde

Muonde has found that digital mapping is actually relevant to their projects, and can be useful. the team has also showed how the maps can benefit multiple stakeholders, not only Muonde. Muonde can reach out to local leaders and extension officers to collectively address emerging needs. Muonde now imagines many other applications for digital mapping, including implementing and monitoring more Muonde homestead and farmland improvement projects (including water harvesting structures and domestic architecture innovations, among others), using maps to settle land claims and for inheritance procedures, land-use planning, and in mapping distances to services other than schools.

We assessed the scope of each of Muonde's mapping projects and evaluated whether the origin of the idea (visiting outsider or community member) could statistically predict the scope of the project (individual, village, ward, communal area, or regional/national). The leaders of the Muonde Trust verified our ratings of the scopes of each project. If the community is in a better position to envision projects with wider benefits, then we could run an ordinal logistic regression in R (version 3.2.3) package polr (R Core Team 2015) to statistically test this. We include the data (generated from Table 1 in the main paper) and code to fit the model in a supplementary file. For all projects ($N=21$, $p=0.16$), and only projects conducted when outsider mentors were absent ($N=15$, $p=0.08$), the scopes tended to be larger for community-originated ideas. For such a small sample size, we believe the results are supportive (though not conclusively so) of the pattern we qualitatively observed: The local people were better than international mentors at defining and mapping projects and issues which were important to the community at broader scales.

Muonde is just beginning to explore using mapping for land-use planning. They have mapped the communal grazing area for livestock and many farmers' individual home fields (yards or *bindu*) and/or crop fields, for example. A next step would be to calculate how many animals can be supported by the grazing land or how much seed is needed for a crop field or *bindu*. The community can also use these maps for grazing rotations of the livestock and locations for paddocks during the growing season. Mapping of a proposed irrigated area helped Muonde confirm that the area matched the amount promised by the local authority, as well as predicting the need for equipment, number of people needed to maintain it, and how to rotate the crops. The map will be helpful in communicating with outsiders who wish to help with the irrigation, and with future generations who will have to manage the system. Muonde could play a role with these stakeholders to help different groups come together to make development decisions.

Mapping also allows Muonde to represent, quantify, and monitor their innovation projects throughout Mazvihwa. Making maps showing how far Muonde's innovations have spread, and how numerous they are, can be a compelling argument to donors and funders. Calculating the lengths of stone walls and earthen water harvesting structures can give a sense of the scale of Muonde's interventions. One map they have already completed is a survey of all the stone walls in Madzoke valley, which the Muonde team can use to monitor, assess, and evaluate the progress in the work done on constructing the walls. Maps will also help Muonde keep track of the individuals in their long-term research sample, helping them to determine who is still in the area and available to be interviewed during follow-up surveys. Many of Muonde's projects have yet to be mapped, including dead-level (water harvesting) contours and dams as well as domestic architecture innovations like separate kitchens (with the fire separated from storage and food preparation, to reduce smoke inhalation), segregated trash pits (plastics, metals, and biodegradable materials), and sinks. The mapping team also hopes to map Muonde's tree nursery project which involves growing and distributing fruit trees to people. The team could map every fruit tree distributed by Muonde in order to evaluate whether people are caring for them. The results will help the team conduct research on the possible reasons that people might have difficulty caring for the trees.

Muonde's mapping team could also map individual people's yards (*bindu*) and crop areas to resolve any conflicts regarding ownership (Kwaku Kyem 2004, Brown and Raymond 2014). We do note that this could introduce conflict where peoples' yards are very unequally sized, and this is where understanding the uncertainty in the area calculation is important. That said, inequity cannot be discussed or addressed by the community if no one knows it is happening. The chief's land peggers (surveyors) might use mapping to end the longstanding problem of sharing land equally among the people. The Muonde team might help them map the areas or *bindus* and make sure everyone got the same area. This will also improve the relationship between Muonde and the local authority. And maps can be used as reference tools for inheritance: During the division of a household head's *bindu*, people will have the facts on how big it is and how to divide it equally. As a justice tool, one can then produce a map which shows his father/ancestors lived at that particular place.

Muonde has already done some mapping projects for larger organizations. They were asked to teach digital mapping at Mlezu agricultural college to the agricultural extension staff (AGRITEX), the epitome of bottom-up education. There is potential for Mlezu to compensate Muonde for teaching mapping classes at the college. In a similar way, the Zimbabwe Electrical Supply Authority asked Muonde to map the length of their electrical lines so they would know how much to pay their workers for clearing brush beneath the lines. This kind of job could be compensated in the future. Muonde could also do mapping projects for local authorities, including surveying for land allocations. Even in the US, mapping skills are highly employable, and many applications are possible.

Maps of Muonde projects, other than being useful for monitoring, can also be useful for advertisement both within and outside the country. International researchers may be interested in Muonde's long-term research projects and the associated data. International funders and donors may be attracted by the presentation of Muonde's achievements. Within the country, maps could serve as advertisement for the mapping services described above and could help to make connections with other similar organizations. Already, Kufunda village, a permaculture non-governmental organization near Harare, invited Muonde's team to do a week-long workshop on mapping and water harvesting. Beyond Zimbabwe, Muonde hopes that internationally their maps will be passed along and will generate interest in Muonde's work and lead to new collaborations.

In order to continue to scale up its projects, the community would benefit greatly from having more computers, however, and in order to make progress on new initiatives, other equipment would be necessary. For example, Muonde's ongoing cultural restoration project and bio-cultural protocol involves mapping *rambotemwa* (sacred forests), and for that project to be adopted all throughout Mazvihwa, sturdy bicycles would be needed to get to remote locations, and appropriate gifts would be needed for key informants (e.g. community elders).

That said, with the teaching methods and equipment they currently have, Muonde can teach schoolchildren (given that the new education curriculum stresses practical teaching and learning) and do workshops within Mazvihwa. The team could start small with communities or young people who are interested and willing to learn. This could result in more mapping benefits for people throughout Mazvihwa as the team takes on more projects like the ones listed in Table 1 in the main paper. This strategy could also have larger impacts as other community members learn how to map things on their own by borrowing the existing GPS units and working with the team to make maps on the mapping computer. The Muonde team may also be able to assist farmers subject to the government's "Command Agriculture" program[2], helping the farmers calculate their acreage for the purpose of getting the correct fertilizer, seed, and other inputs, and for calculating the harvest-acreage relationship. These tasks would also require ongoing resources like food for workshop participants, electricity from home solar power systems, and batteries for the GPS units, but these are minimal requirements for the impact the mapping would have for the people of Mazvihwa Communal Area.

One challenge we continue to face for any scaling up, however, is the limited amount of equipment available to the team. With only eight GPS units, individuals still have to share units and take turns to get experience with them. Given that the technology can be intimidating to new learners, it is critical that they get hands on experience accompanied with compassionate guidance from an experienced mentor. (Some learners did find the GPS unit to be more accessible due to its resemblance to an older model cell phone, which may help with the unfamiliarity of the technology.) Both of these problems are much worse with the computer, however. We only had one computer, and it was completely unfamiliar to all but a handful of our learners. Because there was only one computer, we kept it inside and all members of the team had to travel to one household to use it, making it harder for those who lived further away. This is currently the most significant barrier to improving the mapping skills of more people.

In thinking about scaling up beyond Muonde, one concern might be that the research team itself is unusual. However, the Muonde team feels that the characteristics of our mentors and learners are present in everyone, as long as initial mentors help people realize that anyone can be a mentor and learner. They note that this is exactly how they taught their elders to use mobile phones. They also note that the teaching techniques are the keys to their lasting success, and these techniques can be used with others, including how-to sheets and technical support through WhatsApp. Because rote learning by imitation is a common way to develop new skills in rural Zimbabwe (culturally, "the one in front knows the path"), the humble leadership of the mentor was a key method for making sure learners didn't get lost. This is a strategy that can be replicated outside Muonde, especially if long-term teams are built using the open-ended, peer-oriented techniques we have developed.

Finally, a word about an alternative way to scale up the mapping work. While this community adopted cellphones at scale in 2010, smart phones have been slower to spread due to high cost and low

2 In the 2016-2017 farming year, and in an effort to increase national food security, the Zimbabwean government established a scheme to provide agricultural inputs and irrigation inputs on loan to maize (corn) and wheat farmers with a potential for significant yields through irrigation.

bandwidth. There is potential for mapping apps for smart phones to become a way for a much larger population to map their surroundings, especially as they become more widespread. However, consistent internet access is still a challenge in rural Africa so finding a way to collate and share mapped data in a central location would be a serious barrier for this kind of method. The GPS units have the advantage of being identical, and when paired with the how-to sheets designed for them, have proven to be reasonably easy to teach and learn, while apps may appear differently on different phones. The Muonde mapping computer, while only one computer, is at least a place where all the data can be gathered together. There are also the usual concerns about collecting sensitive information via collaborative mapping that should not be posted widely on the Internet. Smart phones may someday become a viable mapping technology in Mazvihwa, but for the moment they are limited in their usefulness. The constraints on this technology may be similar for other low-resource communities elsewhere in the world.

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