Research statement

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Introduction to BANG and its vision

It's 2020 with covid, remote interaction, . . . Zenzeleni has been spun-off and two cooperatives are generating enough income to pay salaries. The 'umbrella' not-for-profit (NPC) is looking to increase the number of rural ISPs and move toward financial sustainability itself with a multi-channel income stream. All the years of mesh network and community-based ICT4D research appear to have yielded something that is truly improving the lives of thousands of people. On the other hand, SignSupport, the ICT for Deaf communities, after a promising 2019 that saw the development of an Emergency Medical Services app and an innovative asynchronous Deaf contact centre, is currently languishing as covid locked down the three Deaf NGOs with whom we most closely worked. The project isn't dead, it's just stalled; as 1 PhD and 3 MSc students write up their theses. There are only 3 Honours students working on Zenzeleni now; as the project has moved from research into technology transfer, and only when Zenzeleni spreads more widely will the research continue: it has moved from research to project to business. We hope to accomplish the same with SignSupport and then combine the two into an ecosystem where local people build their own SignSupport scenarios, in their own local languages, over their own local networks. If they could do that by programming their own apps and networks in their own local languages, wow. That would be amazing. After all, this is what we do as Computer Scientists: we hide the complexity so that end-users can build and manage their own networks and write their own apps and websites. BANG is the name of the research group: Bridging Application and Networks Gaps (see Figure 1). We provide bridging apps for Deaf people to communicate with hearing people, and this technology can be adapted for any language, any scenario, any platform; and we provide bridging networks between the have-nots and the haves, and the Zenzeleni approach can be adapted for any underlying network technology, not just solar-powered rural WiFi. Thus, BANG is producing reference implementations of generalised approaches and solutions for bridging real application and network gaps.

Figure 1: BANG membership at any given year is roughly 15 postgraduates, always multi-disciplinary and generally split around 50/50 male/female; with an international cast. This photo shows two South African CS Honours on the left and then PhD students (from L to R Industrial Design Engineering (Thai/Dutch), Gender Studies (Ethiopia), me, Computer Science (Botswana/India), Social Development * 2 (DRC and Zimbabwe), and Information Systems (South Africa)). This was the 2016-2017 cohort (MSc's not shown).

Work Done over the last 10 years

Zenzeleni

By 2010, we migrated an earlier 1st phase of rural telephony to a 2nd phase that replaced point-to-point telehealth with mesh connectivity in a village. We continued the MUTI power strategy of charging 12v deep cycle batteries with mains and/or solar to power mesh nodes placed throughout the Mdumbi Backpackers campus in Tshani village, Mankosi Community, with the help of TransCape, an NGO operating out of the backpackers (see www.transcape.org.za). This rural Village Telco (see www.villagetelco.com) with its mesh potatoes was meant to help the backpackers service their own staff and the backpacker clientele with the intention to branch out into the community. The fieldwork led us to continue exploring technical aspects of Internet Protocol mesh networks and their applications in light of unreliable power and spotty connectivity, such as push-to-talk (Kobo et al., SATNAC 2010), call capacity (Zulu and Tucker, SATNAC 2010), mobility of IP devices (Chitedze and Tucker, SATNAC 2011 and 2012); and improving router performance and Quality of Service (see Kobo et al., SATNAC 2011 and 2012; Kobo and Tucker, IST-Africa 2012). The mesh network implementation occurred in parallel with related ICT4D-styled efforts, e.g. learning how locals used their phones (Bidwell et al., IWIPS 2011), a tablet based oral repository used by the local community authority (Reitmaier et al., IST-Africa 2012), and community self-provision of solar facilities to charge phones (Bidwell et al., TOCHI 2013). Zenzeleni has grown substantially over the years (see Figure 2).

Figure 2: (a) Zenzeleni coop member who sells vouchers, (b) early days internal custom made enclosure housing 2 * 12v deep cycle batteries, a handset plugged directly into a mesh potato with Power over phone line and phone charging apparati; and (c) installing a router and antenna at a residence (this one has a long range throw).

Inspired and guided by Bidwell, we more strongly prioritised non-technical aspects of our work. Roro et al. (SATNAC 2012) and Rey-Moreno et al. (JITICD4H 2012; ICTD 2013) examined socio-economic models which led us to directly engage the Mankosi community 'tribal' authority with respect to expanding the mesh network from the backpackers to the wider community, spread over 30 square kilometres. Mankosi community leadership helped

us design this network by choosing line-of-sight and secure locations (Rey-Moreno et al., DEV 2013). We grew to explore many other aspects of the project: local ownership (Rey-Moreno et al., JOCI 2015), legality (Rey-Moreno et al., ICTD 2015), gender (Hussen et al., AfriCHI 2016), billing (Ufitamahoro et al., DEV 2013 and SAICSIT 2014; Rey-Moreno et al. DEV 2014), network optimisation (Rey-Moreno et al., SATNAC 2014; Abdalla et al., SATNAC 2015), network performance evaluation (Tiemeni et al., SATNAC 2013 and 2014; SAICSIT 2014), voice over mesh (Meeran and Tucker, VITAE 2014), network security (Mauwa and Tucker, SATNAC 2013) and impact on phone battery life (Om et al., IST-Africa 2017). Rey-Moreno et al. (ITD 2016) collected baseline data on local demographics; and phone usage, charging and costs.

SignSupport

From 2010, we migrated the SignSupport prototype from a scenario where a Deaf person visits a doctor (Mutemwa and Tucker, SATNAC 2010) to a scenario where a Deaf person visits a pharmacist (see Figure 3). The latter scenario was more constrained, and could be mapped to an orchestrated communication sequence, following best practise pharmacy protocol, where a Deaf person and hearing pharmacist exchanged the phone back and forth to communicate about a prescription. The Deaf person's mobile interface had icons, buttons and sign language videos; and the pharmacist interface used textual buttons and dropdowns (Chininthorn et al. IST-Africa 2012, Motlhabi et al. DEV 2013 and SATNAC 2013). We pre-recorded sign language videos on the phone to keep costs down and be able to play them later at any time, e.g. an alarm reminder to take medication.

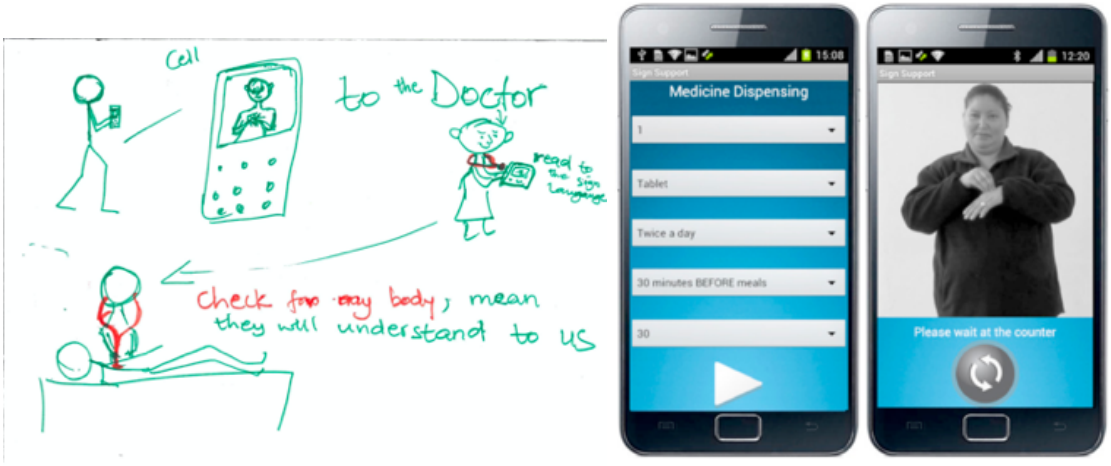

Figure 3: (a) sketches from Deaf community members conceptualising SignSupport, which led to (b) an actual working implementation done by a team comprising a Computer Science MSc, Pharmacy PhD and Industrial Design MSc, together with the Deaf Community of Cape Town (DCCT), a Deaf NGO.

In parallel with the pharmacy scenario, collaborators at UCT built a scenario for sign language video-led instruction of a computer literacy course, the International Computer Driver's License (ICDL). Together, we envisioned an authoring tool to enable end users such as Deaf social workers to build their own SignSupport scenarios (Blake et al., SACJ 2014). The front-end to the authoring tool is effectively a visual programming language that enables a non-programmer to build structured SignSupport scenarios (Duma et al., SATNAC 2015). The authoring tool outputs a script along with a database of sign language video 'assets' that together enable a platform-dependent app to render a GUI for that scenario; as opposed to being hardcoded as were the first two SignSupport scenarios.

Advancement of the pharmacy scenario was held up by ethical concerns, e.g. we were not allowed to let Deaf users use SignSupport for pharmacy with actual drugs until more stringent medical ethics hurdles were cleared. Chininthorn began designing a third scenario that was fundamentally different from the previous two in that it explicitly dealt with the 'I' in ICT, rather than the 'C' (Chininthorn et al., SPWID 2015). She was the industrial design engineer behind the design of the pharmacy scenario, and engaged many Deaf communities throughout the province to design a diabetes self-care and management with animations annotated in sign language videos (Chininthorn et al., JMIR 2016). Her work attracted the attention of an Information Systems Lecturer/PhD candidate, Petersen, who had done similar exploratory fieldwork with poor diabetics in the Cape Flats. Petersen adopted BANG's methods of community interaction and engagement (Petersen et al., ACIST 2017; Petersen et al.; ACIST 2018; Petersen et al. EJISDC 2019; Petersen et al., IFIP 2020). BANG is also concerned with generic access to ICT for Deaf people, such as sign language video help in a popular browser like Mozilla (Adams et al., SETE 2017) to improve accessibility for Deaf end users.

Summary of results

By 2010, we had let go of the telemedicine field study (Chetty et al., SAICSIT 2014; Tucker et al. SATNAC 2007) because of social nuances (Maunder et al., SA-CHI 2006) surrounding the use of MUTI, e.g. nurses, who were not from the villages in which they worked, lost face in front of patients when using MUTI to ask mostly white and foreign doctors for advice; and MUTI usage statistics clearly indicated to clinic managers when nurses overstayed their weekends in their home villages, many hours' drive away. There was also the challenge that the primary technical support technician returned to The Netherlands around 2009; and the network fell into disuse as he had not sufficiently trained locals to keep the system going. Another challenge was that the young woman we trained to provide IT skills to the nurses left for the nearest city to teach IT. We concentrated on the backpackers because of the capacity available from the TransCape NGO. The initial effort later spread to the wider Mankosi community via Zenzeleni. Bidwell's engagement with the local tribal authority made a huge impression on BANG, and by her example, we learned how to engage with Mankosi as a community, which led to more affordable and accessible ICTs for the entire community. One method was simply to spend more time in the area, as Rey-Moreno did, following in Bidwell's footsteps (Dearden and Tucker, ISTAS 2015 and IEEE 2016); and immersion helped create the space for local ownership (Rey-Moreno et al., JOCI 2015). With Zenzeleni, we learned to apply a simplified lens, garnered from Rey-Moreno's PhD thesis, to engage on technical, social, legal and financial terms. BANG spun off Zenzeleni Networks NPC to support community cooperatives like Mankosi along these four axes; to transfer fruits of the research to additional communities. A high-level write-up was provided to a lay audience by Tucker (TCA 2017). An additional community-owned cooperative at Zithulele was started in 2019. Zenzeleni now supplies internet to the well-regarded Zithulele hospital. In a nutshell, anchor clients like Zithulele hospital and small businesses like backpackers at competitive commercial rates subsidise local resident access at an affordable R25/month uncapped (note I pay R919/month for comparable access in Cape Town over fibre).

By 2010, we had migrated from text-to-speech assistive technology for Deaf people (Glaser and Tucker, SATNAC 2004) to video-based apps (Wang and Tucker, SATNAC 2010). We learned from Deaf people that they preferred signed language communication, even though they couldn't afford it. We engaged industrial design engineers based at Delft University of Technology who derived needs and priorities from multiple Deaf communities using generative methods. Two themes emerged: healthcare and computer literacy. BANG chose to

focus on healthcare, resulting in SignSupport, an app designed by Deaf people for Deaf people to engage with non-signing healthcare providers (Chininthorn et al., IST-Africa 2012, SPWID 2015 and JMIR 2016). By abstracting SignSupport away from a single scenario with an authoring tool (Blake et al., SACJ 2014), we came up with a way to make SignSupport independent scenario, platform and even language independent (Duma and Tucker, SATNAC 2015). A high-level description was distributed by UWC to media agencies, and resulted in radio interviews and even a 2-minute video on SABC, our national broadcaster. That attracted one person, Hugo Vaughan, who joined the team to project manage a successful TIA seed fund project that developed a couple of the student prototypes toward commercialisation: the SignSupport for diabetes app and the multimodal relay that we had been working on for many years. In addition, an Emergency Medical Services app was developed, alongside a backend asynchronous contact centre based on a WhatsApp API integration with Salesforce using Zapier. This contact centre can be staffed with Deaf interpreters (as opposed to hearing interpreters that happen to 'speak' sign language), and can be integrated into existing call centres, e.g. provincial EMS. Interest is high, yet covid paused the momentum that was built in 2019.

Significance of the work

Our work in rural community networks led to us being asked to provide an encyclopaedia chapter on Local Access (Tucker and Westerveld, 2015). Rey-Moreno et al. (ITD 2016) revealed that Mankosi residents spend roughly 22% of their meagre income on telecoms from SA's mobile providers; meaning 1) they spend money that could be spent on food and other necessities, on telecoms, and 2) the money exits the community to corporate head offices. Zenzeleni's community ownership dramatically lowers telecoms costs and keeps revenues in the community. Two SA ministries, DST (now DSI) and DTPS (now DCDT), have decided that Zenzeleni, which means "do it yourself" in isiXhosa, is therefore meaningful and significant to the South African telecoms ecosystem; and they are helping us transfer the model to more communities (R2 million in 2018, and a further R2 million in 2020, both from the Technology Innovation Agency (TIA), who also incidentally funded SignSupport for R644k in 2019).

We are also making a significant and meaningful contribution to ICT4D studies with and for Deaf people simply because there is so little work reported in this area. For example, when one combs the tables of contents of TACCESS and related conferences, we find many entries for blind people, some for autism, and an express lack of work for Deaf people. Our work, e.g. Blake et al. 2011 and Tucker 2015, bridges a noticeable gap in the literature on assistive technology, especially in the ICT4D space. Our work supports sign language interfaces, not finger spelling; and apps that can fit into Deaf people's lives, not virtual reality gloves and devices that poor Deaf people in developing regions have no hope to afford or access. SignSupport solutions cost Deaf end users nothing by storing videos on the phone (not over the air), and can be integrated onto phones they already possess. In South Africa, where no video relay services exist, SignSupport could very well be the only form of assistive technology to which Deaf people will ever gain access.

In conclusion, I would like to call attention to the publications that synthesise the lessons learnt from both Zenzeleni and SignSupport field studies, with respect to affordable and accessible communications (Blake and Tucker, AI and Society 2006), socially aware software engineering (Blake and Tucker, IST-Africa 2006), methods (Tucker and Blake, IST-Africa 2008), abstractions for dealing with ICT4D (Tucker and Blake, DEV 2010), ethics (Tucker, 2015; Dearden and Tucker, IEEE 2016), and positive deviance (Tucker, ICT4D 2017).

Best student outputs

Most of the publications listed with this application are first authored by BANG postgrad students. This is how I work, as my job is to empower postgrad students to become researchers in their own right. This section therefore showcases selected references not co-authored with me (to demonstrate what my students are capable of). It should also be noted that occasionally, students who are not supervised (nor co-supervised) by me are still BANG members, e.g. Mdleleni and Hussen; yet I am responsible for funding and mentoring their participation in BANG activities. Supervision vs co-supervision duties are defined in the CV ('with' means the other person was primary supervisor, and 'by' means I am primary), and all students are solely supervised by me unless otherwise indicated. See my CV for a complete list of BANG PhD completions, of which there are 5; with 4 more submitting Nov 2020; 25 MSc's by thesis; 58 Honours and 2 post-docs. These selected publications are from Dr Carlos Rey-Moreno while I supervised his postdoc at UWC 2016-2017, and beyond. He went on to join APC and has even more publications in this space:

a. Rey-Moreno, C., & Graaf, M. (2016). Map of Community Networks in Africa. In L. Belli (Ed.), Community Connectivity: Building the Internet from Scratch: Annual Report of the UN IGF Dynamic Coalition on Community Connectivity (1st ed., p. 147–). Rio de Je Janiero, Brasil: FGV Rio Editions.
b. Rey-Moreno, C., Miliza, J., Mweetwa, F., van Stam, G., & Johnson, D. L. (2016). Community Networks in the African Context: Opportunities and barriers. In First African Conference on Human Computer Interaction (AfriCHI) (pp. 237–241). Nairobi, Kenya: ACM. http://doi.org/10.1145/2998581.2998620C.
c. Rey-Moreno, C. (2017). Supporting the Creation and Scalability of Affordable Access Solutions: Understanding Community Networks in Africa.
d. Luca de Tena, S. L., & Rey-moreno, C. (2018). Challenging Inequality in Post-Apartheid South Africa: A Bottom-up, Community Led Business Model for Connectivity. In Global Information Society Watch 2018: Community Networks (pp. 222–226). APC.
e. Rey-Moreno, C., & Pather, S. (2018). Advancing rural connectivity in South Africa. DST.

and these are from Dr Leon Tinashe Gwaka, whom I supervised, and was co-supervised by Julian May, completed in 2019. He published these in 2017 on his own, and several others co-authored with us (listed in CV):

a. Gwaka, L. T. (2017). Digital technologies and sustainable livestock systems in rural communities. Electronic Journal of Information Systems in Developing Countries, 81(6), 1–24. DOI: 10.1002/j.1681-4835.2017.tb00598.x
b. Gwaka, L. (2017). Towards desired food systems - a community visioning approach. In Top 10 BCFN YES! Barilla Centre for Food & Nutrition.

Best research outputs prior to last 10 years

1. Glaser and Tucker CVHI 2004 Telecommunications bridging between Deaf and hearing users in South Africa
2. Chetty et al. SAICSIT 2004 Developing locally relevant software applications for rural areas: A South African example
3. Blake and Tucker IST-AFRICA 2006a Socially aware software engineering
4. Blake and Tucker AI & Society 2006b User interfaces for communication bridges across the digital divide

5. Maunder, Marsden and Tucker SA-CHI 2006 Evaluating the relevance of 'Real Access' criteria as a framework for rural HCI research
6. Tucker and Blake IST-Africa 2008 The role of Outcome Mapping in developing a rural telemedicine system.
7. Tucker 2009 my PhD thesis
8. Tucker et al. SATNAC 2007 Reflection on three years of telemedicine
9. Hersh and Tucker IFAC 2005 Ethics
10. Tucker and Blake DEV 2010 Softbridge

Best 5 publications submitted for NRF rating in 2018, motivated:

1. Bidwell, N. J., Siya, M., Marsden, G., Tucker, W. D., Tshemese, M., Gaven, N., … Eglinton, K. A. (2013). Walking and the Social Life of Solar Charging in Rural Africa. ACM Transactions on Computer-Human Interaction (TOCHI), 20(4), Article 22, 33 pages. ISSN: 1073-0516.

cited by 41 with 7 self-citations. This article stresses the importance of weaving technology into an existing social fabric, in order to be sustainable. TOCHI is one of the most prestigious ACM journals, and the reviews were almost as long as the article itself. My contribution was the Mankosi background, the discussion around Law (2004). I provided the lead author with the space, and some funding, too, to do the fieldwork in Mankosi; deepening on our ongoing project in the area. Working with Bidwell in terms of community engagement as described in this article, in my opinion, significantly contributed to the success that Zenzeleni has become.

2. Dearden, A., & Tucker, W. D. (2016). Moving ICTD Research Beyond Bungee Jumping: Practical Case Studies and Recommendation. IEEE Technology and Society Magazine, September, 35(3): 36–43. ISSN: 1932-4529.

cited by 3 with 1 self-citation. This article explores the temporal aspects of community engagement through the lens of ICT4D ethics, a topic which receives precious little attention in the literature, within both rural and Deaf community projects. This article therefore, via ethics, offered the opportunity for me to draw synthesised lessons toward ICT4D ethics from my two apparently disparate long-term community engagement projects. The article was invited by the editor to significantly expand an IEEE ISTAS conference proceedings paper that had impressed him (see Dearden and Tucker 2015).

3. Rey-Moreno, C., Tucker, W. D., Bidwell, N. J., Roro, Z., Siya, M. J., & Simó-Reigadas, J. (2013). Experiences, challenges and lessons from rolling out a rural WiFi mesh network. In Proc. 3rd Annual Symposium on Computing for Development (ACM DEV) (Article 11, 10 pages). Bangalore, India: ACM. ISBN: 978-1-4503-1856-3. http://hdl.handle.net/10566/676

cited by 30 with 9 self-citations. This double-blind peer reviewed paper presents and categorises the experiences of the initial rollout of Zenzeleni in Mankosi. It therefore shows how to kick off a rural telephony in terms of community engagement in addition to the technology. I gave this plenary talk, and due this and other appearances at this conference by myself and my students, I chaired DEV-4 in Dec 2013.

4. Tucker, W. D. (2015). Beyond traditional ethics when developing assistive technology for and with Deaf people in developing regions. In M. Hersh (Ed.), Ethical Engineering for International Development and Environmental Sustainability (pp. 293-324), Springer: London. ISBN: 978-1-4471-6617-7. http://hdl.handle.net/10566/1946

self-cited 3 times. This piece reflects on the ethical concerns after fifteen years with the Deaf community case study; an invited chapter by the book editor, who actually introduced me to the role ethics plays in research with disadvantaged communities many years ago (see Hersh and Tucker, IFAC 2005). I also helped Hersh write the book's introduction. This chapter allowed me the space to reflect on how I had evolved my views on ethical community engagement with respect to assistive communication technology.

5. Tucker, W. D. (2017). Amplifying Positive Deviance with ICT. In J. Choudrie (Ed.), Information and Communication Technologies for Development (ICT4D 2017, IFIP AICT 504) (pp. 206–217). Yogyakarta, Indonesia: Springer. http://doi.org/10.1007/978-3-319-59111-7_18

cited by 0 because it is very new. This double-blind peer reviewed paper provided an opportunity to explain how I have come to view ICT4D theoretically, in terms of having led both Zenzeleni and SignSupport projects for so long. When I gave this talk to a rather overfull room, attendees included both Richard Heeks (who asked the most questions) and Kentaro Toyama, a primary source wrt ICT amplification theory. This paper best represents a synthesised theoretical foundation based on my ICT4D research over the last 16 years.

Most recent publications

The following are recently released, mostly ledy by PhD students/research, and reflect more work related to both Zenzeleni (including some more technical work with Om) and SignSupport. Most of these demonstrate the realisation of a shift into fully interdisciplinary Phd level research. However, note that Majoni et al. (2020) resulted from the ICT4D Honours class given in 2019, and demonstrates our interest in applying ICT4D towards food security.

1. Petersen, F., Baker, A., Pather, S., & Tucker, W. D. (2020). Impact of Socio-Demographic Factors on the Acceptance of Information Communication and Technology (ICT) for Diabetes Self-care. In M. Hattingh et al. (Ed.), IFIP I3E 2020/LNCS 12067 (Vol. 2, pp. 73–83). Skukuza, South Africa: Springer Nature Switzerland.
2. Petersen, F., Brown, A., Pather, S., & Tucker, W. D. (2019). Challenges for the adoption of ICT for diabetes self−management in South Africa. The Electronic Journal of Information Systems in Developing Countries, (September 2018), 1–14. https://doi.org/10.1002/isd2.12113
3. Gwaka, L. T., May, J., & Tucker, W. (2018). Towards low-cost community networks in rural communities: The impact of context using the case study of Beitbridge, Zimbabwe. The Electronic Journal of Information Systems in Developing Countries, (e12029), 1–11. http://doi.org/10.1002/isd2.12029
4. Majoni, T., Zegeye, Y., & Tucker, W. (2020). Mose : A Mobile Application for Women Street Vendors in Cape Town. In M. Cunningham & P. M. Cunningham (Eds.), IST Africa (pp. 1–8). IIMC. ISBN: 9781905824656.
5. Petersen, F., Baker, A., Pather, S., & Tucker, W. D. (2020). Impact of Socio-Demographic Factors on the Acceptance of Information Communication and Technology (ICT) for Diabetes Self-care. In M. Hattingh et al. (Eds.), IFIP I3E 2020/LNCS 12067 (Vol. 2, pp. 73–83). Skukuza, South Africa: Springer Nature Switzerland. ISBN: 978-3-030-45001-4.
6. Kassongo, F., Pather, S., & Tucker, W. D. (2018). Government facilitated access to ICTs: adoption, use and impact on the well-being of indigent South Africans. In P. M. Cunningham & M. Cunningham (Eds.), IST-Africa (pp. 1–10). IIMC International Information Management Corporation. ISBN: 978-1-905824-59-5. http://hdl.handle.net/10566/3707

7. Henney, A., & Tucker, W. D. (2018). Mobile video comparison to help Deaf people make informed choices: a South African case study with provincial data. In P. Cunningham & M. Cunningham (Eds.), IST-Africa (pp. 1–13). IIMC International Information Management Corporation. ISBN: 978-1-905824-59-5. http://hdl.handle.net/10566/3705
8. Om, S., & Tucker, W. D. (2018). Battery and Data Drain of Over-The-Top Applications on Low-end Smartphones. In P. Cunningham & M. Cunningham (Eds.), IST-Africa. IIMC International Information Management Corporation. ISBN: 978-1-905824-59-5. http://hdl.handle.net/10566/3704

Self-assessment

BANG's approaches to ICT4D extend mainstream computer science with respect to software engineering (Blake and Tucker, 2006), network design (Rey-Moreno et al., DEV 2013) and human computer interfaces (Blake et al., ID 2011). BANG's activities also differ from mainstream ICT4D research, e.g. with respect to 'bungee research' (Dearden and Tucker, 2016) and *community* vs individual orientation (Blake et al., ID 2011). In our opinion (and obviously the NRF and beyond), we contribute to mainstream Computer Science because of how we emphasise people, in addition to, and most definitely not instead of, the technology (Tucker, ICT4D 2017). The differences emanate from the appropriation of socially-orientated lenses like Real Access/Real Impact toward the design of, instead of (the intended) evaluation of, ICT4D interventions (Tucker and Blake, DEV 2010; Maunder, Tucker and Marsden, 2006). This has resulted in methodological innovations like community-based co-design (Blake et al. 2011) and socio-technical innovations like Zenzeleni and SignSupport. BANG employs mixed methods like any research involving humans. However, we apply quantitative and especially qualitative methods to *communities and community* needs, rather than just individuals and individual needs, as is more commonly accepted (the 'I' paradigm vs. the 'we' paradigm, see van Stam's 2017 PhD thesis). We embrace post-positivist methodology like Action Research, especially ethnographic methods, and apply these to the task of Software Engineering (Blake and Tucker, AI & Society 2006; IST-Africa 2006). We see parallels between iterative incremental software development and community development (Tucker and Blake, DEV 2010; Tucker, 2015; Tucker, ICT4D 2017).

The key word here is 'development'. Our approach to community development, and the role that ICT plays in its processes, is addressed by Tucker (ICT4D 2017). I feel that socio-technical innovations like Zenzeleni and SignSupport have arisen as a result of engaging communities not as 'objective' research subjects; but rather as friends, colleagues and collaborators with whom we can mutually generate new knowledge. When we engage communities/beneficiaries, including our own research community (for we are all beneficiaries in one way or another), it is with an eye toward identifying 'positive deviants' with whom to work; not individuals; rather groups of people that together make a difference in their respective communities. Groups are more resilient and sustainable than individuals. Through the give and take of community engagement - not between individuals, but between communities, e.g. a Deaf community and the ICT4D research community at UWC - we blur borders, i.e. community borders become porous as opposed to solid. It is through such cross-community membership and participation that socio-technical innovation emerges. I concur that Zenzeleni has rightly deserved more awards and attention. Yet in my opinion, Zenzeleni is preparing BANG to do something similar with SignSupport because we are learning how to transfer socio-technology from one domain to another, e.g. academic to the field; from one community to another. And we are poised to juxtapose and generalise SignSupport on top of Zenzeleni, e.g. with applicability to food security and covid.

We value neutrality and platform/technology independence, e.g. connectivity instead of WiFi, and authoring tool and contact centre over specific SignSupport scenarios. We are thereby able to move from one technology to another, e.g. for Zenzeleni, from point-to-point and point-to-multipoint hybrid with mesh, and to GSM (e.g. with OpenBTS) and TVWS, given the licensing (we have decided not to 'pirate' any longer, and are fully ICASA compliant). While healthcare is a priority for Deaf people, we also realise that we can populate SignSupport with any scenario in any human language, video or audio; i.e. we can easily repurpose any SignSupport app and its support contact centre to any scenario (or sign language) simply by re-recording videos, even in spoken languages like Xhosa and Zulu. We can apply our innovations to other domains because beneath all the social emphases, we are Computer Scientists, and we understand the concepts of layering and abstraction.

If I must self-assess BANG's research outputs, I would suggest that BANG has pushed the boundaries of Computer Science in terms of software engineering, human computer interface and network design; all by including illiterate co-designers in the processes of community-based co-design. We have also pushed the boundaries of ICT4D by engaging in two community-based projects for so many years (almost 2 decades each), and neither project shows any signs of stopping. I am not aware of any other projects that have lasted so long, where both projects are poised for further socio-technological innovation and transfer (to other communities). Further, in both cases, BANG has done a sterling job in bringing the topic of ethics to the forefront; not by merely including a paragraph on ethics in a Methods section. We have published pieces dedicated to ethics, e.g. Hersh and Tucker, 2005; Dearden and Tucker (ISTAS 2015 and IEEE 2016) and Tucker (2015). It's telling that these, and other similar publications on ethics and ICT4D, are few and far between (there are a couple by Dearden, Sterling, and also Traxler). In my opinion, any contribution to this space is valuable, as we are dealing with vulnerable populations. Other disciplines and fields, e.g. Health, Social Work, Anthropology and Development Studies, have worked on ethical issues for decades; and ICT4D still has a long way to go. All the more why multidisciplinary studies are a boon to ICT4D. In that respect, BANG also is a shining example of how to realise multidisciplinary research (witness BANG PhD grads: electrical engineering, government, pharmacy, social development and information systems; and BANG PhD submissions in 2020: computer science, industrial design, gender studies, and social development).

Ongoing and planned future research

The ideology and methodology of ongoing and planned future research for BANG is best summed up by Tucker (ICT4D 2017). The ongoing and future tasks address how to leverage ICT as an amplifier for community development, e.g. rural communities with self-provided Zenzeleni infrastructure and services, and Deaf communities with self-provided SignSupport scenarios; and further how to combine the two, perhaps leveraged towards food security and the dust settling from the aftermath of covid. For example, see Figure 4 which shows the overall vision in a generalised way.

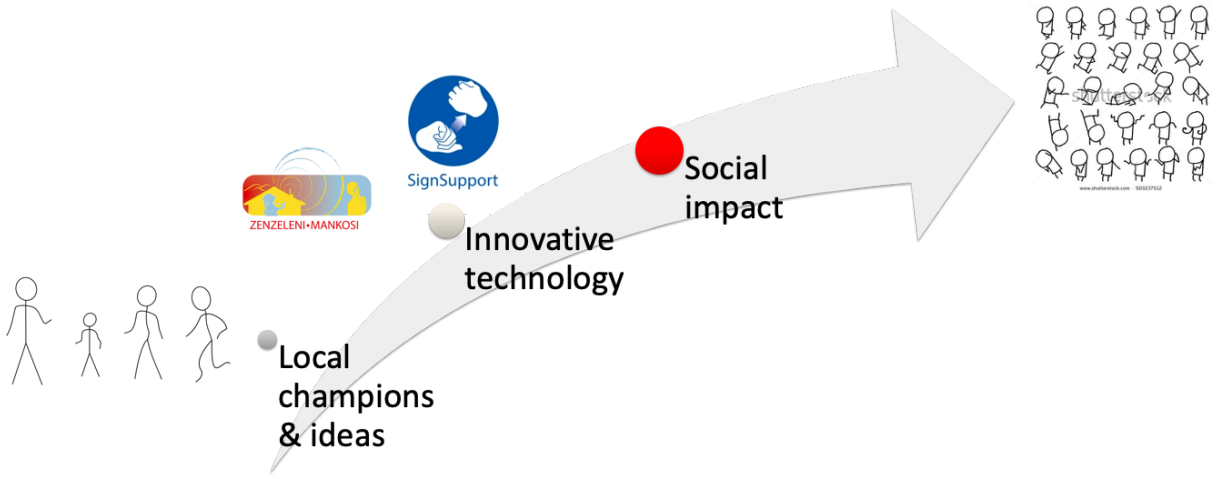

Figure 4: High level visualisation of our work with Zenzeleni and SignSupport showing how we leverage community based champions and ideas to realise community-based co-designed innovative technology that yields the potential for social impact.

BANG aims to complete several more PhDs in the near future (hopefully by Nov 2020). For Zenzeleni and related work, this is 1) Om's work on mesh network scalability with respect to Quality of Service for VoIP services over wireless technologies and their impact on low end smartphone batteries; 2) Kassongo's work on government facilitated public access and 3) Hussen's work on gender, social media and social movements in Africa. For SignSupport, this includes 4) Henney's work on mobile video relay services and the protection of personal information; 5) Chininthorn's work on diabetes self-management with mobile informational interfaces for poor Deaf people in the Western Cape; and 6) Petersen completed her work on diabetes self-managed with mobile devices for poor Muslim Cape Flats inhabitants, and graduates in Dec.

We will continue attracting funding for both Zenzeleni and SignSupport projects, and our research activities will extend and strengthen the technical, social, legal, economic and governance activities and results described above by having more end users on both projects from which to collect data. I view the expected growth in both Zenzeleni and SignSupport numbers of users over the next 10 years, via commercialisation in for-profit and not-for-profit spin-offs and community-owned entities, as a source of much more automated data collection, e.g. VoIP and Internet usage with Zenzeleni, and video and scenario usage (even closing feedback loops, e.g. a Deaf user indicates when medication has been taken) with SignSupport. Continuing with community-based co-design and community engagement and its corresponding ethnographic methods, we will have much more quantitative data with which to triangulate; thereby strengthening the results we can draw from our data.

The goal is to leverage that data to attract long-term, sustainable, and both internal and external funding to community-owned initiatives to provide services that mainstream industry is simply not able or willing to address, e.g. affordable and accessible internet for largely disadvantaged and taken-advantage-of groups like rural and Deaf inhabitants. The near future, say 5 years, we want to learn how to establish a socio-technical innovation ecosystem that is formed in an interdependent way: the outputs from the research team at the university (and its collaborators) is fed to a development team which is in turn fed to the implementation teams, e.g. Zenzeleni Networks Mankosi who operate in the field as sustainable entities. Then, the needs from the implementation teams are fed back to the research team in a neat cycle. We fully recognise that the timeframes and needs of the various

teams differ, e.g. a MSc takes 2 years while Zenzeleni networks at some future community may need a VoIP calling interface enhancement by next month. These differences need to be managed; and can be managed by continued communication and negotiation. These mechanisms are what we hope to a) iron out by 2024 and b) transfer from Zenzeleni to SignSupport and also c) combine SignSupport and Zenzeleni, e.g. for food security in isiXhosa in the Eastern Cape, and in Afrikaans in local Western Cape rural farming communities.

I envision a SignSupport ecosystem where the development team is comprised of and mandated by Deaf programmers and managers (both South African and beyond via open source communities). And further, by rural isiXhosa and Afrikaans speaking communities. This can be accomplished with a technology development entity, as well as multiple operational entities that license/use the technology as they see fit, e.g. a Deaf desk at a Deaf NGO servicing a bank's call centre; or a Deaf desk inside provincial/municipal EMS call centre. Similar to Zenzeleni, competitively priced Deaf services (especially if the SA government makes SASL the 13th official language) can subsidise Deaf NGOs' ability to provide services to their own Deaf communities (see Figure 5).

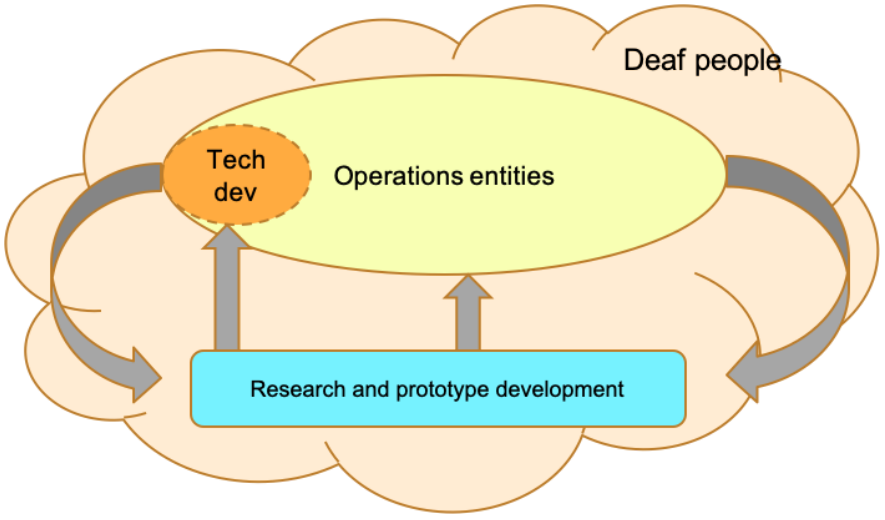

Figure 5: Our envisioned ecosystem where Deaf people provide input into Deaf ICT research and prototype development, again with community-based co-design, to spin off a commercial technology development company that in turn licenses software, e.g. SignSupport apps and the innovative asychnrous contact centre, to operational entities that consist of anchor clients, e.g. banks and government agencies who subsidise cheaper access for Deaf NGOs (or similar entities).

It is my belief that by making all research, development and implementation processes and results free and open (free and open source software/hardware; creative commons and open data) is how Zenzeleni and SignSupport will achieve sustainability; beyond me, beyond my postgrads and even beyond the Deaf and rural communities who came up with all these ideas. Therefore, the next 10 years entails formalising and growing online open source communities to share the technical, social, legal, financial and governance (and also environmental ,see below) knowledge beyond academic research, into the public domain, in local languages, e.g. isiXhosa, Afrikaans and SASL, so that socio-technical transfer is realising by empowering communities to do it themselves. This is what BANG means when we talk about leveraging ICT to amplify positive deviance toward realising community development (again, see Tucker, ICT4D 2017); helping people, including ourselves, help themselves and one another with ICT.

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