That work is ongoing, but there are key points of theoretical connection to current research in PPLs for end-user and educational applications.

Firstly, while we adopted the spinners as appropriate teaching aids for use in a low-resource context, the action of the spinners turns out to be an intuitive representation of the Monte Carlo simulation mechanisms that are integrated in many PPLs, including end-user data science tools such as BayesDB. Although AI and machine learning applications are as yet not extensively deployed in Tsumkwe[3], it was possible to explain the underlying mechanisms of such systems in relation to internal random variables as (notional, invisible) spinners that might operate inside the computer to select probabilistic outcomes, for example when an AI system outputs natural language text based on how likely the individual words are. The role of data in adjusting the likelihood of particular outcomes in a machine learning system can also be understood as arising from observations – in that example, by counting the words that have been seen in previous texts.

In principle, although we did not address this question during our field research, important questions for public understanding of AI, such as data bias in algorithmic decisions, can be directly understood in these terms. Similarly, the role of prior expectation in Bayesian modelling can be understood in relation to the selection of appropriate spinners.

In future research, we plan to explore whether this representation can be extended to express more complex models, including larger numbers of variables, differing numbers of outcomes and continuous variables with nonuniform outcome distributions. These might be supplemented with other representational devices that offer a visual correspondence between outcome distribution and physical simulation, such as the Galton Board that was suggested in the earlier PPIG paper (Blackwell, Church et al., 2019). An example of a prototype application recently implemented by an undergraduate design team in Cambridge can be seen in Figure 3b).

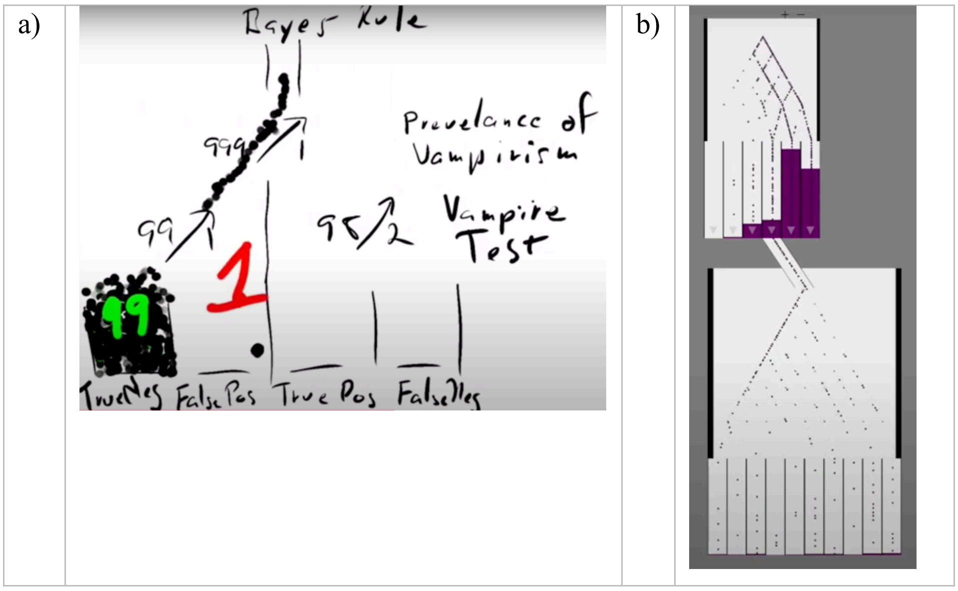

*Figure 3 – Visual simulations demonstrating the interaction of distributions in conditional probability via "cascading" Galton boards. a) whiteboard animation created by Breck Baldwin (screenshot from video available at [https://youtu.be/18qeLk-fsCI](https://youtu.be/18qeLk-fsCI) and b) as implemented by Computer Science undergraduates in Team Delta 2021 (screenshot from video available at [https://youtu.be/k_ETDeWA4MU](https://youtu.be/k_ETDeWA4MU))*

In anticipating this future work, we wish to emphasise that sketches and prototypes such as these, created in a Western context to support current conventions of describing and representing probability, will not necessarily be appropriate to our field site in the Kalahari. Although the current pandemic has

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[3] Other than familiar applications built-in to the Android platform such as predictive text or recommendation facilities in online stores

created additional challenges for our continuing co-design work, the technical experiments reported in this paper can only be considered a starting point for mutual exploration with Ju|'hoan colleagues, not a product in themselves.

## 5. Related Work

In addition to recent work on end-user PPLs, and other educational tools for teaching Bayesian probability, this approach can be compared to two technical education projects familiar to the PPIG audience: the work of Andrea diSessa and colleagues on the use of programmable simulations in physics education, and the work of Ken Kahn and colleagues on the ToonTalk language. Both of these systems share a concern with supporting intuitive reasoning that is linked to mathematical formalism via visual representation of computational processes.

Ken Kahn uses the phrase "animated programming" to make it clear that intuition relating to dynamic behaviour is supported by presenting a programming environment in which elements can be seen moving (Morgado & Kahn 2008). ToonTalk is also a formally specified programming environment, and it supports an interactive transition between the intuitive physical animation and larger-scale computation.

In the metaphorical ToonTalk world, agents can be watched carrying out individual computations as operations on physical objects, for example when Bammer the mouse uses his hammer to add two numbers by knocking their blocks together. The physical space that Bammer and other characters work in is represented as the inside of a house within which the programmer/player can observe the computation being carried out. When you step outside the house, the work continues, but speeded up to normal computation speed – the program is running, but invisibly following the same algorithmic steps that can still be seen whenever you might choose to go back into the house and observe them.

Andy diSessa's keynote address at PPIG 2018 described the use of programmable simulations, not to teach principles of computation (as in ToonTalk), but to teach basic principles of physics, supporting intuition about the way that different measurable quantities change during the observed behaviour of a typical classroom physics demonstration such as observing acceleration under force (e.g. Sherin, diSessa & Hammer, 1993). diSessa proposed that understanding the computation of those quantities over time offered superior intuition to the conventional algebraic representation using calculus notation.

In programming with physical simulations of probabilistic behaviour, we are similarly presenting an intuition of fundamental principles (here, relating expectation, observation and likelihood) in relation to animated mechanical representations of the same underlying principles. In further developments of this approach, we plan to explore whether simulation of local conditional relations can be scaled up to more complex probabilistic programs, in a manner analogous to stepping outside the ToonTalk house, while maintaining the underlying intuition.

We note in passing that many other educational programming systems, also familiar from previous presenters and keynote speakers at PPIG, have been designed specifically to help students program their own physical, biological or environmental simulations. These include systems such as AgentSheets (Repenning et al., 2000), Squeak etoys / Scratch (Steinmetz, 2002; Maloney et al., 2004), and KidSim / Cocoa (Cypher & Smith, 1995). However, we draw a distinction between the use of visual programming tools to teach the structure of a different domain (which has undoubted education value), and the use of diagrammatic correspondence between the structure of the simulation and notational conventions in order to support mathematical intuitions.

As in the previous section, we note once again that this related work has all been developed in US and UK contexts, and reflects the educational needs and curriculum requirements of those countries. Furthermore, any assumption about the cognitive underpinnings of "intuition" should be treated with great care if it presumes that WEIRD (Western, Educated, Industrial, Rich Developed (Henrich, Heine & Norenzayan, 2010)) habits of thought and ways of teaching are universal. To the extent that diagrammatic representations might potentially rely on embodied conceptual metaphor (Johnson, 2013), we must take care that future designs consider the reality of cognitive variations across cultural and historical divides (Lloyd, 2007), a perspective from which there has been very little attention in current research literature.

## 6. Conclusions

This work in progress report, continues the research agenda that was originally set out at PPIG 2019 (Blackwell Church et al., 2019), and more briefly discussed in an unpublished panel contribution at PPIG 2020, addressing the topic of Software for Indigenous Communities (presented by the first author together with Jason Lewis – see Lewis et al. 2018, Running Wolf et al 2020) during the conference session on Community Computing.

Although our fieldwork is currently suspended as a consequence of the Covid-19 pandemic, we would welcome feedback on this work from the PPIG community. We are keen to continue our educational experiments, especially the potential for new curriculum perspectives to be influenced by scientific traditions outside the usual Western assumptions. Theories of probability are particularly bound up in ways of seeing the world, as can be seen by the recent debates between Bayesian and frequentist traditions even in Western curricula.

The future of machine learning systems, in which computational tools increasingly operate on probabilistic principles inferred from training data rather than explicitly specified deterministic algorithms, is having many consequences in all countries of the world. Interactive representations that help people from many backgrounds to understand such systems, and even more importantly, to influence, modify, adapt and customise them, could be a valuable contribution to international development, inclusion and equity.

We have set out a direction of travel, with a work in progress report on grounds that are relatively familiar to PPIG. The work reported here is, however, a very small contribution by comparison to much larger and more important questions. National policy in Namibia, and elsewhere in Southern Africa, is seriously concerned with preparation for the opportunities of the Fourth Industrial Revolution, including large national educational initiatives with similar curriculum goals to our own, such as Data Science Nigeria (Adekanmbi, 2020). Despite national policy priorities, serious questions are raised by local researchers with regard to potential inequities arising from these policies (Adams, 2021a).

Furthermore, research with local communities must pay close attention to their own priorities, and much of our discussion in Tsumkwe was concerned with educational needs and practical problems beyond those discussed in this paper. When considering these broader questions in development settings and in relation to indigenous knowledge practices, future research must not only ensure that work with local communities is not extractive, but collaborative, and ideally co-constructed. In working across such divides, it is essential to remain aware of the colonial legacies embedded in AI technologies and research (Adams 2021b), and the need for research methods that acknowledge and advance beyond these where possible (Awori, Bidwell et al, 2016). The CHI community is becoming increasingly alert to the activism that is inherent in designing and deploying software tools, as others in the PPIG community are aware (e.g. Leal et al 2021), and we would not want to give the impression that any of this is easy. Nevertheless, even in such a specialist setting such as PPIG, there are opportunities to step aside from old assumptions and value other kinds of knowledge.

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## 8. References

Adams, R. (2021a). The gendered impact of artificial intelligence and the fourth industrial revolution in South Africa: Inequality, accessibility and skills development. In W. Pearson Jr. and V. Reddy (Eds) *Social Justice and Education in the 21st Century: Research from South Africa and the United States*, Springer, pp. 365-379.

Adams, R. (2021b). Can artificial intelligence be decolonized? *Interdisciplinary Science Reviews*, 46(1-2), 176-197, DOI: 10.1080/03080188.2020.1840225

Adekanmbi, Olubayo (2020). *Beginners' Artificial Intelligence and Python Programming: For Grades 4 to 8.* Data Science Nigeria.

Awori, K., Bidwell, N. J., Hussan, T. S., Gill, S., & Lindtner, S. (2016). Decolonising technology design. In *Proceedings of the first African conference on human computer interaction* (pp. 226-228).

Bidwell N. J., Arnold, H., Blackwell, A., Nqeisji, C., Kunta, /K., Ujakpa, M. (2022, forthcoming) AI design and everyday logics in the Kalahari. To appear in E. Costa, P. Lange, N. Haynes, J. Sinanan (Eds), *The Routledge Companion to Media Anthropology*.

Blackwell, A.F. (2002). What is programming? In *Proceedings of the Psychology of Programming Interest Group (PPIG 2002),* pp. 204-218.

Blackwell, A. F., Church, L., Erwig, M., Geddes, J., Gordon, A., Gorinova, M., Baydin, A. G., Gram-Hansen, B., Kohn, T., Lawrence, N., Mansinghka, V., Paige, B., Petricek,, T., Robinson, D., Sarkar, A. and Strickson, O. (2019). Usability of probabilistic programming languages. *Proceedings of the Psychology of Programming Interest Group (PPIG 2019).*

Cypher, A., & Smith, D. C. (1995). KidSim: End user programming of simulations. In *Proceedings of the SIGCHI conference on Human factors in computing systems (CHI'95),* pp. 27-34.

Gage, J., & Spiegelhalter, D. (2016). *Teaching probability.* Cambridge University Press.

Green, T. R. G. (1989). Cognitive dimensions of notations. People and computers V, 443–460.

Hadhrawi, M., Church, L. and Blackwell, A. F. (2017). A systematic literature review of Cognitive Dimensions. In *Proceedings of PPIG 2017 - the 28th Annual Workshop of the Psychology of Programming Interest Group.*

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world?. *Behavioral and brain sciences*, 33(2-3), 61-83.

Irani, L. (2015). The cultural work of microwork. *New Media & Society*, 17(5), 720-739.

Johnson, M. (2013). *The body in the mind: The bodily basis of meaning, imagination, and reason.* University of Chicago Press.

Leal, D. D. C., Strohmayer, A., & Krüger, M. (2021). On activism and academia: Reflecting together and sharing experiences among critical friends. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'21).*

Lewis, J. E., Arista, N., Pechawis, A., & Kite, S. (2018). Making kin with the machines. *Journal of Design and Science*. https://doi.org/10.21428/bfafd97b

Liebenberg, L. (2013). *The origin of science.* Cape Town: CyberTracker. https://cybertracker.org/downloads/tracking/Liebenberg-2013-The-Origin-of-Science.pdf

Lloyd, G. E. R. (2007). *Cognitive variations: Reflections on the unity and diversity of the human mind.* Oxford University Press.

Maloney, J., Burd, L., Kafai, Y., Rusk, N., Silverman, B., & Resnick, M. (2004, January). Scratch: a sneak preview [education]. *Proceedings Second International Conference on Creating, Connecting and Collaborating through Computing*, IEEE. pp. 104-109.

Mansinghka, V., Tibbetts, R., Baxter, J, Shafto, P., Eaves, B. (2015). BayesDB: A probabilistic programming system for querying the probable implications of data. arXiv:1512.05006 (2015).

Morgado, L., & Kahn, K. (2008). Towards a specification of the ToonTalk language. *Journal of Visual Languages & Computing*, 19(5), 574-597.

Repenning, A., Ioannidou, A., & Zola, J. (2000). AgentSheets: End-user programmable simulations. *Journal of Artificial Societies and Social Simulation*, 3(3), 351-358.

Running Wolf, C., Running Wolf, M., Moses, C. and Davison, J. (2020). Development Process for Hua Kiʻi and Next Steps. In J.E. Lewis (Ed.) *Indigenous Protocol and Artificial Intelligence Position Paper*. Honolulu Hawaiʻi: The Initiative for Indigenous Futures and the Canadian Institute for Advanced Research (CIFAR), pp. 110-116 https://spectrum.library.concordia.ca/986506

Sherin, B., diSessa, A. A., & Hammer, D. (1993). Dynaturtle revisited: Learning physics through collaborative design of a computer model. *Interactive Learning Environments*, 3(2), 91-118. DOI: 10.1080/1049482930030201

Spiegelhalter, D., Thomas, A., Best, N., & Gilks, W. (1996). *BUGS 0.5: Bayesian inference using Gibbs sampling manual (version ii).* MRC Biostatistics Unit, Institute of Public Health, Cambridge, UK.

Steinmetz, J. (2002). Computers and squeak as environments for learning. In M. Guzdial and K. Rose, Eds., *Squeak: Open Personal Computing and Multimedia*, Prentice-Hall, Inc., Upper Saddle River, NJ. 453–482.

Zuboff, S. (2019). *The Age of Surveillance Capitalism: The fight for a human future at the new frontier of power*. Profile Books.