THE AFRICAN JOURNAL OF INFORMATION AND COMMUNICATION (AJIC)

ISSUE 29, 2022

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Published by the LINK Centre
University of the Witwatersrand (Wits)
Johannesburg, South Africa
https://www.wits.ac.za/linkcentre

ISSN 2077-7213 (online version)
ISSN 2077-7205 (print version)

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Published by the LINK Centre, School of Literature, Language and Media (SLLM), Faculty of Humanities, University of the Witwatersrand (Wits), Johannesburg, South Africa
https://ajic.wits.ac.za

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AJIC acknowledges with gratitude the following peer reviewers of submissions published in this issue: Najma Agherdien, Ufuoma Akpojivi, Bassem Awad, Mark Burke, Reuben Dlamini, Bertram Haskins, Anika Meyer, Carolina Odman, Marisella Ouma, Kiru Pillay, Bobby Tait, and Aaron van Klyton.

Production

Sub-editing: LINK Centre
Proofreading: Linda Van de Vijver
Desktop-publishing: LINK Centre

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This Issue 29 of *AJIC* is dedicated to 100 years of knowledge production at the University of the Witwatersrand (Wits) as the university celebrates its centenary (1922-2022); to the continuous production of knowledge on the African continent, generating value for its countries and communities; and to all the authors, editors and peer reviewers who have contributed to this journal since its establishment. See https://wits100.wits.ac.za

AJIC is published by the LINK Centre, School of Literature, Language and Media (SLLM), Faculty of Humanities, University of the Witwatersrand (Wits), PO Box 601, Wits 2050, Johannesburg, South Africa. The LINK Centre is based at the Wits Tshimologong Digital Innovation Precinct, 41 Juta St., Braamfontein, Johannesburg, https://www.tshimologong.joburg

ISSN 2077-7213 (online version)
ISSN 2077-7205 (print version)

Past issues of *AJIC*, and its precursor *The Southern African Journal of Information and Communication (SAJIC)*, are available at https://ajic.wits.ac.za/issue/archive and https://www.wits.ac.za/linkcentre/sajic

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RESEARCH ARTICLES

Digital Vaccination Records: Exploring Stakeholder Perceptions in Gauteng, South Africa

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Abstract
Electronic health (eHealth) is one of the focus areas of the South African Department of Health (DoH), with the ultimate goal being the development of an electronic health record (EHR) for every citizen. A commonly used subset of eHealth data, vaccination records, is still not yet fully digitised in South Africa. This study aimed to determine the perceptions of key stakeholders (doctors, nurses, parents, and school administrators) about a digital system for vaccination records for minors in South Africa's Gauteng Province. Using a prototype online, cloud-based vaccine records management system created during the research, called e-Vaccination, quantitative and qualitative interaction-related data from 118 participants were collected using a five-point Likert-scale questionnaire. The questionnaire was based on Lund's (2001) USE user perception framework, which considers usefulness, satisfaction, ease of use, and ease of learning. This study found that the participants supported the use of the digital vaccine records management system, with an emphasis on five identified factors: user friendliness, graphical design, practicality, user experience, and usability. Accordingly, this article recommends that policymakers and system designers carefully consider these factors in the design and development of South Africa's digital vaccination records management system.

Keywords
vaccination records, eHealth, digitisation, health information systems, user perception, USE framework, Gauteng, South Africa

Acknowledgement
This article draws on elements of the first-listed author's MSc dissertation (Moonsamy, 2021).

DOI: https://doi.org/10.23962/ajic.i29.13756
Recommended citation

Moonsamy, W., & Singh, S. (2022). Digital vaccination records: Exploring stakeholder perceptions in Gauteng, South Africa. *The African Journal of Information and Communication (AJIC), 29*, 1-26. https://doi.org/10.23962/ajic.i29.13756

1. Introduction

The recent fire at one of South Africa's largest academic hospitals, Charlotte Maxeke Johannesburg Academic Hospital (Motara, Moeng, Mohamed, & Punwasi, 2021), as well as the riots in the KwaZulu-Natal and Gauteng Provinces—in which organisations, including pharmacies and healthcare facilities, were looted and vandalised (South African Government, 2021b)—highlight the need to secure vital medical information such as patient records. Information that is exclusively stored on local servers, on hard drives, and in paper-based files is at risk of total loss during such events and other disasters.

An increasingly critical subset of patient information, vaccination records, has shown a hastened conversion to a digital form as a result of the COVID-19 pandemic (GAVI, 2020). There are several "patient-facing" health information systems in South Africa, including MomConnect and B-wise (DoH, 2020b; Health Enabled, 2021). A new addition to these disparate systems is the Electronic Vaccination Data System (EVDS), which was created as a self-registration portal that allows South Africans to register to receive their vaccination against COVID-19 (South African Government, 2021a).

The hybrid EVDS, with a digital back-end but a physical vaccination card handed to a patient once the vaccination has been administered, allows the government to track and monitor the COVID-19 vaccination rollout. This hybrid approach, however, does not give the patient easy access to a digital version of their vaccination record as it requires the proof of vaccination code, which can easily be misplaced. Decades since the first physical vaccination cards were handed to patients, South Africans must continue to store their physical vaccination cards safely, even with expensive technology having been created to register the patient. Such systems lack patient-centeredness, which is the key to eHealth (Nyatuka & De la Harpe, 2022).

Immunisations are one of the greatest success stories of modern medicine (WHO,

2019). The study considered the grassroots level of vaccines and focused on the digitisation of vaccination records for some of the most vulnerable in our society: minors (from new-born to 12 years of age). The research therefore focused on South Africa's expanded programme on immunisation (EPI) schedule (DoH, 2018). (The research did not focus on the COVID-19 vaccinations because adult vaccination records storage is at the infancy stage in South Africa.)

This study commenced by determining the main challenges associated with the paper-based vaccination card in Gauteng. This was followed by an assessment of how vaccination records are stored by government and non-government entities globally. The eHealth aims of the DoH were then investigated. Based on information collected, a prototype online digital vaccine records management system, named e-Vaccination, was developed and tested with key stakeholders to determine their perceptions of the system. This was achieved by a questionnaire comprising of three sections. Section A was used to collect demographic information, section B collected perceptions of vaccinations in Gauteng, South Africa, and Section C collected user perception (usefulness, satisfaction, ease of use, and ease of learning) information based on the USE tool (Lund, 2001. In addition to these four categories, one more user perception category (design and visual aids) was added due to the graphical nature of e-Vaccination's user interface. The questionnaire was guided by the study's core research question: What are the perceptions of the key stakeholders about replacing the paper-based vaccination card with a digital vaccination record system?

2. Challenges with paper-based vaccination cards

Paper-based records are prone to damage or total destruction by disasters such as fires and flooding. In addition to this, South Africa experienced civil unrest during 2021, in which some healthcare facilities were looted and vandalised. In certain cases, patient records were stolen or damaged. These events fall under the vulnerability challenge. Another challenge, accessibility, has also been noted. In some instances, the vaccination card, which has been the primary storage mechanism for over three decades, has to be presented to a healthcare worker for medical purposes or to school administrators for admission to a school. If the card is not available, the vaccination records cannot be accessed easily. Another challenge related to the use of paper-based vaccination records is the reliability of the data. Handwritten paper-based records are prone to human error and have the added disadvantage of being illegible. This can also cause downstream digital records captured from this medium to be incorrect. Processes that load vaccination records as daily, weekly, or monthly batches cannot provide real-time information. These scenarios result in information that is not always reliable. These three main challenges are further explained in Table 1.

Table 1: Challenges with paper-based vaccination cards

Challenge	Category	Details
Vulnerability	Fires	Fire hazards pose a threat to physical documents such as vaccination cards. Fire hazards include fires at dwellings as well as healthcare facilities. During such events, paper-based documents, as well as physical hardware containing patient records such as vaccination records, can be damaged.
	Floods	Flooding, especially in informal settlements, poses a threat to homes and with it, paper-based records such as vaccination cards.
	Civil unrest	During civil unrest such as the recent riots in Gauteng and KwaZulu-Natal, healthcare facilities can be looted and damaged. Paper-based documents, as well as physical hardware containing patient records such as vaccination records, can be damaged or stolen.
Accessibility	Medical care	In cases where patients need medical care requiring previous vaccination records, doctors have to rely on the presence of the physical vaccination card or the parental recall of the child's vaccination history.
	Admission at schools	In some cases, a child cannot be admitted into a school if the vaccination records are not produced. If the vaccination card is not available, this can cause delays in admission.
Reliability	General statistics	Vaccination statistics that are compiled by hand are prone to errors. Real-time vaccination statistics cannot be measured if physical records have to be manually captured at various levels.
	Reporting of herd immunity	The concept of herd immunity is receiving much attention due to the current COVID-19 pandemic. Herd immunity, however, has always been valid in terms of vaccine-preventable diseases affecting minors. Without accurate and up-to-date data, policymakers will not be fully equipped to make critical decisions regarding vaccination campaigns and other programmes.

Source: Authors

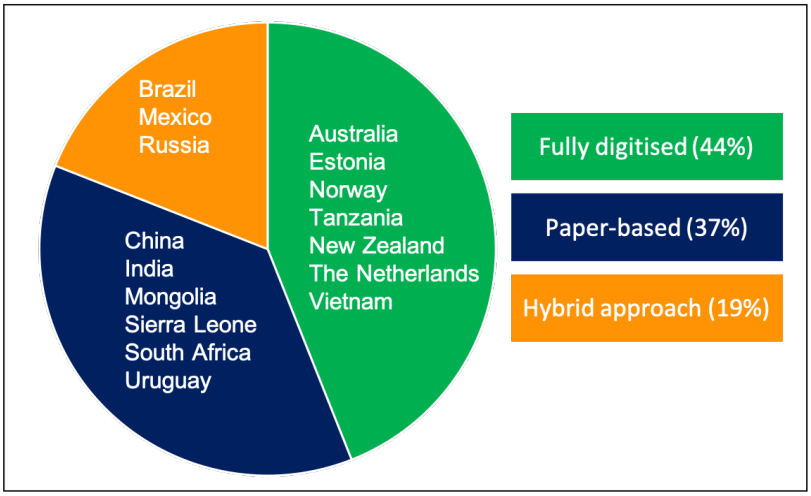
3. Management of vaccination records

An investigation of 16 countries (developed, developing, and countries in transition) was carried out to determine how they managed their vaccination records. The findings were categorised as follows:

- **Fully digitised** – A child's entire vaccination record can be accessed with or without the presence of the vaccination card. The card merely serves as proof for the parent or guardian.
- **Paper-based** – The primary storage mechanism is a paper-based vaccination card or other paper-based documents.
- **Hybrid approach** – A digital system that stores the vaccination records does exist, but it is not updated in real-time and, healthcare practitioners, as well as parents, cannot access these records. The primary storage mechanism remains the vaccination card.

The investigation revealed that 44% of the investigated countries had a fully digitised storage mechanism whilst 37% were paper-based and 19% used a hybrid approach. This is illustrated in Figure 1.

Figure 1: Vaccination record storage mechanisms across 16 investigated countries



Source: Authors

In addition to determining how other countries managed their vaccination records,

non-government-related initiatives, such as mobile applications (apps) that can be downloaded from the Apple iStore or Google Play store, were also investigated. The capabilities of the mobile applications that were assessed are listed in Table 2.

Table 2: Main features of investigated mobile applications

Mobile app name	Register child	Add vaccination records	View vaccination records	Share vaccination records	Vaccination reminders	Schedule-based vaccination records	Pass-code protection
Vaccine Reminder	✓	✓	✓	×	✓	✓	×
Vaccines Log – Vaccination Reminder & Tracker	✓	✓	✓	✓	✓	✓	✓
Child Immunisation Tracker – Baby Immunisation	✓	✓	✓	×	×	×	×
My Kids Vaccine Tracking	✓	✓	✓	×	×	✓	×
My Immunizations	✓	✓	✓	✓	✓	×	×

Source: Authors

The five investigated mobile applications listed in Table 2 had features that were common. These features were the registration of a child, adding a vaccination record, and viewing a vaccination record. These features do represent the core functionality of a vaccination records management system. Similar datasets were noted amongst these mobile applications. It should be noted that none of them shared data with any government entity. The applications were meant to be used as stand-alone systems to assist parents and guardians with keeping track of their children's vaccines.

This led to the understanding that there were no freely available mechanisms for parents to store and retrieve official (verified) vaccination records that share data with government entities in South Africa. An investigation of South Africa's DoH's aims for eHealth was then conducted.

4. Department of Health's aims for eHealth

The 2019–2023 National Digital Health Strategy prioritises EHRs, digital processes, linkage of patient data across various systems, mHealth (mobile health), and knowledge in a digital form (DoH, 2020a). Some of these priorities relate to the previous National eHealth Strategy 2012–2016, which indicates that the measure of success of a country's eHealth maturity is made up of five stages (DoH, 2012). These stages are summarised in Table 3.

Table 3: Five stages of eHealth maturity

Stage	Description
Stage 1	District health indicators are collected using paper-based systems
Stage 2	The optimisation of the paper-based systems. This is achieved by the simplification of information and reducing the amount of duplication
Stage 3	Converting the paper-based district health information systems into electronic storage and reporting
Stage 4	Introducing working ICT systems as the source of data in the Health Information System
Stage 5	Integrated and fully comprehensive National Health Information System

Source: Adapted from DoH (2012)

The DoH's eHealth maturity model is a framework that guides the development of electronic health records using the flows and sources of health information (DoH, 2020a). Overall, South Africa is at Stage 3 of eHealth maturity. Some provinces, however, are at Stage 4 in certain areas and other provinces are at Stages 1, 2, or 3. The DoH has outlined the following steps for South Africa to reach Stages 4 and 5 of eHealth maturity:

- patient-based health information systems need to be implemented at the point where health care is delivered;
- these systems need to be linked to a national health record system;
- all information should be captured into the electronic system at the point of patient care;
- every South African should have a unique identifier on the Health Information System;
- births and deaths need to be effectively registered; and
- all facilities must be able to access information from other facilities (DoH, 2012).

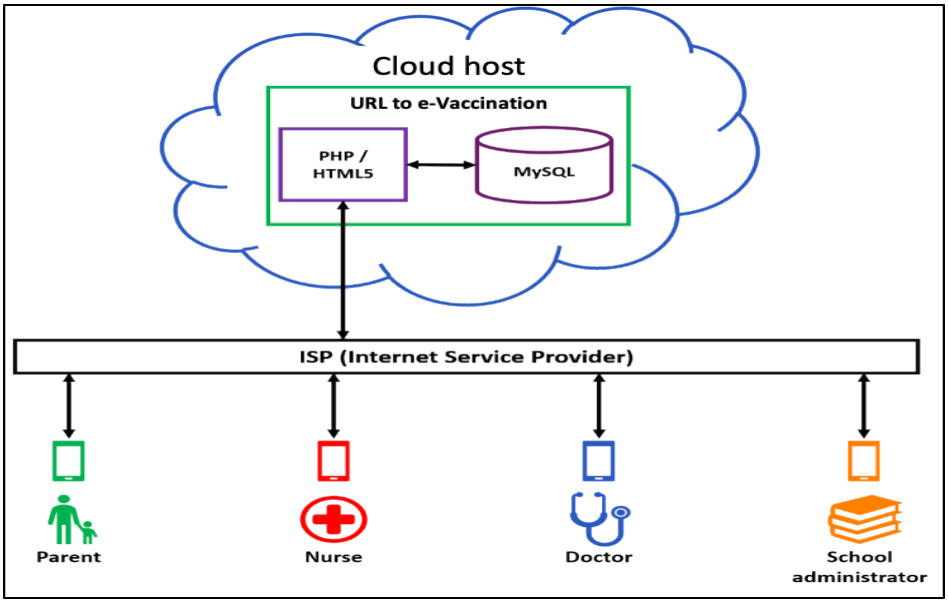
These steps essentially describe a system that stores the digital records centrally, and

which can be accessed and updated from any healthcare facility. This would remove the need to recapture information from the individual healthcare facilities to the district, provincial, and national levels. Equipped with the aims of the DoH, together with generally used datasets and key functions of vaccination record systems, a prototype centrally based digital vaccination records management system called e-Vaccination was developed.

5. e-Vaccination prototype

e-Vaccination was created with four different profiles, one for each of the four key stakeholder types (doctors, nurses, parents, and school administrators). This allowed each stakeholder to engage with e-Vaccination from their particular perspective. With reference to the eHealth aims of the DoH, e-Vaccination was designed as a centralised system that allowed the stakeholders to access it via their internet-enabled devices. This centralised architecture is illustrated in Figure 2.

Figure 2: Architecture of e-Vaccination prototype



As illustrated in Figure 2, the key stakeholders could use their internet-enabled

device (smartphone, tablet, laptop) to access e-Vaccination via their web browser. e-Vaccination was hosted on a remote server (the cloud) and was accessible via a URL (www.e-vaccination.co.za).

The features that were built into e-Vaccination took into consideration those features that were included in the investigated mobile applications. Since prototypes are normally built with limited purposes (Houde & Hill, 1997), only selected features were included in the design of e-Vaccination. The included features were viewing, requesting, and adding vaccination records. Vaccination statistics, in the form of reports at national, provincial, and district levels, were also included. The features linked to the different stakeholder views are described in Table 4.

Table 4: Features included in e-Vaccination, per stakeholder type

Feature	Doctor	Nurse	Parent	School administrator
View a child's vaccination records	✓	✓	✓	×
Request a child's vaccination record	×	×	×	✓
Add a vaccination record	×	×	✓	×
View national reports	✓	✓	✓	✓
View provincial reports	✓	✓	✓	✓
View local government (district level) reports	✓	✓	✓	✓

e-Vaccination had six features built into it, as listed in Table 4. The viewing of reports was common amongst all the stakeholder types. The rest of the features were selectively added to the relevant stakeholder type. Based on the features and profiles built into e-Vaccination, 18 process flows (some process flows were common amongst the stakeholder types) were designed. These are illustrated in Figures 3 to 6.

Figure 3: Process flows for parents

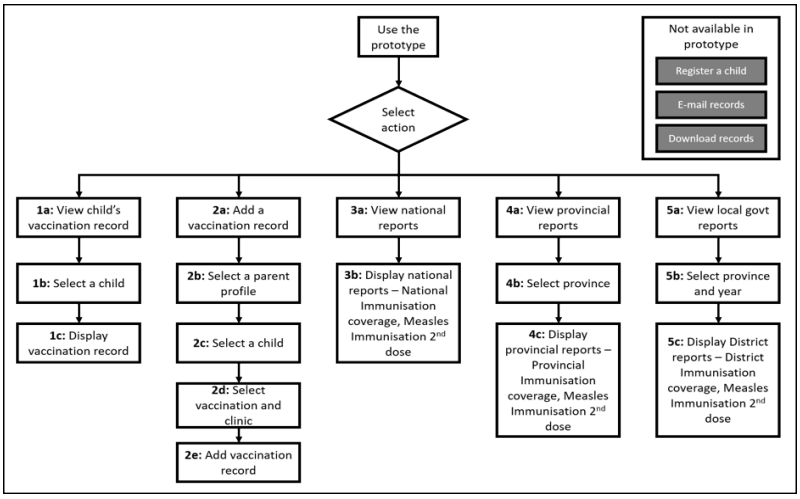
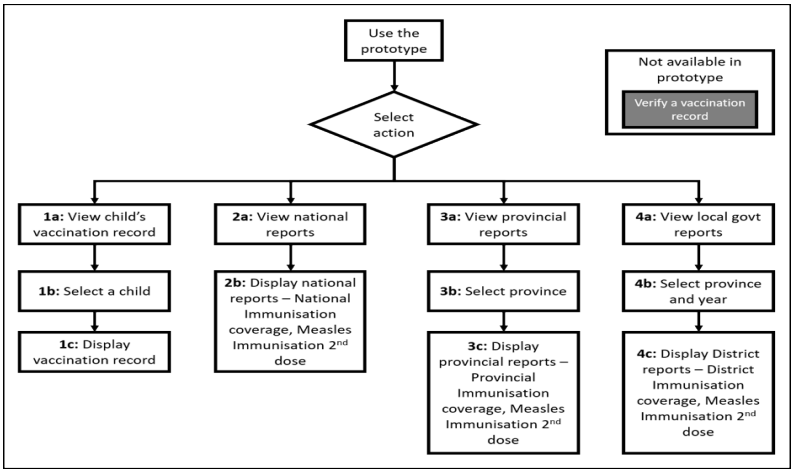


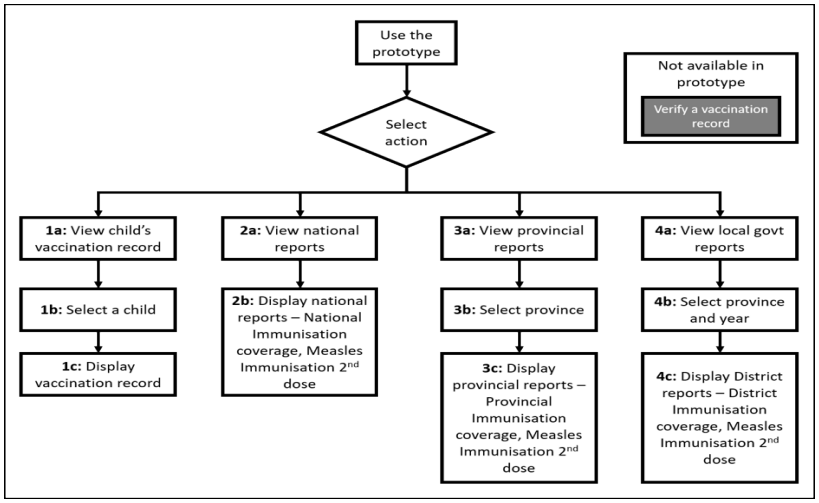
Figure 3 is an illustration of the process flows that were built into e-Vaccination for the parent stakeholder type. Once a parent logged into e-Vaccination, they could select from a list of five processes. To avoid complexity due to e-Vaccination being a prototype and not a live system, some of the processes that were identified early on in the design were not built. These are the "register a child", "e-mail records" and "download records" processes.

Figure 4: Process flows for nurses



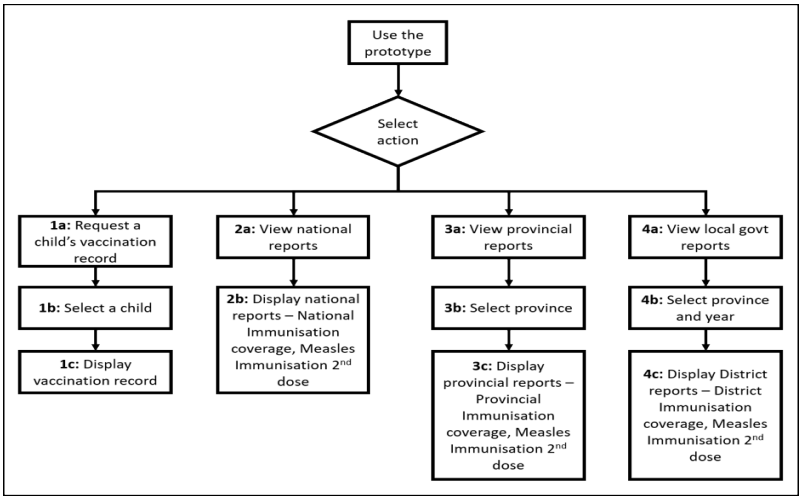
The overall process flows for the nurse stakeholder type are illustrated in Figure 4. Nurses could select from four main processes. These processes are to view a child's vaccination record and to view national, provincial, and local government (district level) vaccination reports. The "verify a vaccination record" process was not built into the prototype.

Figure 5: Process flows for doctors



The process flows illustrated in Figure 5 are for the doctor stakeholder type. The process flows for doctors are the same as the process flows for nurses. The "verify a vaccination record" process was not built into the prototype.

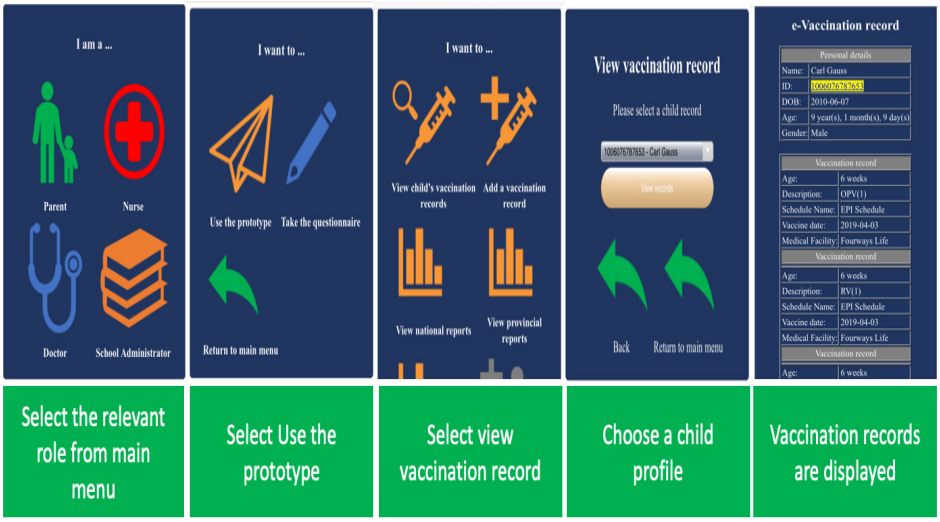
Figure 6: Process flows for school administrators



The process flows for the school administrator stakeholder type are illustrated in Figure 6. School administrators could select from four possible processes. Apart from viewing the national, provincial, and local government vaccination reports as the other stakeholder types could, school administrators could also request a child's vaccination record.

e-Vaccination was designed to be more graphical, allowing the user to type as little as possible with most of the options provided by large icons and dropdown lists. Figure 7 shows the actual user interface of e-Vaccination.

Figure 7: e-Vaccination's user interface



6. Assessment of e-Vaccination prototype

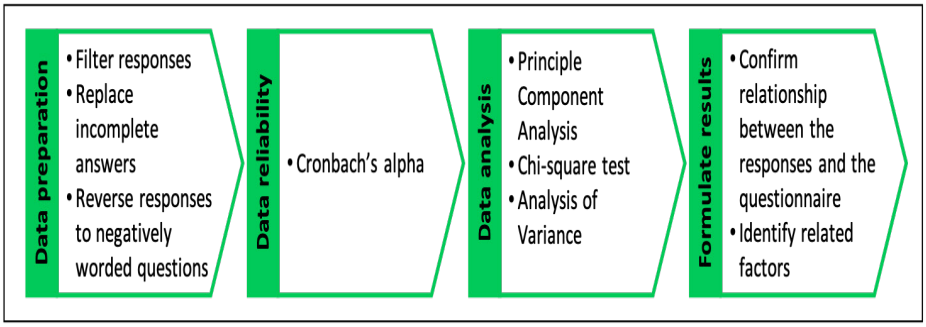
To assess the effectiveness of e-Vaccination, a questionnaire was designed to collect feedback from the relevant stakeholders. e-Vaccination was initially piloted by 10 users, who provided their feedback regarding the system. e-Vaccination was thereafter refined and prepared for distribution to the potential participants.

A quantitative research analysis was conducted on the data collected from the questionnaire, which was based on the stakeholder's engagement with e-Vaccination. A questionnaire with three sections was designed to collect demographic information (Section A), perceptions about vaccinations in Gauteng (Section B), and user perception (usefulness, satisfaction, ease of use and ease of learning, design and visual aids) information (Section C). (See Appendix 1 for the questionnaire.)

The participants who completed the questionnaire were anonymous. They were selected by word-of-mouth as well as via contact information that was available in the public domain. A link to e-Vaccination and the questionnaire was distributed to the prospective participants via e-mail, phone call, SMS, or visit. The prospective participants were asked to use e-Vaccination and to select the user profile based on their stakeholder type. Once they had used e-Vaccination, the participants answered the questionnaire and submitted their responses.

Following the data collection process, the data were statistically tested for reliability using a Cronbach's alpha test. The Cronbach's alpha scores were verified against the rating table by Gliem and Gliem (2003). To confirm that the data collected were not a randomised occurrence, a chi-square goodness of fit test followed as a subsequent step. The ANOVA test was used to determine if there were significant differences between different experimental conditions (Rutherford, 2000). This statistical method was used to analyse Likert-type scales in a similar study by Holtz and Krein (2011). Once it was proven that the data were reliable, not random and that stakeholder groups did not have a significant difference between them in their responses, a principle component analysis (PCA) test was conducted. A PCA is a data reduction method (UCLA IDRE, 2020) that can be used to investigate a relationship between dependent variables (Syms, 2019). The PCA was used to determine whether the responses to the questionnaire were related to the overall research question as well as to uncover any underlying factors that influenced the responses. The data analysis steps are summarised in Figure 8.

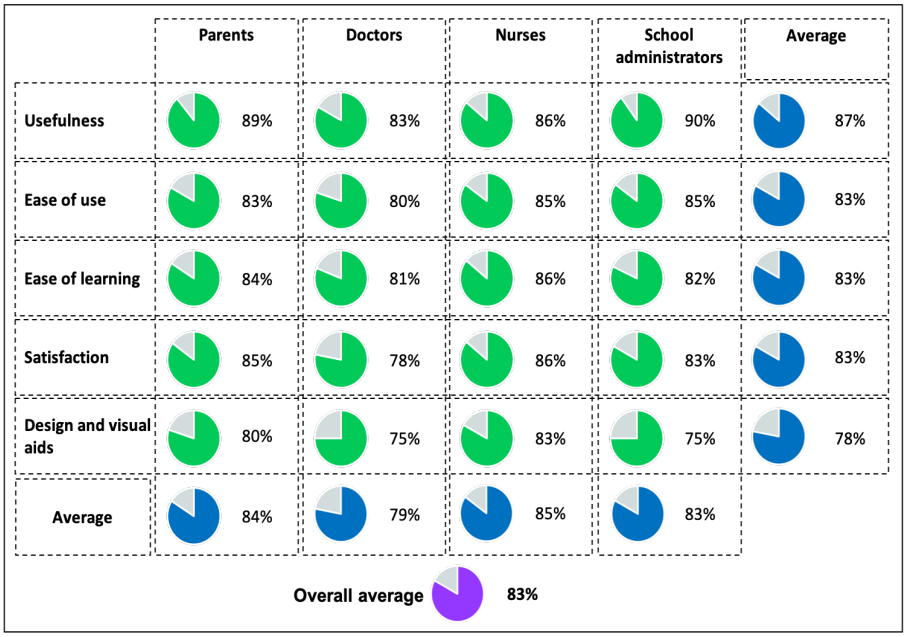
Figure 8: Data analysis steps



7. Results

There were 118 respondents to the questionnaire (doctors: 16; nurses: 16; parents: 74; school administrators: 12). Of the 118 respondents, 95% had access to a smartphone and at least 96% had access to the internet and email. The paper-based vaccination card was the primary storage mechanism according to 91% of the respondents, while 5% felt that a digital system was the primary mechanism. Approximately 4% were uncertain. Most of the respondents, 94%, had at least one experience with a lost vaccination card. The results of the Cronbach's alpha test showed that the data collected were reliable. The chi-square test showed that the data collected were not a random occurrence and were due to an underlying factor. There was no significant difference in the data collected between the four stakeholder groups according to the results of the ANOVA test. The weighted scores for the questionnaire per user perception category and stakeholder type are depicted in Figure 9.

Figure 9: Weighted scores per user perception category and stakeholder type



The weighted scores as illustrated in Figure 9 show that the overall perceptions about the digitisation of vaccination records scored an 83%. The usefulness of e-Vaccination had the highest weighted score, 87%.

The PCA test was conducted on all 33 questions of section C of the questionnaire for all 118 participants (the full dataset). This test was used to determine the underlying factors relating to the five categories of the questionnaire as well as the perceptions of the stakeholders about the digital vaccination record. Eigenvalues were calculated and thereafter used to determine the main factors for each of the 33 questions. The factors with eigenvalues greater than 1 should be retained (UCLA IDRE, 2020). These factors are the significant factors that make up the principal components of the dataset. The factors with eigenvalues greater than 1 are displayed in Table 5.

Table 5: Factors with eigenvalues greater than 1

Factor	Eigenvalue
1	16.93
2	2.05
3	1.78
4	1.38
5	1.22
6	1.05

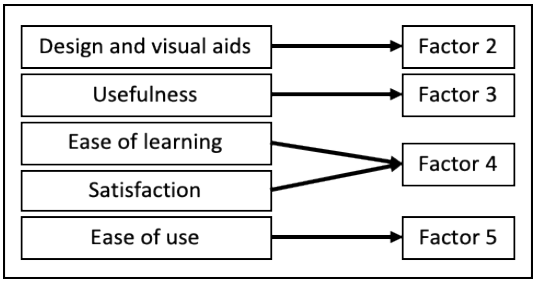
Factor 1, with an eigenvalue of 16.93, generated the steepest gradient on a scree plot (see Appendix 2). This main factor was identified as the one concerning the overall research question on the digitisation of the vaccination record. The remaining factors were renamed Factors 1 to 5. The contributions of the factors towards each of the user perception categories are detailed in Table 6 below.

Table 6: Percentage contributions of five factors to user perception categories

User perception categories	F1 (%)	F2 (%)	F3 (%)	F4 (%)	F5 (%)
Usefulness	18.608	17.457	60.125	3.225	0.584
Ease of use	23.421	0.000	9.301	3.367	63.911
Ease of learning	21.340	0.229	17.994	52.903	7.533
Satisfaction	21.586	8.105	4.648	39.850	25.810
Design and visual aids	15.045	74.208	7.931	0.654	2.162

For each user perception category, the factor that the category contributed most towards was determined. The factors were then labelled based on the underlying reason for why they contributed towards that category. The relationship between the factors and the categories, based on the highest contributions, is illustrated in Figure 10.

Figure 10: Main factor contributions of each user perception category



None of the user perception categories made its highest contribution to factor 1. The "ease of use" category which revealed the "user friendliness" factor during the PCA, however, made the highest contribution towards this factor. The contributions, labels, and descriptions are listed in Table 7.

Table 7: Five underlying factors uncovered by PCA test

Factor	Contribution (%)	Label	Description
Factor 1	23.421	User friendliness	The system has to be appealing to the stakeholders and should not intimidate those who are new to such platforms.
Factor 2	74.208	Graphical design	The use of graphics adds to the intuitiveness of the system and guides the user on accessing the features they want to access with minimal effort.
Factor 3	60.125	Practicality	The system must provide the users' anticipated features.
Factor 4	52.903	User experience	The user experience must be engaging; users must not feel the need to use help files to access the features they want to use.
Factor 5	63.911	Usability	The features of the system must match the users' expectations. The features must also work in the way that the user anticipates.

The result of the statistical analysis demonstrated that e-Vaccination is user-friendly, practical, usable, provides a good user experience, and has a graphical design that aids in the use of the system. The results of each statistical test are summarised in Table 8.

Table 8: Summary of data analysis

Statistic	Usefulness	Ease of use	Ease of learning	Satisfaction	Design and visual aids
Data Reliability					
Cronbach's alpha	0.91	0.92	0.9	0.9	0.67
Chi-square test					
Chi-square value †	151.41	165.47	154.97	128.36	169.20
df	4	4	4	4	4
Critical chi-square value ‡	9.49	9.49	9.49	9.49	9.49
Approximate *p value*	<0.001	<0.001	<0.001	<0.001	<0.001
Alpha value	0.05	0.05	0.05	0.05	0.05
Outcome of calculation	151.41† > 9.49‡	165.47† > 9.49‡	154.97† > 9.49‡	128.36† > 9.49‡	169.20† > 9.49‡
Result	$H_{0\text{- usefulness chi-square}}$ Rejected	$H_{0\text{- easy to use chi-square}}$ Rejected	$H_{0\text{- easy to learn chi-square}}$ Rejected	$H_{0\text{- satisfaction chi-square}}$ Rejected	$H_{0\text{- design and visual aids chi-square}}$ Rejected
ANOVA test					
Alpha value §	0.05	0.05	0.05	0.05	0.05
df between groups	3	3	3	3	3
df within groups	114	114	114	114	114
F value	1.48	0.54	0.55	1.54	1.45
p value ¦	0.23	0.66	0.65	0.21	0.23
f crit	2.68	2.68	2.68	2.68	2.68
Outcome of calculation	0.23¦ > 0.05§	0.66¦ > 0.05§	0.65¦ > 0.05§	0.21¦ > 0.05§	0.23¦ > 0.05 §
Result	$H_{0\text{- usefulness ANOVA}}$ Accepted	$H_{0\text{- easy to use ANOVA}}$ Accepted	$H_{0\text{- easy to learn ANOVA}}$ Accepted	$H_{0\text{- satisfaction ANOVA}}$ Accepted	$H_{0\text{- design and visual aids ANOVA}}$ Accepted
Principle component analysis					

Statistic	Usefulness	Ease of use	Ease of learning	Satisfaction	Design and visual aids
Contribution to Factor 1 (User friendliness)	18.6	23.4	21.3	21.6	15.1
Contribution to Factor 2 (Graphical design)	17.5	0.0	0.2	8.1	74.2
Contribution to Factor 3 (Practicality)	60.1	9.3	18.0	4.7	7.9
Contribution to Factor 4 (User experience)	3.2	3.4	52.9	39.9	0.7
Contribution to Factor 5 (Usability)	0.6	63.9	7.5	25.8	2.2
Overall					
Result	$H_{0\text{- usefulness}}$ Accepted	$H_{0\text{- easy to use}}$ Accepted	$H_{0\text{- easy to learn}}$ Accepted	$H_{0\text{- satisfaction}}$ Accepted	$H_{0\text{- design and visual aids}}$ Accepted

The data analysis alone cannot tell us the full story as it is important to consider the current context. Whilst conducting this research, the COVID-19 pandemic reached South Africa, necessitating the implementation of the EVDS. Though the EVDS was not examined in detail, it can be noted that some of the features, such as creating and viewing vaccination records, are common in both systems.

8. Response to new challenges

The current COVID-19 pandemic has introduced a new paradigm, namely vaccination records for adults. Whilst the EVDS has been created primarily as a vaccination registration tool for COVID-19 vaccinations, it also serves a secondary purpose, which is to store the vaccination records of the patients (adults). It is not unreasonable to assume that we will possibly move to adult immunisation schedules on a seasonal basis. The vaccination card, SMS notifications and QR codes provided to

the patients after their vaccination still represent one-way information flow from the healthcare facility to the patient. Whilst the EVDS seems to satisfy some of the eHealth aims mentioned earlier, such as the centralisation of data (which facilitates the sharing of data between healthcare facilities), the patient is not yet fully able to access his or her vaccination records through an available portal independently. It must be noted that the sharing of medical information, even with the patient, must take into account the Protection of Personal Information Act (POPIA) (RSA, 2013).

The COVID-19 pandemic has also raised another consideration. This is vaccination coverage, which can contribute towards herd immunity reporting. If the information is appropriately utilised, herd immunity reporting can be done at a national level. Further research needs to be conducted regarding the reporting of herd immunity for other vaccine-preventable diseases based on the EPI schedule and at a more granular level, such as district level or lower.

Though the EVDS does indeed represent a leap towards an EHR for South Africa, it has now contributed to a patchwork of systems created to address an immediate need. It contributes towards an EHR for every citizen, but we should be wary of it becoming the foundation for EHRs. Information Systems principles tell us that a solid foundation must first be laid. This includes getting the interconnectedness between the various systems done (whilst considering aspects such as POPIA) and then getting the related (medical) records appropriately positioned. In the past, other developing countries such as Tanzania have made massive investments in Health Information Systems, but issues relating to the adoption of integration resulted in resources being wasted (Smith et al., 2008). Considering that South Africa has a history of failed e-Government projects (Singh & Travica, 2018), the coupling of the current eHealth foundations and the EVDS needs to be analysed for current and future-readiness. In its haste, the DoH may have failed to adequately assess a key factor, which is the usability of the EVDS. The downstream applications of the EVDS as well as an assessment of whether it fully meets the DoH's eHealth aims are other areas that need further research.

9. Conclusions

The results of the study show that the key stakeholders supported the development of a digital system for the safe and secure storage of vaccination records for minors in Gauteng. The successful design of such a system is influenced by several factors. These factors (user friendliness, graphical design, practicality, user experience, and usability) were identified during this research and should drive the design and development of a digital vaccination records management system.

The DoH's response to the COVID-19 pandemic has accelerated the strides that South Africa is taking towards an EHR for all citizens. Vaccination records for minors (based on the EPI schedule), however, have still not made the same advances.

The reason could be that the move towards stages 4 and 5 of the eHealth model might require a more gradual approach as historic information needs to be considered.

Facets of prototypes such as e-Vaccination, working eHealth systems like the EVDS, and existing healthcare infrastructure should converge when considering the factors uncovered during this study as well as future research. If the usability of the system satisfies the key stakeholders, the chances of the system being used and the overall vision of the DoH being met will increase. To avoid wasteful expenditure, eHealth designers and policymakers should carefully consider the usability of applications that are being proposed for all key stakeholders.

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Appendix 1: Questionnaire

SECTION A: Respondent information (Demographics)

1. Regarding this questionnaire, please select your primary role:

Medical Doctor		Parent	
Nurse		School Administration Staff	

For the following questions, please tick the appropriate box	Yes	No
2. Do you work in Gauteng, South Africa?		
3. Do you have access to a smartphone?		
4. Do you have access to the Internet?		
5. Do you have an e-mail address?		

SECTION B: Vaccination records in Gauteng, South Africa

1. In your experience with vaccinations, how is a child's vaccination records primarily stored?

Paper-based vaccination card		No records are kept	
Electronic systems		Not sure	

2. Paper-based vaccination cards can be susceptible to loss or damage. Are you aware of a vaccination card that has been lost?

Yes		No	

3. If your answer to the question above was "Yes", please select the measures taken to recover the lost vaccination records. If your answer was "No", please select "Not applicable".

Successfully obtained vaccination records from the vaccination clinic	
Performed a blood analysis on the child to determine the vaccines that were administered	
Other (if Other, please describe the measures taken below):	
Not applicable	

4. In your opinion, who should be responsible for ensuring that a child's vaccination records are safely stored?

Parents / Guardians		Govern-ment	

Please indicate the extent to which you agree or disagree with the statements below:

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
5. Children living in Gauteng receive their vaccinations on time					
6. Paper-based vaccination cards are a reliable way to store a child's vaccination records					

SECTION C: A centralised electronic vaccination record system in Gauteng, South Africa, managed by the government

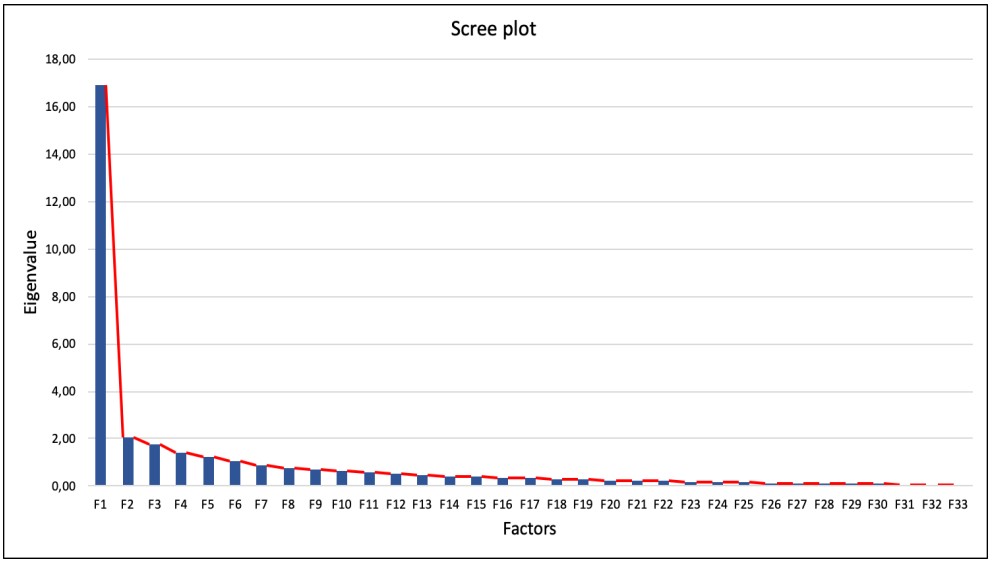
Based on the prototype system (e-Vaccination application) that you have used, please indicate the extent to which you agree or disagree with the following statements:

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Usefulness					
1. The e-Vaccination application can help me to be more effective when handling vaccination records					
2. The e-Vaccination application can help me to be more productive when using the vaccination functions					
3. The e-Vaccination application is useful for managing vaccination records					
4. The e-Vaccination application will save me time when storing vaccination records					
5. The e-Vaccination application will save me time when accessing vaccination records					
6. The e-Vaccination application meets my needs in terms of storing vaccination records					

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
7. The e-Vaccination application meets my needs in terms of retrieving vaccination records					
8. The e-Vaccination application saves my inputs as required					
9. The e-Vaccination application displays vaccination records in a way that I can understand					
Ease of use					
10. The e-Vaccination application is easy to use					
11. The e-Vaccination application is not a complicated system to use					
12. The e-Vaccination application is user friendly as it minimises the amount of input I need to enter					
13. Any action on the e-Vaccination application is completed with the minimum number of possible steps					
14. Using the e-Vaccination application is effortless					
15. I can use the e-Vaccination application without written instructions					
16. There are no inconsistencies within the e-Vaccination application					
17. I can recover from mistakes easily when using the e-Vaccination application					
18. I can use the e-Vaccination application successfully every time					
Ease of learning					
19. I quickly understood how to use the e-Vaccination application					
20. I easily remember how to use the e-Vaccination application					

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
21. I quickly became skilful with the e-Vaccination application					
22. I quickly learned how to navigate through the e-Vaccination application					
23. I quickly learned what the colour coding of the visual aids (icons) meant					
Satisfaction					
24. I am satisfied with the e-Vaccination application					
25. I would recommend the e-Vaccination application to a friend					
26. The e-Vaccination application works the way I want it to work					
27. I am satisfied with the overall appearance of the e-Vaccination application					
28. I am satisfied with how the navigation of the e-Vaccination application works					
Design and visual aids					
29. The use of visual aids (icons) are helpful when using the e-Vaccination application					
30. I would prefer written instructions on the e-Vaccination application instead of visual aids (icons)					
31. The visual aids (icons) help me navigate the e-Vaccination application easily					
32. The colour coding of the visual aids (icons) helps me to determine what the link means					
33. The vaccination statistics provided are useful					

Appendix 2: Scree plot of eigenvalues



Defining Decentralisation in Permissionless Blockchain Systems

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Abstract
The term *decentralised* as a description of the architecture, operation, and governance of permissionless blockchain systems has become ubiquitous. However, in these contexts, the term *decentralised* has no clear definition. Blockchain ecosystems are complex, and thus it is essential to address confusion among stakeholders about their nature and promote understanding of the intentions and consequences of their implementation. This article offers a theoretical definition of the term *decentralised* in the context of permissionless blockchain systems. It is proposed that five inextricable and interconnected aspects are required, at a minimum, to warrant a claim that a permissionless blockchain system is decentralised. These aspects are disintermediation, a peer-to-peer network, a distributed blockchain data structure, algorithmic trust, and open-source principles. The relationship between the five aspects is discussed, and it is argued that decentralisation is not binary but exists on a spectrum. Any variation in one or more aspects may impact the system's decentralised nature as a whole. The researchers identify areas where further investigation in this field is required and propose instances where the knowledge garnered may be used.

Keywords
blockchain, permissionless, decentralised, disintermediation, distributed ledger, algorithmic trust, open source, peer-to-peer network

DOI: https://doi.org/10.23962/ajic.i29.14247

Recommended citation
Bezuidenhout, R., Nel, W., & Maritz, J.M. (2022). Defining decentralisation in permissionless blockchain systems. *The African Journal of Information and Communication (AJIC), 29*, 1-24. https://doi.org/10.23962/ajic.i29.14247

1. Introduction

When the term *decentralised* is used to refer to a permissionless blockchain system, the term tends to lack precision with respect to its meaning and the aspects of the system it is being used to refer to (Walch, 2019, p. 40). Many terms are used to describe technologies built on so-called *decentralised* blockchains. The terms decentralised consensus systems, decentralised applications, decentralised digital currencies, cryptocurrencies, altcoins, meta coins, smart contracts, distributed applications, distributed autonomous organisations, and distributed autonomous companies are routinely used throughout the literature (Glaser & Bezzenberger, 2015). Some authors simply refer to blockchain or blockchain technology (Holotescu, 2018). It may be that within the computer science community, the term *decentralised* blockchain is generally understood. However, one would be hard-pressed to find a clear theoretical definition for it. The vagueness represents a potential problem for any stakeholder needing to engage with the technology on some level.

This study provides a proposed clear theoretical definition of the term *decentralised* in the context of a permissionless blockchain system. In establishing and setting out the definition, this study seeks to make an important contribution to stakeholders engaging with blockchain by inserting critical, theoretically founded analysis into the subject's discourse.

What is a theoretical definition, and why is it important?

The conclusion Walch (2019) draws is that in law, the term *decentralised* already represents a legal standard that has implications for regulators and business, and its current lack of proper definition may result in misleading conclusions being drawn from it. This is exacerbated by the fact that regulators and managers have to deal with many different types of business models that are being established using blockchain systems (Stabile et al., 2020). Whether the underlying blockchain system is centralised or decentralised is fundamental to the type of business model and, therefore, its regulatory environment.

Notwithstanding its vagueness, the term *decentralised* found its way into regulators' language from early on, as this description by the US Department of the Treasury Financial Crimes Enforcement Network (FinCEN) shows:

> c. De-Centralized Virtual Currencies
> A final type of convertible virtual currency activity involves a de-centralized convertible virtual currency (1) that has no central repository and no single administrator, and (2) that persons may obtain by their own computing or manufacturing effort. (FinCEN, 2013, p. 5)

And the practice is still ongoing, as is evident in this more recent US government statement:

> The vast majority of cryptocurrencies are decentralized, as they lack a central administrator to issue currency and maintain payment ledgers—in other words, there is no central bank. (US Department of Justice, 2020, p. 3)

In the first example above, the term *decentralised* is contained in the definition of the system (decentralised virtual currency), while the second example explains what a decentralised cryptocurrency lacks, not what it contains. A theoretical definition must go beyond a superficial description. In addition to specifying what is required in a decentralised blockchain system, this study also answers the *how*, *when* and *why* questions that apply to theories in general (Bacharach, 1989). Specifically, in the context of permissionless blockchain systems, this study answers the following questions:

- What are the aspects (constituent stakeholders and components) of decentralisation in a decentralised blockchain system?
- How do these aspects combine and interact to achieve decentralisation?
- When (and to what end) do the stakeholders and components need to arrange themselves in a manner that delivers decentralisation?
- Why is each aspect necessary? In other words, why can decentralisations not exist without the presence of each aspect?

It is important to note that the end-product is not merely a list of constituent elements and their individual roles, but is more importantly also an explanation of the interactions and causal relationships between these phenomena.

Structure of the article

This article starts with a description of blockchain systems, their components, and their purpose, before defining what a permissionless blockchain system is and the environment in which it operates. The terminology and environment make up the boundary assumptions within which the theoretical definition of *decentralised* will be positioned. Specifically, the definition of *decentralised* is bounded by the key constraint of a *permissionless* blockchain system, as *permissioned* blockchain systems are specifically *not decentralised* (Vukolic, 2017). In the results, we propose a proper, theoretically founded, technical definition of the term *decentralised* in the context of

permissionless blockchain systems. The article concludes with a discussion of the results and concluding remarks.

2. Background

In the literature, some authors refer to blockchain as a data structure, an ordered list of blocks, where each block contains a list of transactions, and where blocks are cryptographically linked to provide a tamper-proof historical transaction record (Nofer et al., 2017; Xu et al., 2017). The idea of a blockchain as a distributed ledger of transactions (therefore a data structure) is echoed by multiple researchers (Mulár, 2018; Rizun et al., 2015; Zheng et al., 2017). Other authors describe a blockchain as a combination of technologies such as distributed ledgers, cryptography, and consensus mechanisms that allow untrusted parties to agree on the state of transaction data that is decentralised – therefore, *a system* (Glaser & Bezzenberger, 2015; Saad et al., 2019; Tasca & Tessone, 2019).

To avoid ambiguity, in this study, the term *blockchain* explicitly means a distributed ledger that conforms to a cryptographically linked data structure that serves as a transaction record and makes up one component of a blockchain system. The data structure characteristics are specifically designed to enable parties to agree on the transaction record without having to trust one another. Furthermore, this study defines a *blockchain system* as a combination of stakeholders and technologies that produce, consume, or interact with required services, or are enabled by the use of a blockchain data structure. While permissionless blockchain systems may differ in their intended application and architecture, they all share essential objectives (Bezuidenhout et al., 2020).

Purpose of a blockchain system

A blockchain's purpose is to record transactions (which may include smart contract programs) that are immutable and cannot be repudiated, and that are secure, transparent and accessible (Tasca & Tessone, 2019; Xu et al., 2017). These terms (related to the nature of the blockchain data structure) are defined in the following way:

- *Immutable* refers to the principle that a recorded transaction cannot be altered or, more accurately, can eventually not be altered (Tasca & Tessone, 2019).
- *Non-repudiation* means that since a transaction cannot be altered, it can also not be undone or "taken back" (Xu et al., 2017). Immutability and non-repudiation are achieved by embedding cryptographic hash pointers into the blockchain to construct a tamper-proof log of transactions (Narayanan et al., 2016).
- *Security* in permissionless blockchain systems pivots on a trifecta of techniques that protect the ownership of data, the integrity of the blockchain, and the system's redundancy as a whole. First, data ownership security is established through public-key cryptography by allowing only the rightful owner of a private key to transact with their own data on the blockchain (Tschorsch & Scheuermann, 2016). Second, the blockchain itself consists of a sequential

series of blocks, each linked by a cryptographic hash pointer to the previous block to produce a tamper-evident log of transactions. This ensures the integrity of the blockchain (Narayanan et al., 2016). Third, a centralised system controlled by a single authority carries the risk of single-point failure (Atzori, 2017). By doing away with a centralised or root authority and by distributing copies of the blockchain across many peers on a peer-to-peer network, a permissionless blockchain uses redundancy to mitigate this type of risk.

- *Transparency* refers to the fact that all the blockchain transactions are open and, therefore, auditable by all the system's participants. In the case of permissionless blockchain systems, this means anyone with an internet connection (Tasca & Tessone, 2019).
- *Accessibility* is narrowly coupled with the idea of transparency, meaning all participants in a permissionless blockchain system have equal rights to transact on and manipulate the blockchain (Xu et al., 2017). For clarification, note that there is a juxtaposition between *accessibility* and *security* here. Accessibility implies the ability to inspect the blockchain, including all the transactions on it. This may include inspecting the data (for auditability purposes) of other participants. Accessibility also means that there is no restriction on participants to transact on the system, but transactions by participants are limited to their own data. Accessibility does not extend to the point where data ownership security is compromised.

In a permissionless blockchain system (see section 2), the definition of *decentralised* becomes critical. This is because it must remain true to its purpose while being decentralised and must therefore operate in the absence of a central trusted authority.

Permissionless blockchain systems and their environment

This study focuses on *permissionless*, i.e., public, blockchain systems. As a starting point, the emphasis is placed on the distinction between distributed and decentralised system architectures as described by Troncoso et al. (2017, p. 208). Note that these definitions are aimed at information systems in general and not blockchain systems specifically:

> Distributed system: A system with multiple components that have their behaviour co-ordinated via message passing. These components are usually spatially separated and communicate using a network, and may be managed by a single root of trust or authority. (Danezis & Halpin, 2017, p. 208)

> Decentralized system: A distributed system in which multiple authorities control different components, and no single authority is fully trusted by all others. (Danezis & Halpin, 2017, p. 208)

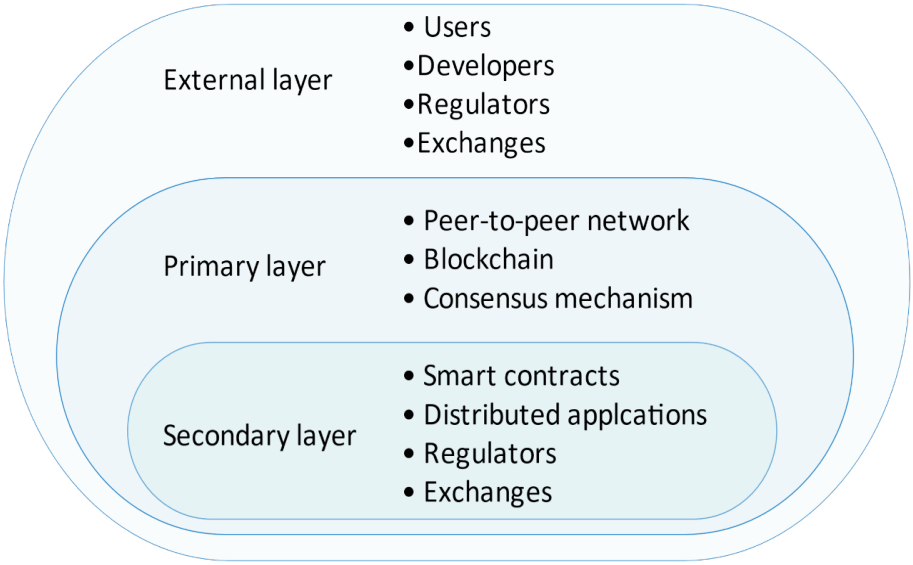
These two definitions show clearly that while all decentralised systems are distributed, not all distributed systems are decentralised. *Permissionless* blockchain systems do not restrict participation. Anyone can join or leave the system at will. They function

on a peer-to-peer basis, without a central authority and require a decentralised consensus mechanism for participants to reach an agreement on a single correct state of the blockchain (Glaser & Bezzenberger, 2015; Tasca & Tessone, 2019; Zheng et al., 2017). These are the only type of blockchain systems where the definition of decentralised may be applicable because permissionless blockchain systems are distributed systems where different components are controlled by multiple authorities. In contrast, *permissioned* (private) blockchain systems are systems where only certain entities are allowed access to the blockchain. Although they are also distributed systems, access is controlled by a central authority, and these types of blockchain systems are not decentralised (Deshpande et al, 2017). The definition of decentralised has no meaning in the context of *permissioned* blockchain systems.

Layers in a blockchain system

Three layers of entities or components in permissionless blockchain systems make up the blockchain environment. These are the external layer, the primary layer, and the secondary layer, as depicted in Figure 1.

Figure 1: Layers in a blockchain system



First is the layer that constitutes its mechanical operation. It consists of the blockchain, peer-to-peer network, and the consensus mechanism (Narayanan et al., 2016; Zheng et al., 2017). This will be referred to as the *primary layer.*

A second layer of more sophisticated applications can be built on top of the basic blockchain implementation through smart contracts. The meaning of the term *smart contract* is extremely broad. However, it allows for a range of automated, dynamic applications to operate independently, using the primary layer's services (Glaser & Bezzenberger, 2015). These applications will be referred to as the *secondary layer*. It is important to note that the interaction with the secondary layer applications occurs by initiating a transaction (containing the smart contract code to be executed) on the primary layer. For example, Ethereum (Buterin, 2013) allows users to pre-program transactions by submitting software code inside a transaction that executes automatically under certain conditions. These transactions do not require any additional action by the users who created them.

Blockchain systems do not suddenly spring into being and then exist in isolation; they are embedded within society at large. They are created and maintained by some entity or entities to fulfil a useful function to a community of consumers or users. These entities include:

- Developers that develop and maintain software related to both the primary and secondary layers of many blockchain systems (Bitcoin.org, n.d.; Cardanofoundation.org, 2020; Ethereum.org, n.d.). These may be not-for-profit communities or business entities that operate for profit (Glaser & Bezzenberger, 2015).
- Users who transact with the blockchain system, either directly with the primary layer or indirectly with the secondary layer. These may be individuals, organisations, or systems (including IoT devices). Users may also transact through intermediaries such as brokers or exchanges, which, in turn, can be viewed as users, organisations, or systems.
- Regulatory authorities that may scrutinise blockchain systems from time to time (Tasca & Tessone, 2019).

The entities above are examples of external stakeholders that make up an *external layer*, comprising all the parties that interact with or provide support to the blockchain system's primary or secondary layers.

The secondary layer is embedded in the primary layer and cannot exist without it. Furthermore, the external layer does not interact directly with the secondary layer but does so through the primary layer. Similarly, the primary layer does not exist without the requirement for, consumption of, and development by the external layer. Within the context provided in the preceding discussions—focusing on the distinction between the terms *blockchain* and *blockchain system*, the *purpose* of a blockchain system, and the definition of a *permissionless blockchain system* and its constituent *layers* (environment)—it is possible to define the term *decentralised*.

3. Methodology

This study investigated literature in the blockchain domain to classify the aspects that authors associated with the decentralised nature of blockchain systems. The purpose was neither to be exhaustive nor comparative, and to extract the meaning of the term *decentralised* as used by authors in information science in the context of the permissionless blockchain environment. Works that dealt with the theory of blockchain systems in general in the preceding five years (since 2016) were selected. Only peer-reviewed material was included, specifically journal articles and conference papers. The primary search was conducted through the internet search services of Academia, ResearchGate, Semantic Scholar, and SSRN. A secondary search was done by looking for appropriate material referenced in articles and papers that passed this selection process.

Each item identified in the literature was studied to determine which aspects the author(s) ascribed to the term *decentralised* in the context of a permissionless blockchain system. In some of the material set aside for further analysis, the authors' treatment of the term *decentralised* was too vague to warrant including it in the study. Eventually, of the 89 articles and papers identified for detailed scrutiny, 46 (see Appendix) were included in the results. At this point, we concluded that it was unlikely that additional interpretations of the term *decentralised* were forthcoming by including more material, and that the disqualified material up to that point did not include any information that was not present in the final 46 articles and papers.

4. Analysis from the review of existing literature

Throughout the 46 items investigated, it was found that the term *decentralised* could be associated with five aspects that apply to permissionless blockchain systems. These aspects, identified from the literature, were disintermediation, a distributed blockchain, peer-to-peer network, algorithmic trust, and open-source principles. They represent philosophical ideas (disintermediation and open-source principles), physical components (peer-to-peer network), and software implementations (distributed blockchain and algorithmic trust) which form the basis of the theoretical definition of *decentralised* in a permissionless blockchain system. Table 1 lists the five aspects of decentralisation against the author numbers in the Appendix.

Table 1: Aspects of decentralisation identified from the literature

Aspect of decentralisation	Author number in Appendix	Count
Disintermediation	1, 2, 3, 4, 14, 15, 16, 18, 19, 20, 21, 22, 23, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 38, 39, 40, 41, 42, 43, 44, 45, 46	32
Distributed blockchain	1, 3, 4, 5, 6, 9, 10, 11, 13, 14, 16, 17, 18, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 33, 36, 37, 39, 40, 41, 42, 43, 44, 45	35
Peer-to-peer network	4, 5, 9, 16, 17, 18, 24, 25, 27, 29, 30, 33, 36, 39, 41, 43, 44	17
Algorithmic trust	1, 3, 4, 5, 6, 7, 8, 11, 13, 14, 16, 17, 18, 19, 20, 24, 25, 26, 27, 28, 30, 31, 33, 34, 36, 38, 39, 40, 41, 42, 44, 45, 46	33
Open-source principles	5, 12, 20, 28, 41	5

The study did not assign any weight to the number of times an aspect presented in the literature ("Count" column in Table 1). This was done for two reasons. First, the literature reviewed did not aim to define the term *decentralisation* but assumed that decentralisation was a valid descriptor of a blockchain system because one or more of the specific aspects were present. Second, as will be shown in the results (section 5), no aspect is more important than the other; all are required in a decentralised blockchain system. Each of these aspects is now discussed in detail to provide the context of how they were represented in the reviewed literature.

Disintermediation

Disintermediation is a philosophical idea that was central to Nakamoto's introduction of Bitcoin. He posited a system of electronic payments where individuals could transact without the mediation of a central institution (Nakamoto, 2008). The idea of disintermediation, which refers to the absence of a central authority in a blockchain system, whether the transactions are meant to be of a monetary nature or not, is an assertion that comes across often in the literature. Some authors refer to a blockchain system being decentralised because of the lack of central authority within the peer-to-peer network directly, while others refer more indirectly to the absence of a central

point of trust or authority. Hackius and Petersen (2017, p. 5) called it "without relying on a central authority or centralised infrastructure establishing trust", while Lin and Liao (2017, p. 653) state that "blockchain doesn't have to rely on a centralized node". This philosophical flavour can border on political ideology, as noted by Atzori (2017, p. 46): "the advocates of decentralization tend to have in common the same dissociative attitude towards centralized institutions and the State in particular". In this study, the researchers opted for the term "disintermediation" used by Holotescu (2018, p. 276) to describe the spectrum of phrases ranging from "not having to rely on a central node" to "dissociative attitude towards centralized institutions" as the term summarises all of the above ideas into a single word.

Disintermediation means that any party that aims to participate in the blockchain system's primary layer (for instance, join the peer-to-peer network, submit a transaction, or attempt to extend the blockchain) can do so without the permission of any other party. Furthermore, any party that participates in the primary layer of the blockchain system may send data to, or receive data from, any other party. This can be done by contacting that party directly or through an intermediary, and if it does so through an intermediary (another node or series of nodes on the network), the party can expect that the data will be transmitted without any interference or changes whatsoever. This includes any undue delay in transmission. We argue that, as part of a theoretical definition, disintermediation can be interpreted as a software policy, loose standing from the motivations, political or otherwise, of any party that engages with the blockchain system.

Distributed blockchain

The most common reference regarding the nature of the blockchain data structure among authors reviewed includes the notion of a *ledger*, *transaction ledger*, or *transaction record*, distributed or shared among the nodes of the peer-to-peer network. For example: "At the heart of these systems is a shared ledger that reliably records a sequence of transactions" (Chen & Micali, 2017, p. 1); "Every different user constitutes a network node and maintains a copy of the ledger" (Konstantinidis et al., 2018, p. 384); and "The information about every transaction ever completed in Blockchain is shared and available to all nodes" (Limata, 2019, p. 5). Other authors used the term *distributed database*, for instance: "A blockchain is a distributed ledger database" (Manski, 2017, p. 512), and "a distributed database of records" (Perwej et al., 2019, p. 82).

All these terms refer to the cryptographically linked, tamper-proof blockchain data structure identified in section 2. In the context of decentralisation in permissionless blockchain systems, the blockchain has no central custodian and is duplicated on many peers (but it need not be duplicated on all) on the peer-to-peer network.

Peer-to-peer network

A peer-to-peer network refers to the well-known network topology where no central node controls access to or data flow within a network (Schoder et al., 2005; Schollmeier, 2001). Logically it makes sense to argue that a peer-to-peer network is the only network topology that enables disintermediation because, if the network is hierarchical, the ability for stakeholders to interact with the network or transmit or receive data on the network will not meet the standard set for disintermediation (see above).

In the literature reviewed, the purpose of the peer-to-peer network was named in relation to the storage of copies of the blockchain (Boudguiga et al., 2017; Labazova, 2019), the verification of transactions, the recording of transactions, and the verification of the validity of the blockchain (Atzori, 2017; Nawari & Ravindran, 2019). We add to these functions the provision of disintermediated communication (data exchange) between stakeholders and components.

Algorithmic trust

Disintermediation requires a transparent method whereby parties can agree that additions to the blockchain are valid. This mechanism is called a consensus algorithm (Tschorsch & Scheuermann, 2016; Zheng et al., 2017) and constitutes a distributed protocol (Blocki & Zhou, 2016; Cachin & Vukolic, 2017) to deliver community trust (Aste et al., 2017). Many terms exist to summarise how participants in a permissionless blockchain system eventually agree on a single correct blockchain (transaction history) and verify that the blockchain has not been tampered with. In the reviewed literature, these descriptions included mostly references to cryptography, proof-based consensus, and trust by computation. The consensus process in a permissionless blockchain system aims to select the node that is allowed to add a block of transactions to the blockchain at random (Glaser, 2017). Essentially, the community of participants in a blockchain system accept a set of digital governance rules or "cryptolaw" (Rueda et al., 2020, p. 182), which will govern the system.

For this study and in the context of permissionless blockchain systems, we define algorithmic trust as a set of rules that disintermediated stakeholders share to manage the blockchain's extension and security. Logically these rules must be consistent (the same for all stakeholders), transparent (the details of how they work must be known to all stakeholders), and rigid (not changeable at the whim of any minority). However, algorithmic trust extends beyond the computational processes verifying and adding transactions or transaction blocks to the blockchain; the consistency, transparency, and rigidity requirements also apply to the communication protocols of the peer-to-peer network because these play a critical role in the disintermediation process.

Open-source principles

The meaning of open-source development (Glaser & Bezzenberger, 2015), open-source system (Lin & Liao, 2017), and developers operating on open-source principles (Tasca & Tessone, 2019) is more difficult to pin down into a single definition. Arguments will be presented in the discussion that the source code of the system must be open-source. This includes all modules that control communication, security, verification, and consensus. However, it goes beyond software. The entire decision-making structure of the developer community must be transparent. On the other hand, to demand that the decision-making structure must be open for participation by every stakeholder that wishes to do so seems more idealistic than practical.

5. Results

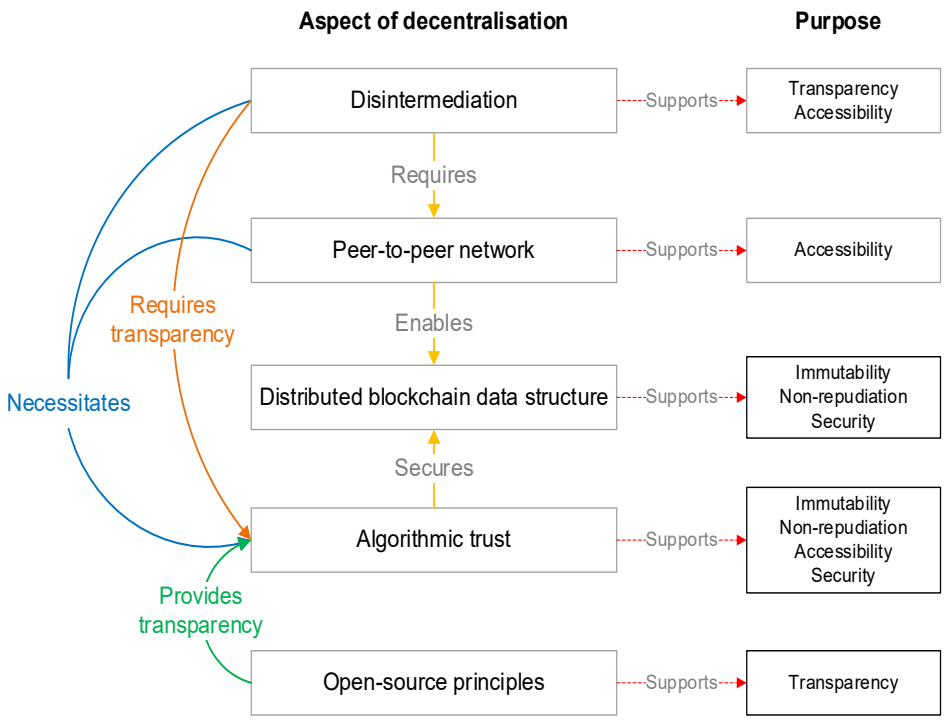
Armed with the five aspects of *decentralisation*, namely disintermediation, a distributed blockchain, a peer-to-peer network, algorithmic trust, and open-source principles identified from the literature (see section 4), it is now possible to construct a theoretical definition of the term *decentralised* or *decentralisation*, in the context of permissionless blockchain systems.

Decentralisation defined

The aspects of decentralisation are inextricable, and decentralisation cannot exist if any one aspect is lacking. However, a theoretical definition must explain not only which aspects are required, but also when and why each aspect is required and how it contributes to decentralisation. Figure 2 shows the interrelationships between the aspects of decentralisation and how these aspects support the purpose of a decentralised blockchain system.

The primary driver of the decentralisation process is the aspect of disintermediation at the top centre of Figure 2. The requirement that the blockchain system must be permissionless (by definition) is the reason why disintermediation is needed. Any party must be allowed to participate in the blockchain system *without the permission* of any other party. In practice, it means that the blockchain must, in the first instance, be available to anyone or any system that may want to use it for any purpose it may see fit – because no permission is needed. Secondly, disintermediation also means that any party can send valid data to any number of the nodes on the peer-to-peer network with the expectation that it will be propagated across the whole network and be accepted as part of the blockchain. Valid data refers to a transaction, a new addition to the blockchain, or any other data that may form part of the system's operation. The processing of any valid data by any source must be indistinguishable from any other valid data from any other source. In other words, disintermediation gives rise to a software policy of data and source equivalence. Disintermediation supports the permissionless blockchain system's purpose of transparency and access.

Figure 2: Interrelationships between the aspects of decentralisation and how they support the purpose of a decentralised blockchain system



Disintermediation creates the requirement for a peer-to-peer network—the second aspect of decentralisation in Figure 2. A peer-to-peer network requires no central authority to grant or deny access to any would-be participant. Peers on the network do not screen data in any way except for checking its validity according to the consensus rules of the system. It allows for the unencumbered flow of data between all the stakeholders in the system. The peer-to-peer network supports the permissionless blockchain system's purpose of accessibility.

A peer-to-peer network enables a distributed blockchain environment—the third aspect of decentralisation in Figure 2. The distributed blockchain ensures that the transaction data has no single custodian. A distributed blockchain contributes towards the blockchain system's purpose of security by providing redundancy of the blockchain and operational nodes. Since the blockchain is also a tamper-proof log of transactions, it also supports the purposes of immutability and non-repudiation.

The requirement for algorithmic trust is a consequence of disintermediation (the fourth aspect of decentralisation in Figure 2) and the peer-to-peer network. Since

no central authority exists in a permissionless blockchain system to serve as an authoritative source of truth concerning which information is to be trusted or not, it requires a mechanism for algorithmic trust. Algorithmic trust is the implementation of the software policy of data and source equivalence, the security protocols, and the communication protocols of the system (section 4). It provides both the mechanism for constructing valid data to be transmitted on the peer-to-peer network and the mechanism whereby all participants can verify the validity of data received. Algorithmic trust ensures accessibility through data and source equivalence, immutability through accessibility, and non-repudiation and security through data validation of transactions, new transaction blocks, and the blockchain.

In practice, algorithmic trust is the result of software programs that are executed by participants in the blockchain system. The programs may construct and broadcast new transactions to the peer-to-peer network, they may verify transactions and attempt to construct new blocks of transactions to add to the blockchain, they may broadcast new transaction blocks or new versions of the blockchain to the peer-to-peer network, or they may validate newly received transaction blocks or blockchain versions. In section 4, we argued that three requirements must apply to the rules that these software programs follow. The rules must be consistent (the same for all stakeholders), transparent (the details of how they work must be known to all stakeholders), and rigid (not changeable at the whim of any minority). These requirements necessitate that all stakeholders have access to the details of how algorithms are implemented in the code, and the permissionless blockchain system must therefore operate on open-source principles – the fifth aspect of decentralisation in Figure 2. Open-source principles ensure the transparency that is required by disintermediated parties to function in an environment of algorithmic trust. It is the pivotal aspect that allows permissionless blockchain systems to fulfil their purpose of transparency. Section 6 will explain, however, that this is the most precarious aspect of the decentralisation of a permissionless blockchain system.

Our definition of *decentralisation* in a permissionless blockchain system can be summarised as follows:

> *When a **distributed blockchain** data structure is implemented between **disintermediated** parties, it provides the basis for a decentralised blockchain system. This creates the logical requirement for a **peer-to-peer network** topology that serves to transmit data between parties and store the blockchain in a distributed manner. Since no central authority exists in this system to serve as an authoritative source of truth concerning which information is to be trusted or not, it requires a mechanism for **algorithmic trust**. This algorithmic trust mechanism must be auditable by any stakeholder in the system and must, therefore, operate on **open-source principles**. These five aspects are a minimum requirement to define a decentralised, permissionless blockchain system.*

5. Discussion

As the results have shown, the aspects of decentralisation are inextricable and thus cannot be viewed in isolation. If all five aspects of decentralisation are present, one may ask if it is enough to define the blockchain system as decentralised. The answer is no. One must consider the presence of the five aspects and their individual nature, which may be much more nuanced. For example, many consensus algorithms have been proposed for blockchain systems that operate between disintermediated parties. Two of the most prevalent are proof-of-work and proof-of-stake, which are both probabilistic. They aim to give all participants a random chance of adding a new block of transactions to the blockchain. However, this random chance does not mean equally probable for all participants; in fact, there may be significant discrepancies that give some parties a larger chance of proposing a block than others (Nguyen & Kim, 2018).

In the case of Bitcoin (using proof-of-work), it is generally accepted that when 51% of the computing power in the network is centralised, then the consensus mechanism loses its decentralised nature (Eyal & Sirer, 2014). Eyal and Sirer (2014) have, however, shown that even at concentrations as low as 25%, consensus can be manipulated to some extent in favour of some stakeholders. It shows that decentralisation is not a binary aspect (it exists on a spectrum (Walch, 2019)), and for any stakeholder to evaluate the decentralisation of algorithmic trust, the software needs to be open-source (so that its exact mechanics can be interrogated, as Eyal and Sirer (2014) have done).

Similarly, Di Bella et al. (2013, p. 21) have shown that evidence exists to indicate that a small core (concentrated group) of developers take the most important decisions about the *"architecture and evolution"* of open-source software projects. This type of centralised behaviour has many examples within the developer communities of Bitcoin and other blockchain systems. Gervais et al. (2014) and Walch (2019) warn that, despite the presence of open-source principles, the algorithmic trust mechanisms of both Bitcoin and Ethereum have been altered through the decisions taken by a small group of developers and miners. On the other hand, practical considerations regarding the maintenance of complex software systems preclude consultation with every stakeholder.

6. Conclusion

The introduction to this article identified the confusing nature of the term *decentralised* in blockchain literature and made the case for a proper definition of the term. A review of a large body of recent blockchain literature has identified five aspects (disintermediation, distributed blockchain, peer-to-peer network, algorithmic trust, and open-source principles) that are required for a permissionless blockchain system to be defined as decentralised. Table 1 shows that while many authors have some of these aspects in mind, very few refer to all of them in unison when claiming decentralisation. The confusion seems to arise from this incomplete description that is of-

ten used by authors. Perhaps the term is so ubiquitous that not much thought is given as to the details of its meaning. This study addresses the shortcoming by providing authors with a set of five aspects to consider when they refer to a permissionless blockchain system as decentralised, and therefore it contributes to the understanding of blockchain technology. The study goes further by describing the interrelationships between these aspects, acknowledging that the aspects are not of an entirely fixed nature and must be evaluated against the real-world practicalities that are faced by all complex systems.

This article represents an opening statement, a foundation on which arguments that seek to answer many unanswered questions about the implications of decentralisation and its building blocks may be built. Especially in the fields of blockchain governance and regulation, there remains much work to be done in the interpretation of these aspects and how they affect the legal standing of permissionless blockchain systems. It is also important to the ongoing search for better blockchain technology, such as data structures, cross-chain functionality, and consensus algorithms. Consideration should be given to the implications of these technological advances for the decentralised nature of the blockchain system.

We stopped short of investigating or making claims about the nature of decentralisation in the secondary layer of blockchain systems. This is an important shortcoming that must be addressed in future research efforts. Finally, while it was not the purpose of this article, the definition may also serve as a basis for refuting false claims about decentralisation in a blockchain system that is in fact not decentralised.

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Appendix: Listing of reviewed literature

Author(s)	Topic	Applicable layer	Type of literature[1]
1. Adhami et al. (2018)	Initial coin offerings	Primary	J
2. Alharby & Van Moorsel (2017)	Blockchain research theory	Secondary	J
3. Aste et al. (2017)	Blockchain impact on society and industry	Primary	J

Author(s)	Topic	Applicable layer	Type of literature[1]
4. Atzori (2017)	Decentralised governance	External Primary	J
5. Beck & Müller-Bloch (2017)	How society deals with blockchain	External Primary	C
6. Beck et al. (2016)	Application of blockchain	Primary	C
7. Bentov et al. (2016)	Cryptocurrencies, consensus protocols	Primary	C
8. Blocki & Zhou (2016)	Cryptocurrencies, consensus protocols	Primary	C
9. Boudguiga et al. (2017)	Application of blockchain	External Primary	C
10. Burilov (2019)	How society deals with blockchain	Secondary	J
11. Cachin & Vukolic (2017)	Consensus protocols	Primary	C
12. Calvão (2019)	Blockchain impact on society and industry	Primary	J
13. Chen et al. (2017)	Consensus protocols	Primary	C
14. Dai et al. (2019)	Application of blockchain	External Primary	J
15. Dierksmeier & Seele (2020)	Blockchain impact on society and industry	Primary	J
16. Gaggioli (2018)	Blockchain impact on society and industry	External	J
17. Glaser (2017)	Application of blockchain	Primary Secondary	C
18. Hackius & Petersen (2017)	Application of blockchain	External Primary	C
19. Holotescu (2018)	Blockchain impact on society and industry	External Primary	C

Author(s)	Topic	Applicable layer	Type of literature[1]
20. Homoliak et al. (2019)	Blockchain security	Primary	C
21. Inghirami (2018)	Blockchain impact on society and industry	Primary	C
22. Konstantinidis et al. (2018)	Application of blockchain	Primary	C
23. Kotobi & Bilén (2017)	Application of blockchain	Primary	C
24. Kuo et al. (2017)	Application of blockchain	Primary	J
25. Labazova (2019)	Blockchain research theory	External Primary	C
26. Lewenberg et al. (2015)	Blockchain data structures	Primary	C
27. Li et al. (2020)	Blockchain security	Primary	J
28. Limata (2019)	Blockchain impact on society and industry	External Primary Secondary	J
29. Lin & Liao (2017)	Blockchain security	Primary	J
30. Maas (2019)	How society deals with blockchain	Primary	J
31. Manski (2017)	Blockchain impact on society and industry	External Primary Secondary	J
32. Maume & Fromberger (2019)	How society deals with blockchain	External Primary	J
33. Nawari & Ravindran (2019)	Application of blockchain	External Primary Secondary	J
34. Nguyen & Kim (2018)	Consensus protocols	Primary	J
35. Niranjanamurthy, Nithya & Jagannatha (2018)	Blockchain research theory	Primary	J

Author(s)	Topic	Applicable layer	Type of literature[1]
36. Nofer et al. (2017)	Application of blockchain	External Primary Secondary	J
37. Perwej et al. (2019)	Blockchain impact on society and industry	External Primary	J
38. Rueda et al. (2020)	Application of blockchain	External Primary Secondary	J
39. Ali Syed et al. (2019)	Application of blockchain	External Primary Secondary	J
40. Tama et al. (2017)	Application of blockchain	External Primary	C
41. Tasca & Tessone (2019)	Blockchain taxonomy, ontology or classification	Primary Secondary	J
42. Tschorsch & Scheuermann (2016)	Blockchain taxonomy, ontology or classification	Primary	J
43. Tselenti (2019)	Blockchain impact on society and industry	External Primary	C
44. Xu et al. (2017)	Blockchain taxonomy, ontology or classification	Primary	C
45. Zheng et al. (2017)	Blockchain taxonomy, ontology or classification	Primary	C
46. Zheng et al. (2018)	Application of blockchain	Primary	J
Count (J = 26, C = 20)			

[1] J = Peer-reviewed journal article, C = Peer-reviewed conference paper

International Copyright Flexibilities for Prevention, Treatment and Containment of COVID-19

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Abstract
Most policymaking attention with respect to intellectual property barriers to COVID-19 prevention, treatment and containment has been focused on patents. This focus is reflected in the World Trade Organisation (WTO) Ministerial Decision on the TRIPS Agreement, adopted on 17 June 2022, which provides a limited waiver of TRIPS rules on compulsory licences for production of COVID-19 vaccines. The original WTO proposal for a TRIPS waiver, however, explicitly applied to all forms of intellectual property, including copyright. This article outlines the numerous ways in which copyright can create barriers to addressing COVID-19. It also provides a description of international copyright treaty provisions that permit uses of copyright materials in response to the barriers identified, despite the exclusion of copyright from the final TRIPS waiver.

Keywords
COVID-19, prevention, treatment, containment, vaccines, devices, tests, intellectual property, patents, copyrights, education, research

Acknowledgements
The article draws on the contents of the authors' 2021 PIJIP/TLS Research Paper (Flynn, Nkrumah, & Schirru, 2021). Research reported in this article was aided by members of civil society and academic networks of PIJIP's project on the Right to Research in International Copyright Law. The authors thank Teresa Hackett of EIFL, who advised on the literature examined and reported on in the article, and Prof. Jorge Contreras and Prof. Jonas Anderson for their comments and assistance

during the research. The researchers are grateful for the financial support provided by Arcadia, a charitable fund of Lisbet Rausing and Peter Baldwin, to PIJIP and PIJIP's Right to Research project.

DOI: https://doi.org/10.23962/ajic.i29.13985

Recommended citation
Flynn, S., Nkrumah, E., & Schirru, L. (2022). International copyright flexibilities for prevention, treatment and containment of COVID-19. *The African Journal of Information and Communication (AJIC), 29*, 1-19. https://doi.org/10.23962/ajic.i29.13985

1. Introduction

There is a growing understanding that COVID-19 vaccine patents—which cover inventions that were supported by substantial public funding—should be opened to competition in the public interest (see, for example, Buranyi, 2021; Tedros, 2021). This understanding is prominently expressed in the 2021 proposal by India and South Africa that the World Trade Organisation (WTO) implement a "Waiver from Certain Provisions of the TRIPS [Trade-Related Aspects of Intellectual Property Rights] Agreement for the Prevention, Containment, and Treatment of COVID-19" (hereafter "TRIPS Waiver") (WTO, 2021).[1] The final result was a June 2022 WTO Ministerial Decision (WTO, 2022), which waives a part of TRIPS rules on compulsory licenses for patents so as to allow developing countries to more freely import and export generic vaccines.

The logic underlying calls for suspension of certain intellectual property rules in relation to COVID-19 vaccine inventions rests on a weighing of the costs and benefits of granting exclusive rights to information. Generally, the protection of exclusive rights to use information resources may benefit social welfare through incentives to create information goods, even where some access to those goods is curtailed. But enforcement of exclusive rights can also cut the other way. Enforcement of too many intellectual property rights can raise the cost of innovation unduly, "with strong IPR enforcement actually deterring innovative efforts" (Dosi & Stiglitz, 2013, p. 22). Especially when applied in countries with high income inequality, strong intellectual

1 The 2021 proposal was a revised version of the original proposal made by the same two countries in 2020.

property rights can incentivise exclusionary pricing, causing undue economic and moral harm (Flynn et al., 2009; Pogge, 2005).

The economic and moral logic of opening intellectual property rights where necessary to promote the public interest is more broadly applicable. Copyright laws give authors of original expressive "works" an exclusive right to reproduce those works and make other uses of their expression. Copyright law, like patent law, contains numerous limitations and exceptions that allow certain uses of protected materials without permission of the right holder. All copyright laws permit quotation of works by others without licence, for example, because such use serves broader societal interests in free expression and information-sharing that outweigh the author's interest in compensation and control. Most copyright laws also permit unlicensed uses for education, research and other uses. But as described more fully below, such exceptions are, around the world, much less uniform than the quotation right. The COVID pandemic provides a unique window into the problems that inadequate copyright exceptions can cause.

This article surveys barriers to COVID responses that are posed by copyrights—barriers that would have been covered had the WTO adopted the broad TRIPS Waiver proposal from South Africa and India. Section 2 explains copyright dimensions that can prevent equitable participation in scientific research. Section 3 discusses copyright dimensions that can block the creation, marketing, and repair of health technology. Section 4 surveys the copyright dimensions that can frustrate online learning and research in the context of mandatory social distancing that, over the past two years, closed down many schools and cultural heritage institutions. Section 5 concludes with reflections on international copyright law provisions that make clear that countries are free to implement exceptions to permit essential activities, including through emergency regulations. It is hoped that this brief review of copyright problems and solutions to them can help policymakers respond to the immediate crisis as well as to review their laws to ensure adequate flexibility for serving the general public interest.

2. Copyright barriers to COVID-19-related research

Research is essential to development of vaccines and treatments, and to contributions to scientific progress. Such research may require access to copyrighted works. For example, advanced research methodologies using text and data mining (TDM) can require the copying of thousands and millions of copyright-protected works. But in many countries, these critical uses of research materials can be prevented through a lack of copyright permissions.

Access to research material

Health professionals rely on researchers to track a virus, identify vaccine and treatment candidates, and search for other clues as to how society can best respond. Researchers, in turn, rely for their study on access to materials through libraries and other repositories. During COVID, many of those repositories of knowledge were physically closed, cutting researchers off from the sources they needed for their study. This constraining of access to materials during COVID may help to explain why about a fifth of researchers globally reported that COVID significantly altered, or halted, their work (Rijs & Fenter, 2020).

Researchers and governments have called for voluntary efforts by publishers to provide open access to research materials and data, so as to aid the global fight against the pandemic (European Commission, 2020b; White House Office of Science and Technology Policy, 2020).[2] Many publishers responded by making publications relevant to COVID-19 freely available (Wellcome, 2020). However, the number of articles being made available through open-licensed platforms is diminishing over time. Brainard (2021) reports, for example, that the number of free-to-reads COVID-19 papers decreased from 85% in May 2020 to 77% in September 2021.

In the digital age, the closing of a physical library need not cut a researcher off from access to information. As described below, international copyright treaties include provisions permitting exceptions for public interest uses, including allowing for emergency access to copyrighted materials. Some repositories in countries with relatively open and flexible copyright exceptions adopted temporary digital access policies to aid researchers (HathiTrust, n.d.). But many copyright laws require libraries to restrict access to digital materials to "the premises" of the library.[3] In such countries, researchers may face significant hurdles in continuing their work when physical premises close, as occurred frequently during COVID.

Text and data mining (TDM)

Text and data mining—in which computational processes are used to derive data from or about a corpus of works—has been central to many research breakthroughs

2 A letter from the national science and technology advisors of 12countries to the members of the scholarly publishing community (13 March 2020), https://wellcome.org/sites/default/files/covid19-open-access-letter.pdf, called for action to open access to research materials to help scientists "to keep up with the rapidly growing body of literature and identify trends and relevant information in efforts to characterize this novel virus and address the associated global health crisis".

3 See, e.g., Australian Copyright Act, 1968 (Act No. 63, 1968, consolidated as of 1 January 2019) Art. 9(1)(v) (limiting the ability of libraries to communicate works in their collections "for the purpose of research or private study, to individual members of the public by dedicated terminals on the premises of establishments"); Law of Ukraine No. 3792-XII of 23 December 1993, on Copyright and Related Rights (as amended up to 26 April 2017) Art. 23 (limiting digital uses to "on the premises" of a library); and Kiribati Copyright Act 2018 (Act No 8/2018), Art. 20(4) (limiting educational uses to a "classroom").

regarding COVID-19. The outbreak was discovered by BlueDot, a Canadian TDM company that tracks emerging health threats by analysing "a variety of information sources, including chomping through 100,000 news reports in 65 languages a day" (Stieg, 2020). TDM projects, including machine-learning systems and computational analyses, have also "played an important role in the vaccine quest" (Waltz, 2020), including "helping researchers understand the virus and its structure, and predict which of its components will provoke an immune response" (Arnold, 2020).

Many of the materials used for COVID-related data mining projects are covered by copyright. These include the news articles mined by BlueDot and the scientific articles mined by vaccine researchers. Nearly every copyright law in the world has an exception allowing research uses of copyrighted works. But few of those research exceptions are broad enough to fully permit even non-commercial TDM research (see Carroll (2019), describing the flexibility in U.S. law as providing a "comparative advantage" for U.S. researchers and firms). The lack of copyright exceptions for text and data mining may be one reason that research on COVID has been primarily located in the U.S. and EU, where research exceptions are common. In July 2021, for example, a group of researchers in India was forced to retract a paper on vaccine hesitancy and COVID-19 because the group lacked a licence to mine a database of news articles used in the study (Retraction Watch, 2021).

3. Copyright barriers to COVID-19 vaccines and treatment

Uses of vaccines, treatments and devices are essential to saves lives threatened by COVID-19. Patents are not the only form of intellectual property that can prevent such uses. Copyright protections can also be a hindrance.

Algorithms for mRNA vaccines

Vaccine developers use computational algorithms in the creation of mRNA vaccines. Such algorithms aid in the identification of microRNAs (miRNAs) that "target gene expression at post-transcriptional level" (Ray & Pandey, 2017). Critical to this process is the use of computational algorithms and other research tools that have been identified as essential to understanding the virus and its structure (Waltz, 2020). Algorithms are subject to copyright protection in many countries, raising the possibility that even without patent barriers mRNA production can be blocked by a refusal to share essential intellectual property (see Asay, 2020; Michaels, 2018; Noto La Diega, 2018).

Product labels and package inserts

Labels and package inserts may be considered protected by copyright in some countries. A recent report by the WTO, the World Health Organisation (WHO), and the World Intellectual Property Organisation (WIPO) (2020) provides examples of litigation in South Africa and Australia that used such copyright claims to block generic entry into medicine markets. A South African court, for example, precluded a gener-

ic manufacturer from reproducing copies of package inserts for its generic antibacterial medicine—due to the existence of copyright coverage. Package inserts are often required by regulations to be included with marketed products, and thus a refusal to license reproduction of such inserts may block generic entry into the market. A similar decision was reached by an Australian court in 2011, prior to the amendment of the country's copyright legislation to permit the use of already existing product information. There is a similar history in the United States of pharmaceutical companies making (ultimately ineffective) copyright-protection claims on labels and inserts to block generic market entry (Rosen, 2017; Termini & Miele, 2013).[4]

Right to repair

COVID-19 has created a significant increase in the need for health professionals to repair ventilators and other devices. But copyright can stand in the way. Repair professionals often need access to manuals that are protected by copyright. Koebler (2020) describes how manufacturers have established a "repair monopoly […] by lobbying against legislation that would make it easier to repair machines, keeping access to repair guides out of the hands of independent repair professionals, and using software controls to limit who can perform repairs". In a recent example reported by the Electronic Frontier Foundation (EFF), a maker of sterilisation-related devices used during COVID treatment demanded that its products' documentation be taken down from an open-access repository (Walsh, 2020; Wheatley, 2020).

Ventilators and other medical devices may also have copyrighted software integrated into their operation (see Medtronic, n.d.). Accordingly, to repair such equipment, copyright permission to access the software and bypass technological protection measures may be required (see Grinvald & Tur-Sinai, 2019). The small number of instances of voluntary licensing of COVID-related software (see Baharundin, 2020; Bluetrace Protocol, n.d.) do not include the most-needed copyrighted software for COVID-related medical devices. A complaint to U.S. Congress by over 300 hospital repair experts (Proctor, 2020) led to the introduction of a bill to eliminate "liability under federal copyright law for creating an incidental copy of service materials or for breaking a digital lock during the course of equipment repair in response to COVID-19" (Wyden, 2020). Right to repair laws and regulations have been proposed in numerous other countries as well (see Moore, 2019; Montello, 2020).

3D-printing files and 3D-printed objects

3D-printing technology can produce replacement parts for ventilators and other devices. Copyright can cover the 3D digital file needed to print such objects, and copyright or design rights may cover the form and shape of the printed object (Malaty & Rostama, 2017). In one recent example in Italy, access to copyrighted files and man-

4 See, for example, *SmithKline Beecham Consumer Healthcare, L.P. v. Watson Pharm, Inc.*, 211 F.3d 21 (2d Cir. 2000), cert. denied, 531 U.S. 872 (2000), rejecting copyright claims to label information as grounds for restricting marketing of a generic drug.

uals needed to print ventilator valves was reportedly denied to researchers attempting to use 3D printing to fill critical parts shortages during the COVID-19 outbreak (see Brown, 2020; Urian B, 2020a, 2020b).

Equipment standards

The production of personal protective equipment (PPE) can be subject to copyright-protected standards that need to be licensed from standard-setting organisations. To address shortages of PPE, the European Committee for Standardisation and the European Committee for Electrotechnical Standardisation granted open access to their copyrighted standards for PPE production (European Commission, 2020a). The European Commission explained that "the derogation from this business model is a strong European response, based on a sense of social responsibility and solidarity, to address the shortage problem of protective equipment deriving from the Covid-19 epidemics" (European Commission, 2020a).

4. Copyright barriers to COVID-19 containment through social distancing

To promote social distancing during COVID, as encouraged by the WHO (2019), essential public institutions—including schools, universities, libraries, archives, and museums—were closed for extended periods. According to the UN (2020), COVID-19 "created the largest disruption of education systems in history", "affecting nearly 1.6 billion learners in more than 190 countries", "94 per cent of the world's student population", and "up to 99 per cent of students in low- and lower-middle income countries".

To enable essential activities like education and research to continue when physical institutions are closed, it is essential that copyright laws permit digital access for public interest uses such as education and research. The WIPO Copyright Treaty (1996) requires that its members' national laws provide copyright-holders with a right of "communication" or of "making available" of works through digital platforms. In the absence of an operative exception to this right, materials from a library or school cannot be shared online.

In response to COVID, some publishers have adopted voluntary efforts to make some works available for digital uses by libraries and schools, such as to conduct children's storytime readings online (see Access Copyright, n.d.1). But these efforts have been largely insufficient. In reviewing publishers' voluntary pledges to allow copyright-free educational uses of their materials, Craig and Tarantino (2020) find "that many titles in their catalogues are unavailable, certain publishers have made nothing newly available, and access to free volumes is stringently limited to particular audiences and for a specified time" (2020, p. 20). In the South African context, Nicholson (2020) reports that university professors faced problems obtaining permission for sharing of learning materials on password-protected e-learning platforms when physical reserves for course materials in the library were closed because of COVID.

5. Copyright flexibilities for COVID-19

Copyright law need not stand in the way of critical activities that are necessary to respond to COVID or to serve other public interests. Copyright laws, like laws on patents, are governed by international treaties that create certain minimum standards of protection that most countries have agreed to follow. The Berne Convention for the Protection of Literary and Artistic Works (1886) requires that all countries protect a right of authors to exclude others from reproducing their works.[5] The 1996 WIPO Copyright Treaty (WCT) requires its members to protect a right to exclude others from "communicating" a work, such as on the internet.[6] All of the activities described above, in sections 2 to 4 of this article, require either a reproduction or communication of protected works that could implicate the copyright protections that are internationally required in terms of the Berne Convention and the WCT. But these protections are not absolute. The international copyright architecture contains ample flexibility for countries to adopt exceptions to these rights to serve the public interest, including the particular public interest needs present in an emergency.

Reproductions

The Berne Convention was originally drafted in 1886 and has been subject to numerous amendments since then. The original Convention focused on ensuring that all countries treated foreign and local authors similarly through a so-called "national treatment" requirement. That version did not require countries to protect a right of reproduction, even though such a right was the core of most copyright laws at the time. It nevertheless included a specific exception, then in Article 8, safeguarding ability of each country to recognise "the liberty of extracting portions from literary or artistic works for use in publications destined for educational or scientific purposes".

The 1967 Stockholm revision of the Berne Convention added the right of reproduction in Article 9(1).[7] The Stockholm revision's Article 9(2) grants countries the general authority "to permit the reproduction of such works in certain special cases, provided that such reproduction does not conflict with a normal exploitation of the work and does not unreasonably prejudice the legitimate interests of the author". Furthermore, the Stockholm revision's Article 10(2) added a permissive exception for educational uses—allowing countries to authorise utilisation "by way of illustration in publications, broadcasts or sound or visual recordings for teaching".

5 Berne Convention for the Protection of Literary and Artistic Works (1886), https://wipolex.wipo.int/en/treaties/textdetails/12214

6 WIPO Copyright Treaty, Dec. 20, 1996. S. Treaty Doc. No. 105-17 (1997); 2186 U.N.T.S. 121; 36 I.L.M. 65 (1997), https://wipolex.wipo.int/en/treaties/textdetails/12740

7 Berne Convention for the Protection of Literary and Artistic Works (1886), as revised at Stockholm on July 14, 1967, https://wipolex.wipo.int/en/text/278720

Article 9(2) and 10(2) are open to a variety of public interest exceptions. Article 9(2) allows countries to permit reproductions of any work, by any user, for any purpose—as long as the other steps of the test protecting the author's rights are adhered to. Article 10(2) is restricted to educational uses, but similarly applies to a use of any work by any user. The terms are drafted in such a way that they are flexible enough to be applicable in the digital environment and to permit uses needed in a pandemic.

Communication to the public

The 1996 WIPO Copyright Treaty was the first to require copyright laws to protect an exclusive right of "communication to the public". The WCT was specifically crafted to apply on the internet—applying to acts of sharing "by wire or wireless means, including the making available to the public of their works in such a way that members of the public may access these works from a place and at a time individually chosen by them" (WCT, Art. 8). Thus, depending on how it is implemented in national law, the WCT's copyright protection of communication may restrict libraries, schools, and other institutions from sharing access to their collections digitally, including during COVID. This protection is not, however, absolute.

Like the Berne Convention, the WCT authorises limitations and exceptions to the communication right through an open exception:

> Contracting Parties may, in their national legislation, provide for limitations of or exceptions to the rights granted to authors of literary and artistic works under this Treaty in certain special cases that do not conflict with a normal exploitation of the work and do not unreasonably prejudice the legitimate interests of the author. (WCT, Art. 10(1))

Moreover, an agreed statement makes clear that WCT Contracting Parties may "carry forward and appropriately extend into the digital environment limitations and exceptions in their national laws which have been considered acceptable under the Berne Convention".[8] It is thus clear that countries may extend traditional exceptions, such as for educational and research uses, to digital uses. A country could, for example, permit course materials to be used online to the same extent as in a classroom, or permit libraries to share research materials digitally with their patrons.

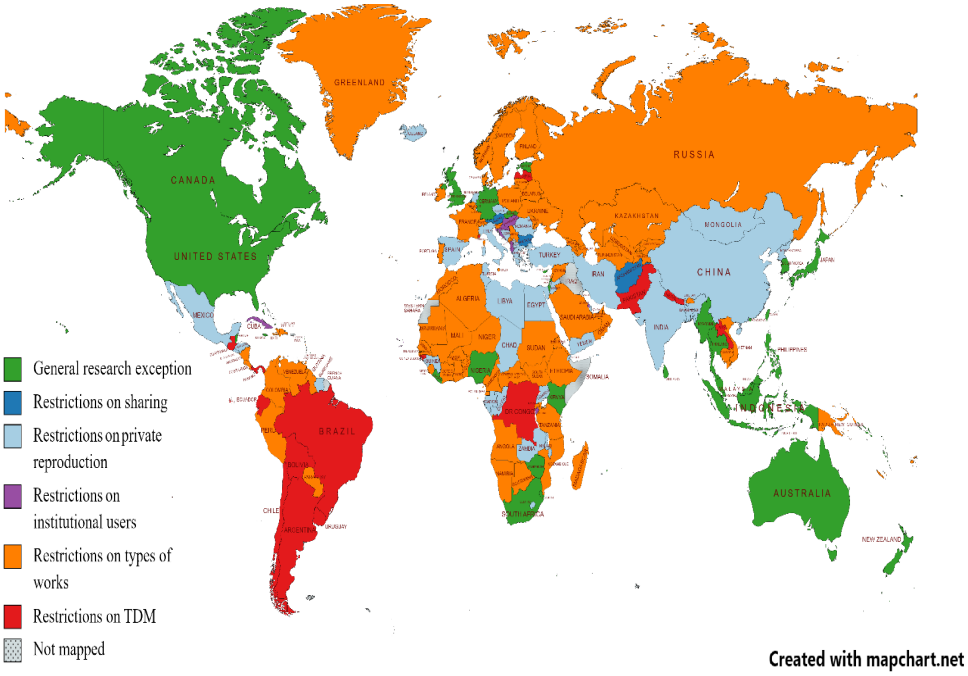
Emergency uses

Despite the flexibility provided for in international copyright legal instruments, many national copyright laws fail to provide adequate exceptions for modern digital uses. This is in part because many laws are highly specific as to the uses, works and users that may benefit from exceptions, thus not anticipating present needs (see Flynn et

8 See agreed statement on Article 10, in Agreed Statements Concerning the WIPO Copyright Treaty (adopted by the Diplomatic Conference on Dec. 20, 1996), https://wipolex.wipo.int/en/text/381455

al., 2022, describing measurements of the "openness" of limitations and exceptions.) A study by Flynn, Schirru, Palmedo and Izquierdo (2022) reviews research exceptions around the world and finds that while nearly every national copyright law has at least one exception that promotes uses for research purposes, very few (those in green in Figure 1) fully authorise the full range of research uses of all works by all users that are needed to engage in TDM and many of the other activities, as described above, necessary to respond to COVID.

Figure 1: Research exceptions in copyright law



Source: Flynn et al. (2022)

The lack of adequate limitations and exceptions for addressing COVID in many national copyright laws raises the question, under international law, of whether countries can take non-legislative measures to permit uses of copyrighted works during an emergency. One possible source of such authorisation can be found in Article 17 of the Berne Convention.

The WTO's June 2022 Ministerial Decision on the TRIPS Agreement (WTO, 2022) includes international recognition of an ability to administratively override patent rights:

> 2. For greater clarity, an eligible Member may authorize the use of the subject matter of a patent under Article 31 without the right holder's consent through any instrument available in the law of the Member such as executive orders, emergency decrees, government use authorizations, and judicial or administrative orders, whether or not a Member has a compulsory license regime in place. For the purpose of this Decision, the "law of a Member" referred to in Article 31 is not limited to legislative acts such as those laying down rules on compulsory licensing, but it also includes other acts, such as executive orders, emergency decrees, and judicial or administrative orders.

Although the WTO Ministerial Decision does not extend to copyright, a similar authorisation has long existed in Article 17 of the Berne Convention, which states:

> The provisions of this Convention cannot in any way affect the right of the Government of each country of the Union to permit, to control, or to prohibit, by legislation or regulation, the circulation, presentation, or exhibition of any work or production in regard to which the competent authority may find it necessary to exercise that right.

Article 17's authorisation of "necessary" measures to permit uses of copyrighted works by "regulation" and "legislation" parallels paragraph 2 of the 2022 WTO Ministerial Declaration. Article 17 permits a country to use general emergency authorities to interpret or declare copyright protections to not apply to certain necessary uses of materials.

At least three countries (the Dominican Republic, Cuba and Mexico) have implemented the Berne Convention's Article 17 in their national copyright legislation, permitting the executive to order the sharing of copyrighted works to promote critical public interests.[9]

One possible government response to COVID, in terms of Article 17, "to permit […] by […] regulation, the circulation, presentation, or exhibition of any work or production in regard to which the competent authority may find it necessary to exercise that right" could be a declaration that a copyright exception for uses "in the classroom" or "on the premises" of a library will be administratively interpreted as applying to digital access to the same extent as to person use. Alternatively, a

9 See the Dominican Republic's Law No. 65-00 on 21 August 2000, Art. 48; Cuba's Ley n. 14 de 28 de diciembre de 1977 de Derecho de Autor, Art. 37; and Mexico's Ley Federal del Derecho de Autor, publicada en el Diario Oficial de la Federación el 24 de diciembre de 1996, Art. 147.

government might declare that, during COVID, exceptions for "reproductions" for "research" should be interpreted as permitting TDM, and/or permitting the reverse engineering of software needed to repair critical devices.

6. Conclusion

Copyrighted works are critical non-patent forms of intellectual property that can be used to monopolise health markets and impede equitable responses to COVID. Copyrighted materials, including software, are essential for COVID-19-related research, for manufacture and repair of medical devices and equipment, for manufacture of mRNA vaccines, and for social distancing in education and other spheres required to contain outbreaks. Copyright issues were left out of the 2022 WTO Ministerial Decision implementing a limited waiver of TRIPS rules on the compulsory licensing of patents. However, that omission need not dissuade governments from acting. International copyright treaties contain flexibilities that permit exceptions to copyright protections for reproductions and digital communications, including through emergency decrees and executive action.

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Value Creation and Socioeconomic Inclusion in South African Maker Communities

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Abstract
In socioeconomic environments affected by high and persistent income inequalities and unemployment, there is a need for participative approaches to innovation in support of socioeconomic inclusion. This article explores the features of collective action, in support of socioeconomic inclusion, identified in South African maker communities. Drawing on data from interviews with participants in seven maker communities, the study explores the kinds of value that participants experience through being part of these communities. Value creation is assessed in terms of the five overlapping cycles of value that Wenger et al. (2011) propose are present in successful communities and networks: *immediate value*, *potential value*, *applied value*, *realised value*, and *reframing value*. The study finds that all five value cycles are present in the experiences expressed by the South African maker community participants. The value is found to be particularly pronounced in the *immediate value* and *applied value* cycles. In respect of socioeconomic inclusion, the findings point to strong currents of *social* inclusion in the *immediate value* cycle, and strong elements of both *social* and *economic* inclusion in the *applied value*, *realised value*, and *reframing value* cycles.

Keywords
maker communities, value creation, communities, networks, inclusion, socioeconomic inclusion, situated learning, social learning, community of practice, innovation, networking, collaboration, skills development, access to resources, South Africa

DOI: https://doi.org/10.23962/ajic.i29.14245

Acknowledgements
This study was carried out under the auspices of the Open African Innovation Research (Open AIR) network, which is a partnership between the University of Cape Town, the University of Johannesburg, The American University in Cairo, Kenya's Strathmore University, the Nigerian Institute of Advanced Legal Studies,

and the University of Ottawa. The authors acknowledge the support provided for this research by Open AIR, the Social Sciences and Humanities Research Council (SSHRC) of Canada, and the International Development Research Centre (IDRC). The authors also acknowledge the data transcription work provided by research assistant Outlwile Maselwanyane. Prof. Kraemer-Mbula is supported by the National Research Foundation of South Africa (Grant Number: 118873) through the DSI/NRF/Newton Fund Trilateral Chair in Transformative Innovation, the Fourth Industrial Revolution and Sustainable Development, at the University of Johannesburg. The views expressed in this work are those of the authors and do not necessarily represent those of the research funders.

Recommended citation
Armstrong, C., & Kraemer-Mbula, E. (2022). Value creation and socioeconomic inclusion in South African maker communities. *The African Journal of Information and Communication (AJIC), 29*, 1-25. https://doi.org/10.23962/ajic.i29.14245

1. Introduction

The maker movement extols the virtues of, *inter alia*, tinkering, do-it-yourself (DIY) innovation, consumers transforming themselves into creators, and peer-to-peer learning in hands-on environments, i.e., as the term suggests, *making* things for ourselves rather than going out and buying them ready-made (Anderson, 2012; Dougherty, 2012; Hatch, 2014). Sheridan et al. (2014) provide a usefully broad definition of making as "creative production in art, science and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products" (2014, p. 505). This article conceptualises maker communities, in accordance with the Sheridan et al. (2014) definition just quoted and as stated in De Beer et al. (2017), as "transcending specific disciplines to cover art, science, and engineering"; "applying creative skills using technologies and tools both digital and analogue, both virtual and physical"; and being driven "by values of collaboration, experimentation, and problem-solving" (De Beer et al., 2017, pp. 2–3).

While maker communities come in many different shapes and sizes, and with diverse orientations, tools typically found in their workspaces include digitally controlled tools such as 3D printers; laser-cutters; and computer numeric control (CNC) machining tools (e.g., drills, lathes, mills routers, vinyl cutters) for processing metals, plastics, wood, ceramics and composite materials; and non-digital tools such as welding equipment, sewing machines, soldering irons, saws, and other traditional fabrication tools. Having said that, some maker communities, such as the Our Workshop

community in South Africa that is part of this study, are not focused on the use of digital equipment and are, rather, focused almost entirely on non-digital tools for wood, metal, plastic and textile fabrication, using a mix of electrically powered and hand-powered analogue tools.

The first African Maker Faire (separate from the US Maker Faire brand) took place in Accra in 2009 (Maker Faire Africa, 2009), followed by Nairobi (2010), Cairo (2011), Lagos (2012), and Johannesburg (2014). The US-based Maker Faire organisation staged a Maker Faire in Cape Town in 2015 and a Mini Maker Faire in the same city in 2016.

The Open African Innovation Research network (Open AIR, n.d.), of which we are part, has, since 2016, been studying the maker movement in Southern, East, West, and North Africa, resulting in several publications (see Armstrong et al., 2018; De Beer et al., 2017; ElHoussamy & Rizk, 2020; Kraemer-Mbula & Armstrong, 2017; Schonwetter & Van Wiele, 2020). These publications explore African maker communities approaches to, inter alia, innovation, collaboration, skills development, knowledge appropriation (including intellectual property protection), and institutionalisation. The focus of this article is on maker communities' roles in value creation and, in turn, socioeconomic inclusion. The core question we applied to the collected data was: to what extent do maker communities generate value and social and economic upliftment for their participants? We qualitatively analysed interview data collected in terms of the five elements of value creation set out by Wenger et al. (2011, pp. 19–21): *immediate value*, *potential value*, *applied value*, *realised value*, and *reframing value*.

The next section of this article situates the Wenger et al. (2011) value creation framework within the literature on situated learning and communities of practice. Section 3 describes the research design, section 4 provides the findings, section 5 offers analysis, and section 6 concludes.

2. Analytical framework: Value creation in communities and networks

The Wenger et al. (2011) value creation framework deployed in this article has its origins in the study of situated learning and of situated/social learning in communities of practice.

Situated learning and communities of practice

Lave and Wenger (1991) position the concept of "situated learning" as

> a bridge, between a view according to which cognitive processes (and thus learning) are primary and a view according to which social practice is the primary, generative phenomenon, and learning is one of its characteristics. (Lave & Wenger, 1991, p. 34)

In line with their conceptualisation of situated learning, also known as social learning, Lave and Wenger (1991) advocate "shifting the analytic focus from the individual as learner to learning as participation in the social world" (1991, p. 43). Lave (1991) and Wenger (1998; 2000) also pioneer development of the now widely deployed notion of communities of practice. In the words of Wenger (1998):

> On the one hand, a community of practice is a living context that can give newcomers access to competence and also can invite a personal experience of engagement by which to incorporate that competence into an identity of participation. On the other hand, a well functioning community of practice is a good context to explore radically new insights without becoming fools or stuck in some dead end. (Wenger, 1998, p. 214)

As put more simply in Wenger et al. (2002):

> Communities of practice are groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis. (Wenger et al., 2002, p. 4)

The concept of communities of practice has since come to be applied to a wide range of settings. Koliba and Gajda (2019) document the concept's appearance in anthropology, business management, computer science, education, engineering, gender studies, health care, higher education, political science, public administration, social psychology, and social work (2019, pp. 99–100).

Maker communities as communities of practice

Sheridan et al. (2014), in examining the role of makerspaces in education, adopt the community of practice concept as one of their lenses. These authors argue for the relevance of the concept to making on the grounds that

> [t]he communities of practice framework, where learning is an ongoing part of social interaction rather than a discrete activity, allows us to see how different elements of makerspaces work in concert in each space. Specifically, it helps us frame how the shared use of space, tools, and materials; shifting teaching and learning arrangements; individual and collective goals; and emergent documentation of rules, protocols, and processes for participation and action work together to form each community of practice with its own particular features. (Sheridan et al., 2014, p. 509)

Galaleldin and Anis (2017) identify community of practice elements in the study of the role played by the University of Ottawa makerspace in the activities of the university's engineering students.

Maker communities of practice and socioeconomic inclusion

Poverty, inequality and social exclusion remain central and persistent challenges in South Africa. The country is ranked as the most unequal in the world (World Bank, 2022) and sustains one of the world's highest levels of unemployment, particularly among the youth and still largely correlated with racial constructs. It follows that large segments of society are excluded from economic opportunities, limiting individual outcomes. De Beer et al. (2017), in their study of the activities and dynamics of South African maker communities, also adopt the community of practice lens, and argue that a core objective of these communities of practice is socioeconomic inclusion. These authors write that "it is assumed that through engagement with the people, tools and activities available in a maker community, participants will enhance their economic and social circumstances" (De Beer et al., 2017, p. 34). In a context of extreme levels of socioeconomic inequality and exclusion, such as those present in South Africa, gaining access to knowledge, learning, social interaction, and livelihood opportunities, through participation in communities of practice, constitutes a potential route towards increased social and economic inclusion.

Value creation in communities and networks

The framework deployed in this article is taken from the report by Wenger et al. (2011) entitled "Promoting and Assessing Value Creation in Communities and Networks: A Conceptual Framework". Wenger et al. (2011) explain that their interest, in developing the framework, is in exploring

> the value that networks or communities create when they are used for social learning activities such as sharing information, tips and documents, learning from each other's experience, helping each other with challenges, creating knowledge together, keeping up with the field, stimulating change, and offering new types of professional development opportunities. (Wenger et al., 2011, p. 7)

Wenger et al. (2011) propose five "cycles of value creation" in communities and networks:

- Cycle 1: Immediate value: Activities and interactions: "Activities and interactions can produce value in and of themselves" (Wenger et al., 2011, p. 19);
- Cycle 2: Potential value: Knowledge capital: "Activities and interactions can produce 'knowledge capital' whose value lies in its potential to be realized later" (Wenger et al., 2011, p. 19);
- Cycle 3: Applied value: Changes in practice: "Looking at applied value means identifying the ways practice has changed in the process of leveraging knowledge capital" (Wenger et al., 2011, p. 21);

- Cycle 4: Realised value: Performance improvement: "what effects the application of knowledge capital is having on the achievement of what matters to stakeholders, including members who apply a new practice" (Wenger et al., 2011, p. 21); and
- Cycle 5: Reframing value: Redefining success: "The last cycle of value creation is achieved when social learning causes a reconsideration of the learning imperatives and the criteria by which success is defined" (Wenger et al., 2011, p. 21).

Wenger et al. (2011) specify that there is not a linear relationship between the five cycles they propose: "While there are causal relationships between the various cycles, it is important not to assume a hierarchy of levels or a simple causal chain" (2011, p. 21).

3. Research design

The research was qualitative and exploratory, with the primary data collected via formal, in-depth, semi-structured interviews with participants in South African maker communities.

Data collection

The data collection consisted of interviews conducted in 2018–19 with 37 participants from seven South African maker communities in two provinces: Gauteng and the Western Cape. Interviewees were recruited via purposive, snowball sampling based on contacts made during previous interviews with South African makers (Armstrong et al., 2018; De Beer et al., 2017; Kraemer-Mbula & Armstrong, 2017). Thirty-one of the 37 interviews were conducted on the premises of the interviewees' maker communities. Four interviews were conducted at non-maker-community locations, and two interviews were conducted remotely via online platforms. The interviewees provided informed consent to participate, and were provided with anonymity through the assignment of interviewee numbers (i.e., interviewee 1, interviewee 2, etc.).

Key themes covered in the interview protocol included: the participants' motivations for getting involved in a maker community; participants' experiences of learning and skills development through participation in the community; collaboration, idea-sharing, and knowledge-sharing through participation in the maker community; and the community's impact on participants' creativity, development and marketing of products, business prospects, enterprise development, income generation, and relationship with the formal sector. The questions did not follow the terminology from the Wenger et al. (2011) framework.

Table 1 provides details on the maker communities and the number of interviewees per community.

Table 1: Maker community names, locations, interviewees

Maker community	Location	No. of interviewees
Geekulcha (Makers Initiative and Raeketsetsa programmes)	The Innovation Hub, Lynwood, City of Tshwane (Pretoria), Gauteng Province	7
eKasi Lab Ga-Rankuwa	Ga-Rankuwa Arts and Crafts Centre, Pretoria North, City of Tshwane (Pretoria), Gauteng Province	2
TMG Makerspace (formerly Wits Digital Innovation Zone (DIZ) Maker Space)	University of the Witwatersrand (Wits) Tshimologong Digital Innovation Precinct, Braamfontein, Johannesburg, Gauteng Province	4
Maker Station	Woodstock, Cape Town, Western Cape Province	3
Our Workshop	Guga S'thebe Arts and Culture Centre, Langa, Cape Town, Western Cape Province	7
Workspace	Hout Bay, Western Cape Province	8
Knysna MakerSpace (formerly Kluyts MakerSpace)	Knysna, Western Cape Province	6

Twenty-six (70%) of the interviewees were (in terms of Statistics South Africa population categories) Black African or Coloured people, and nine (24%) were White people.[1] Given the persistence of racially-correlated divides in income and opportunity in South Africa (see World Bank, 2022), it was important to this study's focus on socioeconomic inclusion that it include a large number of non-White participants. Twenty-five (68%) of the interviewees self-identified as male, and 12 (32%) self-identified as female.

1 In South Africa, the racial constructs instituted during apartheid—in terms of which people were classified as being either Black African, Coloured, Indian/Asian or White—continue to be used today by Statistics South Africa (see Stats SA, 2021a; 2021b) and by academics and policy analysists in order to be able to, inter alia, track progress towards correcting the artificially created, racialised imbalances from the past.

All seven of the maker communities who participated in the study included low-income participants, in the following ways:

- eKasi Lab Ga-Rankuwa maker community: Based in an arts and crafts centre in the low-income settlement of Ga-Rankuwa (greater Pretoria) that, during the apartheid era, was part of the Bophuthatswana "homeland" populated by Black Africans who were forcibly relocated by the government.
- Our Workshop maker community: Working out of an arts and culture centre in the low-income township of Langa (in Cape Town) that was originally the product of government relocation of Black Africans.
- Workspace maker community: Based in a light industrial area of Hout Bay (15 km from Cape Town) adjacent to, and with members from, a low-income informal settlement.
- TMG Makerspace: Part of a university-led digital innovation hub in Braamfontein (central Johannesburg) and with makers from diverse backgrounds, including from Johannesburg's low-income central neighbourhoods and outlying townships.
- Geekulcha maker community: Based in a government-funded business park in Lynwood (Pretoria) and staffed by, and oriented towards, youth.
- Maker Station: Based in a light industrial section of Woodstock (Cape Town) and with participants from diverse backgrounds, including people living in the city's low-income areas and townships.
- Knysna MakerSpace: Based in a furniture woodworking complex in a light industrial area of the town of Knysna (500 km from Cape Town), and serving artisans from diverse backgrounds, including from the town's low-income areas.

Data analysis: Thematic coding

The 37 interviews, all conducted in English, were audio-recorded and transcribed. The master transcript of all of the interviewees' statements was then thematically coded using the NVivo qualitative data analysis software. The coding was conducted on a deductive basis, with codes applied to participant statements showing evidence of one of the five Wenger et al. (2011) value creation cycles—immediate value, potential value, applied value, realised value, and reframing value—and to themes within each cycle. Coding of statements in terms of a cycle (and a theme within a cycle) was guided by the "key questions" (see Table 2) and "typical indicators" (see Table 2) as set out for each cycle by Wenger et al. (2011, pp. 22–23, pp. 25–31).

Table 2: Questions and indicators for the thematic coding

Cycle	Key question(s)	Typical indicators
Cycle 1: Immediate value: Activities and interactions	**Wenger et al. (2011, p. 22):** "What happened and what was my experience of it?"	**Wenger et al. (2011, pp. 25–26):** • "Level of participation" • "Level of activity" • "Level of engagement" • "Quality of interactions" • "Value of participation" • "Networking" • "Value of connections" • "Collaboration" • "Reflection"
Cycle 2: Potential value: Knowledge capital	**Wenger et al. (2011, p. 22):** "What has all this activity produced?" "How has my participation changed me?" "How has my participation changed my social relationships?" "What access to resources has my participation given me?" "What position has the community acquired?" "How has my participation transformed my view of learning?"	**Wenger et al. (2011, pp. 27–28):** • "Skills acquired" • "Information received" • "Change in perspective" • "Inspiration" • "Confidence" • "Types and intensity of social relationships" • "Structural shape of networks" • "Level of trust" • "Production of tools and documents to inform practice" • "Quality of output" • "Documentation" • "Reputation of the community" • "New views of learning"
Cycle 3: Applied value: Changes in practice	**Wenger et al. (2011, p. 23):** "What difference has it made to my practice/life/context?"	**Wenger et al. (2011, p. 29):** • "Implementation of advice/ solutions/insights" • "Innovation in practice" • "Use of tools and documents to inform practice" • "Reuse of products" • "Use of social connections" • "Innovation in systems" • "Transferring learning practices"

Cycle 4: Realised value: Performance improvement	**Wenger et al. (2011, p. 23):** "What difference has it made to my ability to achieve what matters to me or other stakeholders?"	**Wenger et al. (2011, p. 30):** • "Personal performance" • "Organizational performance" • "Organizational reputation" • "Knowledge products as performance"
Cycle 5: Reframing value: Redefining success	**Wenger et al. (2011, p. 23):** "Has it changed my or other stakeholders' understanding and definition of what matters?"	**Wenger et al. (2011, p. 31):** • "Community aspirations" • "Assessment" • "Relationships with stakeholders" • "Institutional changes" • "New frameworks"

Source: Wenger et al. (2011, pp. 19–21)

Where it was found that a respondent statement was relevant to more than one value cycle (or more than one theme within a cycle), the statement was coded in terms of which cycle or theme it was most relevant to, i.e., each coded statement was only coded to one cycle and one theme within the cycle.

4. Findings

Value creation cycle 1: Immediate value: Activities and interactions (38 inputs, 21 respondents)

As seen above in Table 2, the guiding question for determining which interview data demonstrated the presence of the first value creation cycle—*immediate value*—was, as proposed by Wenger et al. (2011): *What happened and what was my experience of it?* Also guiding the coding were themes based on the nine types of indicators proposed by Wenger et al. (2011) for this cycle (see Table 2 above): *level of participation*, *level of activity*, *level of engagement*, *quality of interactions*, *value of participation*, *networking*, *value of connections*, *collaboration*, and *reflection*. It was found (Table 3) that the majority (59%, i.e., 22) of the respondents made statements coded as indicative of this value creation cycle, and that the three prominent themes present in the data for this cycle were *quality of interactions* (10 respondents), *networking* (7 respondents), and *collaboration* (6 respondents).

Table 3: Cycle 1 thematic findings

	Theme	% (no.) of respondents (N = 37)	No. of statements
Totals		**59% (22)***	**37**
Cycle 1: Immediate value: Activities and interactions	quality of interactions	(10)	12**
	networking	(7)	7
	collaboration	(6)	6
	value of connections	(4)	5***
	reflection	(4)	4
	value of participation	(2)	3***

* Some respondents made statements in more than one theme in this cycle.
**2 respondents each made 2 different statements coded to this theme.
*** 1 respondent made 2 different statements coded to this theme.

The strongest theme in this cycle, *quality of interactions* (10 respondents, 12 statements), was identified in statements such as these:

> When you sit across [from] other people, you see your own type. […] So you are able to appreciate other people, who are working on a similar course as yourself, and you draw in from them. […] You want to do something better. You want to improve your design. (interviewee 1)

> We push each other to grow. That's what I enjoy most. (interviewee 2)

> Some people […] want the friendship aspect of it. […] It can be very lonely to be a maker. I remember the time when I was working from home, on my own […]. When I compare being at home to being here, there's more people where you can just say "well, what do you think of this?" It's a quick question. Whereas before, I'd have to wait, and then the moment is gone. (interviewee 22)

> It's fun. We have a lot of fun, creating and making stuff together, and teaching each other as well. That's my biggest thing that I go home every day with, is how much I have learned from other people, and I'll be so bold as to say how much they have learned from me. So we are […] spreading our knowledge with each other. Right from the youngest guy who started at the beginning of the year to the oldest guy […]. We're teaching each other new things every day. (interviewee 23)

> We also share our personal things […]. Because sometimes, although it's said that when you go to work you should leave your problems at home, but you can carry them regardless. So sometimes we share things, [like things] which are stressing me with my house. Maybe it's my kid, she's sick, and I don't have money […]. Maybe then I get advice, because maybe the person has already gone through that situation. (interviewee 30)

> Everyone's mentoring someone. It's amazing […]. It is a constant exchange, really. […] Pretty much all of the members, the adult members, have been teaching younger kids […] different skills. (interviewee 36)

The second-most prominent theme in this value creation cycle, *networking* (7 respondents, 7 statements), was found to be present in the following statements:

> I never networked before. I was just [with] friends. But now, since I came to [this maker community], I've been networking with people who are into business, who are into different businesses. There's a huge difference between seven months ago and now, in terms of networking. […] Now I have the links for the CEO of different companies, people who are working for different companies. (interviewee 5)

> Mostly I hear a lot of ideas from other people. There are people who come here, they do all sorts of things. […] We network, we discuss ideas. […] That's where I learn, and that's where I grow, from other people. (interviewee 12)

> [The maker community manager] sometimes takes us for marketing, to the markets. Then we meet many of the vendors. Then we communicate, we network, then we learn more from others, […] even also [for] improving our products. (interviewee 32)

> Networking […], that is a big thing within our space. […] Because, I think, within our space, […] it is very important to actually get help when you need [it], be it from the internet or within your network. Because we constantly are solving problems, you will always run into problems. So it's comforting when you have some people, or a […] community, that is able to jump in and help you when you need that kind of help. (interviewee 35)

> Network capital in some instances is more important than financial capital, because, you know, if somebody […] gives you a buyer in your network, and somebody gives you a buyer with access to material, you're in a state of flow, you're not stuck […] There's networking with other makers, but there's also networking with suppliers. (interviewee 37)

Statements coded to *collaboration*, the third-most prominent theme in this value creation cycle (6 respondents, 6 statements), included:

> We share, we're sharing quite a lot. I don't think there was ever a moment where I needed, for example, help with something and I felt like I was bothering anyone. It always felt like these guys are here and they are willing to help whenever I have a problem. […] You actually get excited because you know you're going to get more ideas, you're going to get more ways of doing this thing. So, that is the culture that is in […] this space. (interviewee 3)

> Back then at school, I used to hate teamwork, I used to hate groups. But when I came here [to the maker community], I started enjoying it. […] Because back then, at school, we used to do maybe a group of five people for a project, then we will find that only two people, they are dedicated. The rest are not even into the project. So when I came here […], you find that all of us we are working on the same thing every day. So all of us, we are dedicated. (interviewee 5)

> It usually starts with a conversation. […] The creative process […] starts with two people. (interviewee 14)

> The benefits of working as a group. Sometimes you get stuck on working on something. And people can see that you are frustrated. […] And then maybe they say "no, man, why don't you use something else, incorporate another material?" […] From that collaboration of those two people, then you find that […] that product is selling much more. (interviewee 30)

Value creation cycle 2: Potential value: Knowledge capital

The guiding questions for determining which interview data demonstrated the presence of the second value creation cycle—*potential value*; *knowledge capital*—were, as proposed by Wenger et al. (2011) (see Table 2): *What has all this activity produced? How has my participation changed me? How has my participation changed my social relationships? What access to resources has my participation given me? What position has the community acquired? How has my participation transformed my view of learning?* Also guiding the coding were themes based on the 13 types of indicators proposed by Wenger et al. (2011): s*kills acquired*, *information received*, *change in perspective*, *inspiration*, *confidence*, *types and intensity of social relationships*, *structural shape of networks*, *level of trust*, *production of tools and documents to inform practice*, *quality of output*, *documentation*, *reputation of the community*, and *new views of learning*. It was found (Table 4) that 43% (16) of the South African respondents made statements coded as indicative of this value creation cycle, and that the two prominent themes in this cycle were *skills acquired* (9 respondents) and *access to resources* (6 respondents).

Table 4: Cycle 2 thematic findings

	Theme	% (no.) of respondents (N = 37)	No. of statements
Totals		**43% (16)****	**25**
Cycle 2: Potential value: Knowledge capital	skills acquired	(9)	11***
	access to resources*	(6)	6
	confidence	(2)	2
	reputation of the community	(2)	2
	new views of learning	(2)	2
	change in perspective	(1)	1
	level of trust	(1)	1

* This theme is drawn from Wenger et al.'s (2011) guiding question "What access to resources has my participation given me?"

** Some respondents made statements on more than one theme in this cycle.

*** 2 respondents each made 2 statements coded to this theme.

The strongest theme in this cycle, *skills acquired* (9 respondents, 11 statements), was identified in statements such as these:

> I am starting to use […] things I never used before. The skills set has increased, being in this space. (interviewee 1)

> [At the hackathon] I learned how to be a presenter. I was shy. I couldn't talk to people in [large groups]. But that day I actually had to remove my cold feet and stand up for the group. (interviewee 7)

> [I have learned] how to work with people. [Before I was] not so good, didn't talk to people whatsoever. […] A lot of people, yeah, come in here and work here, [and I] work with them, teach them how to work with something. […] We teach some kids here. We teach them, like, to do woodwork, and metalwork, whatever there is for them to do, and even leather work and stuff like that […], [skills] that I've learned here. (interviewee 17)

> A lot of things, I've learned here. Not [every skill] I can use it right now, but […] maybe in future, I can use. And I keep on learning, every day. (interviewee 33)

> The makerspace helped me, in the sense that it taught me the ability to socialise with people. That's the first thing. It taught me to also be able to share with people. And sharing [with] people means learning from them. So it upskilled me a lot in terms of my skills, technically, industry-wise, and also just general logic-wise. It helped me in that sense. Because […] you can't grow as quick if you are alone, [rather] than when you have someone to grow with. It's much quicker, it's much easier, and it's much more fun. (interviewee 34)

Statements demonstrating the second-strongest theme, *access to resources* (6 respondents, 6 statements), included:

> Basically our mission was, from the beginning, to give people access to reasonable workspace, to the equipment they won't normally be able to access, and to the expertise. And that expertise has been growing and in the network of members, the network of makerspaces, the network of suppliers. […] (interviewee 13)

> We worked from our house, from our garage. But then, the area we're in, they keep on stealing the tools. […] They keep on breaking in and stealing the drill, or steal this and that. So when I heard of this place [the makerspace], I immediately jumped. […] It's going great. I even have a couple of new customers. (interviewee 21)

> I've always just had a workshop on my own. So when I saw this [the makerspace] (a) it was available, and (b) I've seen the benefit of having more tools, or the use of more tools than you own. (interviewee 24)

> That time, with my budget, I [did not have] enough funds to rent a space, like a workshop, on my own. So someone just, a friend of mine, I think he had a project here [at the makerspace] once before […] he gave me the address […]. I had no idea that there was a place like [this] where you could just rent, like, a cubicle. It was perfect because of my budget, mainly, and at that moment I just wanted a space where I can just push my work. (interviewee 33)

> So we think that a makerspace like ours is a very useful tool in the many things that we need to do to start creating […] inclusion […]. It gives people access to markets, it's giving people access to knowledge that they would not ordinarily have, about how to make things, methods. It's giving them access to technology, and access to business services […]. And it gives them access to a network. (interviewee 37)

Value creation cycle 3: Applied value: Changes in practice

The guiding questions for determining which interview data demonstrated the presence of the third value creation cycle—*applied value: changes in practice*—were, as proposed by Wenger et al. (2011) (see Table 2): *What difference has it made to my practice/life/context?* Also guiding the coding were themes based on the seven types of indicators proposed by Wenger et al. (2011): *implementation of advice/solutions/insights*, *innovation in practice*, *use of tools and documents to inform practice*, *reuse of products*, *use of connections*, *innovation in systems*, and *transferring learning practices*. (The "use of connections" theme was a slight variation on the "use of social connections" indicator proposed by Wenger et al. (2011), i.e., with the "social" qualifier removed.) It was found (Table 5) that nearly half (49%, i.e., 18) of the respondents made statements coded as indicative of this value creation cycle, and that the clearly most prominent theme in this cycle was *innovation in practice* (11 respondents).

Table 5: Cycle 3 thematic findings

	Theme	% (no.) of respondents (N = 37)	No. of statements
Totals		**49% (18)***	**21**
Cycle 3: Applied value: Changes in practice	innovation in practice	(11)	11
	innovation in systems	(3)	4**
	implementation of advice/solutions/insights	(3)	3
	use of connections	(2)	3***

* Some respondents made statements in more than one theme in this cycle.

** 1 respondent made 2 statements coded to this theme.

*** 1 respondent made 2 statements coded to this theme.

Statements demonstrating the strongest theme in this cycle, *innovation in practice* (11 respondents, 11 statements), include:

> With that [a CNC machine], we've been making quite a bit of stuff. […] We actually make what I call a "d-board", and it's for disabled people in wheelchairs. So it comes across the front of them […] and it is where they would either eat their lunch, draw, have laptops, that sort of thing. (interviewee 23)

> An innovation that I actually did, […] it's a device that senses leakages […] in pipes, [using] bottle caps actually. And […] it was based on the idea that, from a science point of view, you have salt that conducts electricity, so how about coating those sensing points with salt, so that as soon as water comes there, it's a connection? […] It was a great innovation for me. […] And the idea came from [discussions with] high school students, who thought "we have leakages in every corner with the municipality pipes, let's come up with something". […] It's very relevant, and it's something that I'd actually love to see myself [patenting] and taking into industry. I feel like it's relevant for our current situations, and future situations as well. […] I call it the "leakage sensor". […] (interviewee 34)

> The product I am working with now currently are your milk cartons, and your juice cartons, and your wine cartons. So what I make with those, I make bags, I make wallets, I make a big sheet, which that sheet you can use as a table cloth, you can use as a mat, you can use as a blanket. For instance, if you are a person that sleeps with a little blanket or hot water bottle, if you put that sheet in between your blankets and you go in, it holds your body heat, immediately […] Then also it works for insulation, if you are a person who likes to go camping on the mountains. […] You can use it for the floor, or just the tent, around the tent, inside for insulation, so that at least it can be a little bit warmer than normal. […] Depending how creative you are, you can make many things with that product, of milk cartons. (interviewee 30)

Value creation cycle 4: Realised value: Performance improvement

The guiding question for determining which interview data demonstrated the presence of the fourth value creation cycle—*realised value: performance improvement*—was the question proposed by Wenger et al. (2011) for this cycle (see Table 2 above): *What difference has it made to my ability to achieve what matters to me or other stakeholders?* Also guiding the coding were themes based on the four types of indicators proposed by Wenger et al. (2011) for this cycle: *personal performance*, *organisational performance*, *organisational reputation*, *knowledge products as performance*. It was found (Table 6) that just over a third (35%, i.e., 13) of the respondents made statements coded as indicative of this cycle, and the clearly most prominent theme was *personal performance* (11 respondents).

Table 6: Cycle 4 thematic findings

	Theme	% (no.) of respondents (N = 37)	No. of statements
Totals		**35% (13)***	**17**
Cycle 4: Realised value: Performance improvement	personal performance	(11)	13**
	organisational performance	(4)	4

* 2 respondents made statements in more than one theme in this cycle.

** 2 respondents each made 2 statements coded to this theme.

The following are examples of statements demonstrating the dominant theme in this cycle, *personal performance* (11 respondents, 13 statements), include:

> Today, I would argue, I'm not, I'm far better than I was, but I'm not super rich at all, by any stretch. But I'm more comfortable, and for me, that means, okay, I have more money to buy things I want to buy. Because all my resources end up being electronic devices. Any money that I have, I'm buying something to, that is going to help. […] Without this space, I would definitely be behind. I would argue I would still be struggling. (interviewee 1)

> From this place [the makerspace] I can earn a living, yes, I can pay my rents. (interviewee 12)

> It was good [joining the maker community]. I started developing, thinking, my mind started developing. I started seeing things in different ways, like to share a space, to communicate with people. […] [Before] I was just doing my thing [painting], not trying to sell, just doing it, for the love. [Now] I'm selling. […]. I'm doing portraits, and I mix media, I take oil pastel, craft paint, fabrics, yeah I mix with fabrics. So yeah, I sold three paintings in one day the other day. (interviewee 28)

> For me, it [joining the maker community] actually opened many doors. […] You know that when you are part of [the maker community], you are not that employed. You part of, you are a member, but not employed. So you make your own money, by your movements. (interviewee 31)

Value creation cycle 5: Reframing value: Redefining success

The guiding question for determining which interview data demonstrated the presence of the fifth value creation cycle—*reframing value: redefining success*—was, as proposed by Wenger et al. (2011) (see Table 2): *Has it changed my or other stakeholders' understanding and definition of what matters?* Also guiding the coding were themes based on the five types of indicators proposed by Wenger et al. (2011) for this cycle (see Table 2): *community aspirations*, *assessment*, *relationships with stakeholders*, *institutional changes*, and *new frameworks*. It was found (Table 7) that only 22% (8) of the respondents made statements coded as indicative of this cycle, and the strongest theme in this cycle, *changed understanding/definition of what matters*, was found in statements by only 5 respondents.

Table 7: Cycle 5 thematic findings

	Theme	% (no.) respondents (N = 37)	No. of statements
Totals		**22% (8)***	**14**
Cycle 5: Reframing value: Redefining success	changed understanding/ definition of what matters	(5)	5
	community aspirations	(3)	5**
	institutional changes	(2)	2
	new frameworks	(2)	2

*4 respondents made statements in more than one theme in this cycle.
**1 respondent made 3 statements coded to this theme.

Among the statements demonstrating the strongest theme in this cycle, *changed understanding/definition of what matters*, is the following:

> My dream, I want to […] advance, because now, technology, I try to catch up with technology. Because I hope I'm going to go back to Zimbabwe. So I want to go with the full equipment, [for] starting something. (interviewee 16)

> [I enjoy] to help young kids, to collect plastic to do artworks, and then I'm showing them how to melt the plastic, how to use pliers with the wires. I'm so happy. Because when I'm working alone there in my house I'm so bored, so I don't like to work alone, I want to work with the community. […] It's my talent. I didn't go to school to learn how to use the pliers, how to use wire to make sculpture. It's my gift from God, so I am supposed to give to young kids to do this. […] I didn't finish high school. I was dropping [out in] Grade 11. (interviewee 27)

5. Analysis

As summarised in Table 8 below, the most prominent cycle of value creation identified through the thematic analysis was cycle 1 (present in statements by 59% of the respondents), followed by cycle 3 (49%), cycle 2 (43%), cycle 4 (35%), and, finally, cycle 5 (22%). It should be remembered that Wenger et al. (2011) do not propose a linear relationship among the cycles, i.e., the first cycle does not have to lead to the second cycle, and so on.

Table 8: Overview of findings: Percentage (no.) of respondents per value creation cycle

Cycle	% (no.) of respondents (N = 37)
Cycle 1: Immediate value: **Activities and interactions**	59% (22)
Cycle 3: Applied value: **Changes in practice**	49% (18)
Cycle 2: Potential value: **Knowledge capital**	43% (16)
Cycle 4: Realised value: **Performance improvement**	35% (13)
Cycle 5: Reframing value: **Redefining success**	22% (8)

We now consider the findings in each of the five cycles, in descending order of prominence in the data, with particular attention to what the findings reveal about elements of social and economic inclusion.

Cycle 1: Immediate value (59% of respondents)

In the most prominent cycle in the findings, *immediate value*, the three dominant themes (as seen above in section 4) are *quality of interactions*, *networking*, and *collaboration*. The prominence of these three themes aligns with the Wenger et al. (2011) emphasis, in their framing of cycle 1, on "collective reflection", cooperation "on seeking innovative approaches", and feelings of relief and inclusion that come from "being with others who understand one's challenge" (2011, p. 19). The prominence of the *collaboration* theme is also consistent with findings from earlier research into the dynamics of maker communities in South Africa (Kraemer-Mbula & Armstrong, 2017; De Beer et al., 2017; Armstrong et al., 2018).

The strongest theme running through the data for this cycle, *quality of interactions* (10 respondents, 12 statements), includes strong *social* inclusion dynamics, in statements (see section 4) such as "[s]ome people […] want the friendship aspect of it. […] It can be very lonely to be a maker" (interviewee 22), "[i]t's fun. We have a lot of fun, creating and making stuff together" (interviewee 23), and "[w]e also share our personal things […]. Because sometimes, although it's said that when you go to work you should leave your problems at home, but you can carry them regardless" (interviewee 30).

Cycle 3: Applied value (49% of respondents)

In the second-most prominent cycle in the findings, *applied value*, the dominant theme (as seen in section 4) is *innovation in practice.* The prominence of this theme is to be expected, given that a core maker movement objective is fostering innovation. (It bears mentioning here that the Wenger et al. (2011) framework is designed to be applicable to a wide range of networks and communities, including those not having innovation as a core mandate.) It is notable that many of the innovations cited by respondents are innovations that have already been taken to market, i.e., innovations that are earning economic returns for the maker community participants, and thus generating elements of *economic* inclusion. This economic inclusion dimension emerges even more strongly in the findings for *cycle 4: realised value* (see discussion later in this section).

Cycle 2: Potential value (43% of respondents)

In the third-strongest cycle, *potential value*, the two dominant themes (as shown in section 4) are *skills acquired* and *access to resources*. The prominence of the *skills acquired* theme aligns with the Wenger et al. (2011) emphasis on "[p]ersonal assets (human capital)", which "can take the form of a useful skill". The prominence of the *access to resources* theme links to the Wenger et al. (2011) emphasis, in their conception of this cycle, on how "[p]articipating in a community or network gives one privileged access to certain resources" (2011, p. 20). Both these themes carry strong potential *social* and *economic* inclusion dimensions.

Cycle 4: Realised value (35% of respondents)

Elements of socioeconomic inclusion emerge most strongly in the findings for this *realised value* cycle, in which *personal performance* is the strongest theme. There are clear elements of both *social* and *economic* inclusion in statements such as these that are cited above in section 4 as illustrations of the *personal performance* theme: "[w]ithout this space, I would definitely be behind. I would argue I would still be struggling" (interviewee 1), "From this place [the makerspace] I can earn a living, yes, I can pay my rents" (interviewee 12), and "[before] I was just doing my thing [painting], not trying to sell, just doing it, for the love. [Now] I'm selling. […]" (interviewee 28).

But, at the same time, it must be noted that this *realised value* cycle was only found to be present in the statements of just over a third of the respondents, suggesting that roughly two-thirds of respondents were not yet at the point where their participation in a maker community was leading them to fully experience what Wenger et al. (2011) frame as "the application of knowledge capital" resulting in "achievement of what matters to stakeholders".

Cycle 5: Reframing value (22% of respondents)

Socioeconomic inclusion dynamics also seem to be in evidence in the respondent statements coded to this cycle, *reframing value*, specifically in the statements coded to the strongest theme in this cycle, *changed understanding/definition of what matters.* The statements coded to this theme, as set out above in section 4, show evidence of high levels of self-actualisation and ambition that would only seem possible from individuals with a strong sense of *social* and *economic* inclusion, e.g., statements such as "I hope I'm going to go back to Zimbabwe. So I want to go with the full equipment, [for] starting something" (interviewee 16), and "It's my gift from God, so I am supposed to give to young kids to do this" (interviewee 27).

6. Conclusions

Through the application of the Wenger et al. (2011) value creation framework to data from interviews with participants in seven maker communities in South Africa, this study has established that the value that makers gain from their participation in these communities can usefully be understood in terms of five value creation cycles: *immediate value*, *potential value*, *applied value*, *realised value*, and *reframing value*. This study has also identified two value cycles in particular, *immediate value* and *applied value*, as being highly relevant to understanding the dynamics at play in the studied maker communities—because these two cycles were found to be present in the statements of, respectively, 59% and 49% of the respondents. In respect of the other focus of this study—on the roles that maker communities can potentially play as agents of socioeconomic inclusion for their participants—the findings of this study point to strong currents of *social* inclusion in the *immediate value* cycle, and strong currents of both *social* and *economic* inclusion in the *applied value*, *realised value*, and *reframing value* cycles.

As detailed above, 70% of the study respondents were (using Statistics South Africa terminology) Black African or Coloured people. In their interview responses, it was clear that the vast majority of these participants were socioeconomically vulnerable—in keeping with the South African reality, also detailed above, wherein the country's inequality statistics are the world's worst and poverty remains, to a great extent, correlated with racial categorisations. Accordingly, it is significant that this

research found that participation in the studied maker communities had a strong potential to create value for the participant—and also strong potential, as a cross-cutting element of value creation, to be a pathway towards increased social and/or economic inclusion. These findings on the efficacy of maker communities merit strong consideration by any South African actor—be they in the public, private, or civil society sector—seeking to identify tangible entry points for supporting low-income innovators striving towards socioeconomic inclusion.

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Exploration of Public-Speaking Anxiety among Novice Instructors at a Ghanaian University

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Abstract
Glossophobia, or the fear of public speaking, has been researched more among students than among their instructors. This interpretive case study focuses on the latter group by examining their lived experience with public-speaking anxiety. The research involved 12 newly employed assistant lecturers at the University of Cape Coast (UCC), a Ghanaian public university. Data were collected through in-situ direct observation during instructional hours and in-depth interviews with the participants. The study identifies three main causes of anxiety among the participants, namely (1) unpreparedness and/or lack of adequate preparation; (2) fear and diffidence; and (3) perceived intimidation by the audience. The study also finds that these public-speaking challenges can be overcome through frequent practice, active engagement with the audience, and adequate preparation.

Keywords
public speaking, anxiety, glossophobia, strategies, university instructors, Ghana

DOI: https://doi.org/10.23962/ajic.i29.13772

Recommended citation
Coker, W. (2022). Exploration of public-speaking anxiety among novice instructors at a Ghanaian university. *The African Journal of Information and Communication (AJIC), 29*, 1-15. https://doi.org/10.23962/ajic.i29.13772

1. Introduction

Anxiety about speaking in public, also called glossophobia, has attracted considerable interest among researchers. LeFebvre et al. (2018) describe public-speaking anxiety as a type of communication anxiety that stimulates excessive physiological arousal and/or negative cognitive thoughts. This is because as soon as a person's mind becomes victim to anxiety's grip and is uncontrolled, the subject's ability to freely articulate their thoughts is affected. Individuals with public-speaking anxiety usually experience a number of symptoms, including palpitations, sweating, discomfort, diarrhoea, and confusion (Bodie, 2010; Dansieh et al., 2021; Hook et al., 2013). Anxiety may not always be negative; in some contexts, anxiety helps the individual to be fully prepared for the task ahead of them (Gregersen & Horwitz, 2002).

The apprehension that usually accompanies a speaking performance can be inhibiting. Kankam and Boateng (2017) note that it can prevent persons from succeeding professionally or academically. Yet, although public-speaking anxiety can affect every speaker in one context or another (Hofmann, 2007), most of the studies conducted on the subject have concentrated on students as participants and respondents (Dansieh et al., 2021; Dobržinskienė, 2017; Hook et al., 2013; Linardopoulos, 2010; Raja, 2017). Given this focus, speech communication scholars have paid insufficient attention to how public-speaking anxiety impacts on the communication of instructors in the instructional process.

To address this apparent gap in the research, this study examined the nature of public-speaking anxiety among newly employed university instructors at the University of Cape Coast (UCC) in Ghana. Based on my association with this cohort as Faculty Registration and Examination Officer, I understood that these lecturers had little prior training in lecturing during their previous work as either teaching assistants or research assistants. This study therefore sought to examine the lived experience of these largely inexperienced instructors regarding the anxieties they had in speaking publicly during instructional hours. To meet this objective, the study focused on identifying the causes of public-speaking anxiety among this cohort, and exploring the measures they employed to overcome this communication difficulty. Unlike recent studies that have investigated public-speaking anxiety among African tertiary *students* (e.g., Raja, 2017; Dansieh et al., 2021; Prentiss, 2021), the study focused on *instructors*, and addressed the following research questions:

- RQ 1: What factors cause public-speaking anxiety among newly employed instructors?
- RQ 2: How do these instructors overcome public-speaking anxiety?

2. Literature review

Defining public speaking and public-speaking anxiety

Speaking in public requires great tact, and mastery of numerous elements. Among other things, the speaker must be competent in the subject to be shared, must have knowledge of the audience, and must understand the context surrounding the speech. The way one chooses to speak in the classroom, at a job interview, or at a conference, is likely to differ significantly based on the elements just listed. One basic characteristic that may be found in all such genres, however, is that the speech may be a sustained presentation (Verderber et al., 2011, p. 20). The successful presentation of a speech requires the speaker to approach the presentation not only as an act but as a process (Nikitina, 2011, p. 10). Rhetorical knowledge of arrangement, composition, and style is necessary for overcoming the anxiety that is likely to occur during public speaking.

Vitasari et al. (2010, p. 3) define anxiety as "a psychological and physical response to treat a self-concept characterized by subjective, consciously perceived feelings of tension". Public-speaking anxiety can, therefore, be described as a kind of anxiety that occurs in a specific public context, arising from the anticipation of an oral presentation (Bodie, 2010). Bodie (2010) distinguishes between *trait* public-speaking anxiety and *state* public-speaking anxiety. The former refers to anxiety caused by the personality of an individual. For instance, persons with chronic fears, worries, or anxieties may be said to experience trait public-speaking anxiety. State public-speaking anxiety, on the other hand, is a temporary condition that an individual speaker experiences for a short period. This anxiety can be overcome after another condition sets in.

Knowledge of public-speaking anxiety

Pull (2012) analyses the types of psychological and physiological reactivity to public speaking among persons who were anxious about speaking in front of others. The study discovers that virtual reality exposure and internet-based self-help were efficient in overcoming public-speaking anxiety among the participants. Blöte et al. (2009) examine whether specific public-speaking anxiety can be considered a subtype on its own. In their study, participants with public-speaking fears were compared to persons who have more than one kind of fear. Findings concerning fear reactions of the sub-groups are inconsistent. One group with public-speaking anxiety reported higher anxiety when making a speech than the group with more generalised social anxiety, while other groups with public-speaking anxiety reported less anxiety when speaking than those with generalised anxiety. The study also discovers that patients with speech anxiety reacted more physiologically when they spoke in public than those with general phobias. The authors conclude that public-speaking anxiety is a unique type of social phobia that is different from other phobias.

Causes of public-speaking anxiety

Research on the causes of public-speaking anxiety is concerned with the causes of such anxiety at various levels and settings. Of particular reference is a quantitative study conducted by Raja (2017) to identify the causes of anxiety among 50 undergraduate students who took a course in public speaking at a private business school in Karachi, Pakistan. The author emphasises that students felt uncomfortable while speaking to others because they had a meek nature and also lacked confidence. The study also shows that 75% of respondents feared speaking in public, and confessed that the size of the audience caused nervousness among them during presentations. Raja (2017) recommends that practising presentations a number of times with a small number of people will help students to speak in public with ease, and that proper preparation will enable them to recover when they deviate or get confused while speaking in public.

In examining the causes of public-speaking anxiety, one needs to distinguish between the anxiety of speaking in front of a group of individuals and the anxiety of interacting with a group – the difference between what Hook et al. (2013) label performance anxiety and interaction anxiety. They describe performance anxiety as a type of anxiety that occurs when a speaker is being observed or scrutinised by another or an audience, while interaction anxiety takes place in a dyadic and/or group interaction. Hook et al. (2013) observe that panic disorder and other fear disorders are symptoms of both performance anxiety and interaction anxiety. In their view, performance anxiety is caused by external factors and demands from situations that involve concerns regarding other persons' evaluations of a speaker's behavior. Interaction anxiety, on the other hand, deals with attention to internal factors and situational demands that lead to personal assessments.

Public speaking as a challenge among students

Without doubt, public speaking is a daunting task to the majority of students in the context of instructor-student communication. Dobržinskienė (2017) posits that the principal cause of speaking anxiety is the body language and anatomy of the student-speaker. The author states that when an audience notices a tremulous voice, sweaty palms, flushed cheeks, and other physical manifestations by the speaker, this doubles the anxiety of the speaker. Fear of the audience is also reported by the author. One of the participants in Dobržinskienė's (2017) study stated that he wanted to run and return to his seat because he felt that he could hardly breathe. The majority of the participants, who were second-year law students studying at a university in Lithuania, were anxious when preparing for public speaking. Meanwhile, Linardopoulos (2010, p. 2) emphasises that effective public speaking is a skill sought by employers.

3. Theoretical framework

The study employed the processing efficiency theory (PET) as formulated by Eysenck and Calvo (1992). The theory explains the impacts of anxiety on people's lives, and assumes that anxiety is caused by situational threat or stress (Eysenck & Calvo, 1992). The theory holds that level state anxiety determines personal differences in cognitive processing and performance. It stresses that worry is a key element that forms the cognitive component of state anxiety (Morris et al., 1981). Worry during public speaking affects working memory. Working memory has been defined as "those mechanisms or processes that are involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition" (Miyake & Shah, 1999, p. 450).

PET assumes that worry serves as a motivation function through a control system probably located within the working memory system. The functioning of this system leads to the allocation of additional processing resources, that is, effort and to the initiation of processing activities, which are the strategies. Such attempts, if successful, increase available working memory capacity. As a consequence, potential performance impairments caused by the utilisation of working memory resources can be compensated for by the allocation of additional resources or activities. A central contention of PET is that there is a control or self-regulatory system which is involved in mediating the effects of anxiety on processing and performance (Eysenck & Calvo, 1992).

Two major types of reactions to poor performance are initiated by the control system. First, it is sometimes possible to cope directly with the current level of threat and/or worry. There is a consequent reduction in worry and an increase in the available capacity of working memory. Second, it is often possible to reduce or eliminate the negative effects of worry on task performance by applying additional effort, that is, extra processing resources to the task. The complex nature of the various functions of the control system indicates that it is located within the working memory system (Eysenck & Calvo, 1992).

4. Research design

The study employed the interpretive case study design. In interpretive research, the focus is not necessarily on the sample size in the interest of achieving generalisability. Rather, emphasis is placed on depth and rigour (Creswell, 2013; Tracy, 2013). Rather than using a large sample size, the interpretive researcher can work with a fairly small sample while aiming for a thick description of the phenomenon being described. The ultimate goal is to capture an instance of truth, and not to obtain universal, nomothetic laws (Lincoln et al., 2011; Tracy, 2013). I found this methodological approach suitable for obtaining in-depth responses about what the instructors thought and how they felt about sensitive subjects such as public-speaking anxiety.

Sample size and sampling procedure

Using a purposive non-probability sampling method, the study selected 12 assistant lecturers employed during the 2020/21 academic year, out of a target population of 19 assistant lecturers employed in the UCC Faculty of Arts at the time of this study (UCC, n.d.). I recruited the 12 participants based on their willingness to participate in the study, a process aided by their collegial association with me. The sample comprised six male and six female assistant lecturers, from across nine departments within the Faculty of Arts.

Instruments

Two instruments were used in collecting data, namely a direct observation guide and an interview protocol. Direct observation is a naturalistic inquiry that enables researchers to draw on their knowledge and experience to build trust and good relations with their participants in order to obtain information from them (Sirris et al., 2022, p. 138). As a research method, direct observation allows researchers to immerse themselves in the phenomenon under inquiry – and to be able make note of non-verbal cues, feelings, situated behaviours, or social practices – with the aim of interpreting numerous layers of meaning (Fine, 2003). Spanning a period of 12 weeks (i.e., September to November 2021), I was permitted by my participants to sit in on their classes to observe their interactions and instructional processes. This enabled me to make notes of my observations in-situ.

My observations were supported by in-depth interviews with each of the participants. An in-depth interview, according to Oppong (2013), is the best way to explore and gather experiential narratives, and it is the most appropriate method when detailed insights are required from individual participants (Teddlie & Yu, 2007). Such interviews provide participants with the opportunity to describe their experiences and tell their own stories in their own words. The interview protocol comprised three sets of questions, on the following subjects: (1) interviewees' experiences with speaking in the classroom; (2) interviewees' challenges when speaking in the classroom; and (3) measures employed by the interviewees to overcome public-speaking anxiety. The interviews were audio-recorded and transcribed.

Coding and coding scheme

Using Watkins's (2017) rigorous and accelerated data reduction (RADaR) technique, I identified nine main analytical themes in the data connected to public-speaking anxiety. The themes were arrived at through parsing, coding, and systematising data. This involved, first of all, line-by-line coding. I reflected on the data over and over again, so as to underline, circle, and colour-code key words and phrases. The second stage of coding enabled me to link words to form ideas. Here, I penned my thoughts and observations of the data in a relaxed manner, and began to develop concepts.

The emerging ideas gave birth to messy themes and notions, and 13 rough codes were initially generated. These codes were further collapsed into nine themes, using a coding scheme as follows:

- CAU: causes of public-speaking anxiety
- UNP: unpreparedness
- LAP: lack of adequate preparation
- FAD: fear and diffidence
- INT: intimidation by the audience
- MEA: measures for overcoming public-speaking anxiety
- ADP: adequate preparation
- COP: constant practice
- ENA: engagement with audience

Ethical considerations

A number of ethical principles were taken into consideration in conducting the study. Informed consent was obtained from each participant. Participants were assured of anonymity and confidentiality, and were also assured of their ability to withdraw their consent if they felt uneasy or compromised in any way.

5. Results and discussion

University instructors' lived experience of public-speaking anxiety

Analysis of the data revealed that participant-assistant lecturers reported having experienced public-speaking anxiety during instructional hours. The excerpts below reflect what a male assistant lecturer and a female assistant lecturer had to say on the subject:

> **Illustration 1**
> Well, it wasn't rosy. I remember I greeted "good morning" in a level 100 [first-year university] class and I went totally blank. So, the next morning, I organised myself well and it got better. I must say that it is not something that you start with. Some people may have the idea that public speaking is inherent. But it is an act you need to master. At the beginning, you would have bumps here and there. That's what we call stage fright. But with experience it will get better. (Instructor A, 10 September 2021)

> **Illustration 2**
> It was a nice experience but it wasn't easy actually at all. Your first time entering a lecture hall full of students, some even way older than you, and you are lecturing them. It wasn't easy. Hmm, I remember when I stood in front of them and all of a sudden, I lost everything and I was like ouch. I had to do a little breathing exercise to regain my composure. (Instructor B, 10 September 2021)

The excerpts above support the claim by Eysenck and Calvo (1992) that worry, as was experienced by both the male and female assistant lecturers quoted, is a key element that forms the cognitive component of state anxiety.

Causes of public-speaking anxiety among university instructors

The study revealed three major causes of public-speaking anxiety among the Ghanaian university instructors. These are (1) unpreparedness or lack of adequate preparation; (2) fear and diffidence; and (3) intimidation by the audience.

Unpreparedness or lack of adequate preparation

The study showed that seven participants noted that unpreparedness or lack of adequate preparation was the major factor that caused anxiety when speaking in public, particularly in the classroom. The excerpt below from another female participant succinctly captures this observation:

> **Illustration 3**
> It happened when I was asked to chair an occasion which I knew nothing about. The person who was to do it called at the last minute that he couldn't make it. So, as a vice to that person I had to steer the occasion for him and had to give a speech. Hmm, it was something else because I had not prepared and I didn't know what to say and even how to begin. It was a really a big blow to me, and seriously […] I can still remember that day like today. It wasn't easy at all because I had not prepared. (Instructor C, 7 October 2021)

Analysis of the interview transcripts revealed that this type of performance anxiety sometimes occurred among the participants. Besides the participants' lack of preparation and preparedness to make an extemporaneous speech, a special kind of anxiety that I will call "situational speech anxiety" emerges from the data set. Similar to Hook et al.'s (2017) idea of performance anxiety, situational anxiety, on the other hand, may be described as a particular type of performance anxiety in which a speaker is called upon momentarily to stand in for the billed speaker who is either absent or unable to deliver the speech due to circumstances beyond their control. Seen this way, *situational public-speaking anxiety* may also be termed *expectation public-speaking anxiety* as the new speaker is anxious about meeting the expectations of the onlooking audience. This type of stress, according to Eysench and Calvo (1992), may be caused by occasional stress accompanied by the threat of failure.

Diffidence and the fear of making mistakes

In addition to lack of adequate preparation, lack of confidence also caused participants to experience intense public-speaking anxiety. Here is an example from a male informant:

> **Illustration 4**
> In one of my class interactions, I thought others were more qualified than myself to stand in front of the class. I nearly called off the class as I was not too sure where and how to start the lecture. My legs and buttocks began shaking. (Instructor D, 10 October 2021)

One may note from the excerpt above that the level of diffidence experienced by Instructor D was caused mainly by the fear of making mistakes. In addition to Instructor D, five other participants spoke of instances when they feared that they might not perform or speak well on a subject. This finding is consistent with that of Dobržinskienė's (2017) study, which reported on students' tendency to want to run from the classroom when they experience public-speaking anxiety. Although study participants were instructors, and claimed they came prepared, the sight of their audiences scared them. They feared that they might not say the right thing. Here is a continuation of the excerpt in Illustration 4 from the same assistant lecturer (Instructor D):

> **Illustration 5**
> You know, teaching at the SHS [senior high school] level is a different game. You make an error [at SHS level] and […] and your students may notice it, or they may simply tease you afterward. But at the university level, these undergraduate students are, first of all, people who have graduated from senior high school, and so are mature. Secondly, they are now exposed to university education because they are reading lots of books and other educational materials. Therefore, your anxiety as an instructor can be high if you're delivering content and you make unpardonable bloopers. (Instructor D, 10 October 2021)

Analysis of the transcript of this participant showed that the source of his lack of confidence in speaking publicly could be caused by his trait anxiety. One can note that he was concerned about how lack of mastery of subject content could result in his inability to perform optimally in front of his student-audience who, in his own words, "are reading lots of books and other educational materials".

Intimidation by audience

As is to be expected, participants who lacked confidence and therefore feared speaking in public also experienced being intimidated by their audience. Some participants noted that the audience scared them and therefore they could not speak with confidence. This was observed mainly among female participants as they felt intimidated by either their peers during board or faculty meetings, or during instructional hours. Here is what a female participant said on the subject:

> **Illustration 6**
> I was once asked a particular question by a student. I can't exactly recall what the question was, but as I started speaking, it was like everybody in the class was looking at me, and since my mind went on them, I forgot everything that I was supposed to say. (Instructor E, 12 November 2021)

This finding is consistent with the study of pre-service teachers in the Philippines by Kenoh III (2021), which revealed that when audiences have high expectations or are critical of their speakers, this can cause them to experience higher levels of public-speaking anxiety. However, responses from my study participants showed that audience intimidation may be either *imagined* or *real*. It must be noted that even though some participants identified the causes above as reasons for their anxiety during public speaking, they, nonetheless, made frantic efforts to deal with this challenge. Composure, a courageous mindset, and a can-do spirit were employed as coping strategies.

Measures for overcoming public-speaking anxiety among university instructors

Interactions with study participants showed three measures for overcoming public-speaking anxiety among the participants. These are adequate preparation, constant practice, and active engagement with the audience.

Adequate preparation

Adequate preparation was one of the measures that nine participants employed in minimising public-speaking anxiety. This finding is consistent with prior studies among students in different cultures (e.g., Raja, 2017; Blöte, 2021; Kenoh III, 2021). The difference between these two cohorts, with respect to their state of speech anxiety, in my estimation, has to do with the degree of preparation each cohort may engage in. As a matter of fact, the majority of the assistant lecturers indicated that adequate preparation (such as audible speech rehearsals in front of colleagues, advanced teaching preps, and the use of basic

teaching aids) enabled them to have mastery over their subject matter. Below are two examples of what was said:

> **Illustration 7**
> The effective ways of preparing for speaking in public are to do good preparation and also to rehearse the speech. That is, if a speaker prepares well, anxiety becomes minimal. (Instructor F, 14 November 2021)

> **Illustration 8**
> Preparation helps in dealing with the struggle. You don't want to be overly confident and flop. I also read, or do more research on the topic to get more information about the subject matter that I am presenting on to help me to overcome or minimise anxiety. (Instructor G, 14 November 2021)

Constant practice

As has been confirmed by prior research (e.g., Dansieh et al., 2021; Kenoh III, 2021), participants also identified constant practice as one of the measures for overcoming public-speaking anxiety. Analysis of interview transcripts and direct observations showed that the majority of study participants engaged in frequent practice before speaking to student audiences. This included verbal practice. Here is an excerpt from one participant's response:

> **Illustration 9**
> Anxiety is normal and is bound to happen when giving a speech. However, when it happens, you have to come out quickly and don't get stuck where you are. You should be doing it more often if you are the timid type like myself. One can overcome anxiety through constant practice by gathering people and talking to them or standing in front of your mirror and then rehearsing what you are about doing or going to deliver. This may sound awkward to you, but whenever I have a lecture to attend, I first practise. I do it with my teddy bears and it helps. This is what I have been doing before I speak in public. (Instructor H, 15 November 2021)

Engagement with the audience

Participants indicated that active engagement with the audience was another effective way of dealing with public-speaking challenges. The study observed that prior to starting instructional contact with the class, they engaged in phatic communication. For instance, they walked around the lecture hall to engage in small talk and find out how students were faring in their social lives. This was also followed by encouraging group discussions, and engaging in follow-ups on previous class discussions. Only after those initial engagements would the instructor then usher the class into the lecture of the day, and engage the class more formally in a public-speaking mode.

6. Conclusion

The study set out to investigate the lived experience of novice university instructors concerning public-speaking anxiety at a public university in Ghana. The study showed that such anxiety is caused by three main psychological triggers, namely: unpreparedness or lack of adequate preparation; fear and diffidence; and intimidation by the audience. The study also revealed that adequate preparation, constant practice, and engagement with the audience are key strategies employed by the lecturers in order to overcome their anxiety when speaking in public. Although this study did not consider a gendered perspective to public-speaking anxiety, the study, nonetheless, showed that the phenomenon was more pronounced among male instructors than among female instructors.

The discovery of situational or expectation public-speaking anxiety may be considered as a modest contribution to existing knowledge on public-speaking anxiety. It could be classified as a sub-type of state public-speaking anxiety. Again, the study provides a distinction between imagined and/or real intimidation emanating from the audience. It is recommended that gender-based research on public-speaking anxiety among instructors be conducted. Such research can focus on gender variation in terms of prior-speech preparation as well as gendered variation in presentation dynamics.

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Challenges for Foundation Phase Teachers in Interacting with Parents during the COVID-19 Pandemic: A Case Study of Mangaung Primary Schools, South Africa

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Abstract
The sociocultural theory of learning acknowledges parents as integral role players in the process of their children's learning. As in many other parts of the world, when South African schools moved to remote online learning due to the COVID-19 pandemic, teachers became increasingly dependent on the agency of parents. Using an interpretivist lens and a qualitative approach, this study probes the experiences of Foundation Phase teachers in South Africa's Mangaung Municipality in their interaction with parents in 2020, during the pandemic lockdowns. The findings point to the following challenges during the pandemic, as perceived by the teachers: difficulty in communicating with parents; difficulty in working with parents to support learning; and insufficient parental commitment. The findings also point to shortfalls in respect of three dynamics—collaboration, feedback, and trust—as being central to the perceived challenges. The study concludes with a call for improved relations between Foundation Phase parents and teachers, regardless of whether the teaching and learning are occurring remotely or in-person, in order to optimise the sociocultural dynamics at play in children's schooling.

Keywords
COVID-19 pandemic, schools, Foundation Phase, sociocultural theory of learning, transfer of learning, remote learning, teacher–parent interaction, parental participation, communication, collaboration, feedback, trust, Mangaung, South Africa

DOI: https://doi.org/10.23962/ajic.i29.13746

Recommended citation
Grobler, A. (2022). Challenges for Foundation Phase teachers in interacting with parents during the COVID-19 pandemic: A case study of Mangaung primary schools, South Africa. *The African Journal of Information and Communication (AJIC), 29*, 1-15. https://doi.org/10.23962/ajic.i29.13746

1. Introduction

The unprecedented disruptions caused by the COVID-19 pandemic in 2020 and 2021 obliged educators to adopt novel ways of teaching (Wolhuter & Jacobs, 2021). The situation required a transition from traditional classroom-based teaching to decentralised options, with heavy reliance on digital technologies to connect with learners (Timmons et al., 2021). Prior to the pandemic, parents of Foundation Phase learners had ample opportunity to engage personally with the teachers of their children, via regular visits to the classroom, parent evenings, and informal social contact (such as during a sports event). The pandemic closed off such opportunities for face-to-face interaction between teachers and parents. Due to the closed-door policy adopted by schools, teachers were forced to resort to digital communication with parents. As Foundation Phase educators worked hard to continue teaching their learners via remote means, it was imperative that they be able to interact effectively with the learners' parents (Formosinho, 2021).

The urgency of engaging parents, as part of the process of conveying learning to children, created a predicament for many teachers worldwide (Kirby, 2021; McCallum, 2021). The challenges associated with parental involvement in schooling are not new (Epstein, 2001; Lemmer & Van Wyk, 2006), and the pandemic brought into even sharper focus the essential nature of interaction between teachers and parents, particularly for young learners in the Foundation Phase. While older learners were able, during the pandemic, to independently use digital platforms to access their learning, Foundation Phase learners were dependent in a variety of ways on their parents (or caregivers) to unlock the learning opportunity being made available, on a remote basis, by teachers. During the pandemic, the involvement of parents of Foundation Phase students had a direct impact on delivery of the curriculum and transfer of learning. This set of circumstances prevailing during the COVID-19 lockdowns in South Africa in 2020 led to the problem that this study sought to explore.

2. Research context and problem statement

The COVID-19 pandemic in South Africa caused widespread disruptions, including in the field of learning and teaching. The declaration of a National State of Disaster[1] required a prohibition on traditional school attendance by all learners during an initial hard lockdown period from 16 March to 8 June 2020 (DBE, 2020a). For Foundation Phase teachers, offsite teaching continued until late August 2020, when learners were allowed to return to the classroom in a staggered manner (DBE, 2020b). The staggered approach taken by government to the return of learners to the physical classroom meant that Grade 1 learners only returned to the classroom on 24 August 2021, and then only by taking turns to attend in order to adhere to the 50% occupancy rate allowed by the Department of Basic Education (DBE).

1 See https://www.gov.za/documents/disaster-management-act-declaration-national-state-disaster-covid-19-coronavirus-16-mar.

This meant that teaching and learning in South Africa, as in much of the rest of the world, was remote and delivered via digital means (Wolhuter & Jacobs, 2021). Foundation Phase teachers found themselves unable to communicate with their learners without the mediation of the parents (Formosinho, 2021; Taylor, 2020).

From early June to late August 2020, South African Foundation Phase teachers provided all learning and teaching materials in a digital format for their learners to study at home. The approach to curriculum delivery taken by various schools differed along a spectrum that can be linked to individual school's circumstances, with some relying on technology more than others. In all cases, however, the teachers depended heavily on the intercession of parents to help Foundation Phase learners with accessing and engaging with the learning materials. This caused great urgency for establishment of high-quality interaction between educators and parents—both of whom need to be invested in the education of the learner (Epstein, 2001; Mavuso et al., 2017).

Before the pandemic, learners had face-to-face access to the teaching expertise of the teacher, and received most of their instruction at school, with homework only regarded as supplementary material. The reality of the disrupted period of the pandemic meant that, regardless of the effort that Foundation Phase schoolteachers took to deliver curriculum content to their learners, the outcome of their teaching was highly subject to the active participation of parents. The involvement of parents was essential in downloading material, in providing data and devices to learners in order to watch video clips or listen to recordings explaining the learning content, and in ensuring full learner engagement with instructional materials. Intentional and focused communication between teachers and parents, and subsequent involvement by parents, were thus essential to establishment of a learning environment for Foundation Phase learners that was conducive to their engaging with their school activities.

The research reported on in this article attempted to investigate the perceptions of teachers regarding the challenges of interacting effectively, during the pandemic lockdown, with parents of Foundation Phase learners in the Mangaung Metropolitan Municipality of the Free State Province, South Africa. The school phase that was the focus of this investigation, called the Foundation Phase, refers specifically to the introductory stage of formal schooling. In South Africa, the Foundation Phase includes the pre-primary year known as Grade R, followed by Grades 1 to 3. In this study the emphasis was on Grade 1, as the first year of formal learning, characterised by the major achievements of learning to read and write (DBE, 2011, p. 6; Phatudi, 2019, p. 227).

The research question that guided this investigation was: What were the challenges perceived by Foundation Phase teachers in interacting with parents during the pandemic, and what lessons can be learned from the management of the disrupted reality?

3. Theoretical context

Vygotsky's sociocultural theory of learning (1978) provided the theoretical foundation for the exploration. In broad terms, Vygotsky argued that learners internalise and assimilate the culture of their peers and significant others (Oguz, 2007, p. 2). The sociocultural theory of learning posits that a learner actively constructs their knowledge and skills (Wessels, 2014, p. 1). In this sense, Vygotsky's sociocultural theory is a constructivist line of argumentation, whereby optimal learning takes place in the collaborative process of interaction provided by culture, cognition, and language.

All learning, according to Vygotsky (1978), is culturally influenced and thus contextually bound. In other words, the cultural environment of a learner has a strong impact on the learning process, which is simultaneously influenced by cognitive processes or abilities and the medium through which learning takes place. Cox (1997, p. 53) aptly conveys the constructivist view in this way: "Education then becomes a set of embedded cultural practices, and the science of learning becomes obtaining a detailed awareness of how they fit together."

Vygotsky's theory stresses the importance of collaborative teaching and learning—elements also emphasised in South Africa's National Curriculum Statement (NCS) and Curriculum and Assessment Policy Statements (CAPS) (DBE, 2011, 2012; Jacobs et al., 2012). Collaborative learning as envisaged by the sociocultural theory implies the active input of the teacher, learner (Litshani, 2017), and the social context (Maphalala, 2016; McLeod, 2018; Vygotsky, 1978; Wessels, 2014).

Vygotsky (1978) considers the input by a knowledgeable other (most often the teacher expert) as critical to the outcome of the learning process. Litshani (2017, p. 22) points to the role of the teacher as being to "encourage active collaboration by learners" during the process of learning. The normal context of learning before the pandemic provided learners not only with input from the expert teacher, but also the collaborative experience of engaging with peer learners. Both these aspects were missing during emergency remote learning and teaching, with parents having to improvise and perform elements of both roles. When the pandemic forced teaching and learning to move to remote platforms, there was great concern about students' loss of, among other things, collaborative learning via peer input (Kirby, 2021; Taylor, 2020; Timmons et al., 2021).

Learning is subject to internal factors, such as the school environment, and external factors, such as parents, families, and governmental structures (Matlabe, 2017). Fru and Seotsanyana (2017) note that education in the 21st century demands an extension of the focus on "social agents other than teachers" (2017, p. 9), confirming the need for the active collaboration of parents, among other possible stakeholders. Previously the social context was supported by the active input of the teacher as well

as the peer learners but, during the pandemic, because of being isolated from social contact, teachers had to rely greatly on parents to deliver their communications to the learners.

As mentioned above, communication between teachers and parents was a crucial link for Foundation Phase learners unable to physically attend school (Timmons et al., 2021). At the same time, it must be noted that communication is reciprocal, complex and iterative (Jacobs et al., 2012; Sanchez, n.d.), and the possibilities for miscommunication increase with the addition of agents in the process (Landsberg et al., 2012).

Learning requires assessment in order to evaluate the successful reception of material taught, and feedback provides the norms against which learners' progress is documented (Wessels, 2014). Without valid assessment and reliable feedback, the progress of learners will remain inconclusive and undefined (Cox, 1997). Therefore, in a remote-learning context, if communication received back from the parents of learners is scarce, teachers are not in a good position to evaluate whether learning has been successful.

The concept of transfer of learning (Day & Goldstone, 2012) is vested in the cognitivist theory (Cox, 1997) and recognises that learning is modelled by the teacher or instructor in order to assist learners to grasp the cognitive concepts (McLeod, 2018). The input of an expert, such as the teacher, is recognised as crucial to the effective transfer of learning (Day & Goldstone, 2012, p. 160). With the emergency remote teaching during the pandemic, the active input previously rendered by Foundation Phase teachers needed to be replaced, to some extent, by parental input—with parents needing to provide their children with, among other things, the instructions given by the teacher and also interpretations of the instructions.

4. Research design

The 2020 pandemic lockdowns generated a unique situation for South African Foundation Phase teachers—a situation that warranted explorative research. A case study approach was adopted, with the case comprising the experiences of Grade 1 teachers in Mangaung. Ten primary schools were conveniently sampled from the approximately 114 primary schools situated in the Mangaung Metropolitan Municipality (schools4sa, 2021) on the basis of geographical proximity. They were all situated within a radius of 30 km from my workplace at the University of the Free State in Bloemfontein, which is Mangaung's major urban centre. Only teachers who had taught a Grade 1 class in the Mangaung Metropolitan Municipality during 2020 at one of the 10 schools were included.

I compiled a questionnaire (see Appendix) comprising closed-ended, scale, and open-ended items. The closed-ended questions aimed to confirm the number of years' experience of teachers, the approach taken by schools to address the chal-

lenges of responding to the lockdowns, and the learning area most impacted by the COVID-19 pandemic. The open-ended questions invited respondents to share their personal views on, and experiences of, teaching during the emergency remote learning. The semi-structured format gave the respondents the freedom to provide a wide range of responses, and their answers could thus reflected the teachers' authentic lived experiences.

Twenty-three questionnaires were distributed to respondents at the 10 schools, to be completed in writing by the respondents. All 23 questionnaires were collected on a mutually agreed date. All COVID-19 protocols in force at the time were upheld. The data generated by the open-ended items were coded and categorised using the ATLAS.ti qualitative data analysis software. From the subsequent coding and categorisation process, themes emerged from which key findings were formulated. (No surprising or innovative findings pertaining to the identified focus of this investigation emerged from the closed-ended and scale questions, and they were therefore excluded from further scrutiny.)

All open-ended answers were coded in ATLAS.ti according to repetitive phrases. The coding generated the common themes, and the dominant perceptions of the teachers. These dominant perceptions are discussed in section 5 below. It should be noted that while the questionnaire was not focused on teacher–parent interactions, it was those interactions that generated the strongest commons themes in the data—as becomes clear in section 5.

Ethical clearance for conducting the study was obtained both from the University of the Free State and the Free State Department of Education. Participation was anonymous, as respondents were not identified in any way and no personal identifiers were requested. The names of the schools are not disclosed in the research findings. Upon receipt of the completed questionnaires, a random number was allocated to each respondent for administrative purposes. The respondents had the freedom to voice any concern that they might have had with the research process. A study limitation was the fact that the conveniently sampled schools were all located within a radius of 30 km and all were in the fairly urban section of the Mangaung Metropolitan Municipality.

5. Findings

Three core teacher perceptions emerged from the thematic coding of the data.

Perception 1: Difficulty in communicating with parents

Some teachers had positive reactions to the use of WhatsApp group messages. One teacher wrote, "Whats[A]pp groups worked excellent[ly] as a brilliant communication system between parent and teacher." However, a significant number of responses indicated that it was difficult to communicate with parents. "Some parents did not

communicate back at all", one teacher observed, and "[o]ther parents did not have access to WhatsApp or even a smartphone." According to another teacher: "Parents […] do not have the necessary resources e.g. Wi-Fi or printers at home."

Another teacher stated, "[s]chool and teachers need a good electronic communication system e.g. D6 communicator, WhatsApp group etc. to communicate with parents at short notice." A fluid and unreliable database of parent cellphone numbers proved to be an obstacle to effective communication. As one teacher observed, "[p]arents […] did not all receive the WhatsApps".

The cost aspect of data was also emphasised. One teacher noted, "[d]ata—not everyone could afford it", and another wrote: "Not all parents had enough data." As one teacher stated, "[d]ata was not freely available. Some did not have WhatsApp, some had phones with SMS that could not read photos", and "[n]ot all parents have data or the facilities to use technology at home." Differences in platform adoption also posed problems. As one teacher remarked, "[n]ot all parents had WhatsApp." Another added: "[s]ome parents had Telegram and no WhatsApp."

Perception 2: Difficulty in working with parents to support learning

The remote learning environment meant that learners had to access the learning material via the intervention of their parents. This proved to be a weakness in the communication process. As one teacher explained: "It was challenging at times, in the sense that I had to compile lessons for the parents (who mostly have little knowledge in the area of education instruction) and had to then rely on them to disseminate the knowledge/strategies etc. to their children."

Teachers raised their concerns about not being a party to the learning process that took place in the remote settings. One teacher voiced the common frustration as being one of "[n]ot knowing whether learners [understood] the work." In the words of one teacher, "[s]ome parents did not understand what had to be done." According to another, "[p]arents didn't cooperate and due to the language barrier, kids struggled to complete work on their own." The aforementioned "language barrier" was explained in this way: "[Unfortunately many] parents cannot help learners sufficiently since we are English medium and they come from Sotho homes." Another added, "[l]anguage was a problem. Parents did not understand the assignments and could therefore not explain to their children." One teacher complained of "[p]arents not being able to explain concepts and new phonics to learners." Another acknowledged the pressures faced by working parents, stating that "[w]orking parents could not do all the work." One teacher summarised the challenges as follows: "Parents did not all cooperate with work to be done at home. This can be because of lack of knowledge, their own work pressure and lack of resources."

Perception 3: Insuffi cient parental commitment

Many of the teachers voiced dissatisfaction with the level of dedication displayed by parents. Many said that even before the COVID-19 pandemic, they were often disappointed by the lack of parental commitment. The pandemic exacerbated the situation. In the words of one teacher, "[p]arents did not do their part. Their children just fell behind." Another teacher stated, "[p]arents did not always do the work." According to one teacher, "[p]arents were not always assisting at home and some learners would not work at home." In the words of another: "Parents should take more responsibility for their children's education during a time where it is impossible for teachers to educate their children." At the same time, some teachers acknowledged the impact of the pandemic on parents' ability to support their children's learning. In the words of one, "[n]ot all parents [could] cooperate due to COVID." Digital challenges were also seen as playing a role in undermining parental commitment. As one teacher explained, "[s]ome parents could not view the video clips due to data problems."

The teachers' dissatisfaction with parental commitment contrasted sharply with their self-evaluations of their own levels of involvement. According to one, "[t]eachers did above and beyond all they could [to] assist learners [and to] buy data for parents to download. [To] print books and courier [them]. […] We went the extra mile." Another wrote: "Educators did everything they could in order for our kiddies to continue with their work at home."

6. Analysis

The teacher responses outlined above indicate several factors that influenced teacher interaction with parents, leading to suboptimal transfer of learning to Foundation Phase learners. Three of the key factors are now discussed.

Collaboration

As explained above in the "theoretical context" section of this article, the sociocultural theory of learning positions collaboration as central to learner success. It is thus significant finding that the teachers perceived that, during the remote Foundation Phase teaching and learning necessitated by the pandemic, there was, for the most part, insufficient collaboration between parents and teachers, and insufficient collaboration between parents and the learners (their children). The pandemic increased the need for parent collaboration with both teachers and learners and, in the eyes of most of the teachers, parents generally did not rise to the challenge. The teachers' survey responses point to several possible reasons for shortcomings in the parents' actions—some beyond the control of parents (e.g., data access, the language barrier, work commitments), others within the control of parents (e.g., greater appreciation of, and commitment to, their roles as collaborators in their children's learning).

Feedback

The earlier discussion of theoretical context also established that feedback to teachers on learner progress is a central element of successful learning. It is thus significant that the teachers felt frustration, during the remote learning period of 2020 when they had precarious contact with learners, that they were dependent on parents for not only communications with students but also for inputs on their learners' progress. More than one teacher noted the exasperation they experienced when it was unclear whether learners had correctly grasped the learning content—a situation exacerbated when teachers were unsure if the parents had comprehended the assignment correctly. This dependence on parental comprehension was deemed by the teachers to be a significant weak link in the chain of teaching and learning during the pandemic—and again the language barrier was perceived to be one element of this weakness.

Trust

The conviction held by many of the teachers that parents were not sufficiently committed to investing their time and effort in mediation of the learning process of their children points to a breach in the trust relationship between parents and teachers. Among other things, this is indicative of the discomfort generated by a significant shift, caused by the pandemic, in the balance of power (and responsibility) between teachers and parents. The pandemic required a greater emphasis on the parental role, but parents were not, according to the teachers, willing or able to embrace this new responsibility.

7. Conclusions

The remote learning of 2020 for South African Foundation Phase students, precipitated by the pandemic, greatly heightened the need for high-quality interactions between educators and parents who, even in non-pandemic times, need to both be actively invested in the education of the learner (Epstein, 2001; Mavuso et al., 2017). In some respects the pandemic can be said to have brought existing weaknesses—e.g., sub-optimal teacher-parent collaboration, sub-optimal parent-learner collaboration—to a head. At the same time, the pandemic also offered lessons that can be used to initiate necessary reform.

Already at the initial application for admission to the institution, the parent has an obligation to engage with the school on behalf of the learner. Mavuso et al. (2017) hold the parent responsible for maintaining and sustaining positive engagement with teachers. Yet once the learner has been admitted, the communicative relationship between parents and teachers is often dominated by the teachers. This one-sided process dynamic should not be allowed to develop, as parents are part and parcel of the sociocultural processes at play in education. Specific, reliable, and accessible communication between teachers and parents is an essential instrument, regardless of whether the learning is remote or in-person. In both modalities, collaboration effected between teachers and parents can be decisive in the successful delivery of

teaching and in the optimal of transfer of learning, especially in the Foundation Phase years. A pattern of commitment must be established from the beginning of the relationship between the school and the parent. A concerted, broad-based effort is needed to encourage parents to become more actively involved in their children's collaborative learning, and greater collaboration and trust need to be built up between parents and teachers.

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Appendix: Questionnaire

Section A: Biographical detail

1. Number of years teaching grade 1?
2. Number of years teaching any grade?
3. Type of school:
    - Ex-model C
    - quintile 1-3
    - no fee
    - private
4. Number of learners in your class:
5. Number of grade 1 learners in the school:
6. Teaching assistant in your class?
    - Yes/no

Section B: Approach of the school to the pandemic immediately after the lock-down

7. Learners came to school every day
    - Yes/no
8. Learners came on alternate days
    - Yes/no
9. Learners came to school every other week
    - Yes/ no
10. Learners came to school for two weeks at a time
    - Yes/ no
11. No physical school
    - Yes/ no
12. Only online school took place
    - Yes/ no
13. Any learners that did not come back when the school re-opened?
    - Yes/ no

Section C: Approach in the classroom

14. Did the school apply specific strategies to manage the new situation?
    - Yes/ no
15. What kind of strategies were used?
    - Printed material
    - Soft copies to print at home
    - Video clips
    - Other please specify:
16. School/teacher provided printed learning material
    - Once a month
    - Once a week

- Every day

17. School/teacher provided online learning material for parents to print
    - Once a month
    - Once a week
    - Every day
18. School/ teacher relied on other resources e.g. DBE, radio/ TV broadcasts
    - Yes/ no
19. Teacher made video clips for learners
    - Yes/ no
20. Video clips for instruction were given
    - Once a week
    - Every day
21. Length of video clips
    - 1-4 min
    - 5-10 minutes
    - 11-30 minutes
22. School preferred to use Zoom or other type of electronic classroom
    - Yes/ no
23. Which type of platform
    - Zoom
    - Blackboard Collab
    - MS Teams
    - Other
24. On a scale from 1-5, where 1 is very good and 5 is very bad, how did the strategies work?
    - Video clips
    - Zoom or electronic classroom
    - WhatsApp group message
    - Written index of work to be done for the day
    - Photo or pdf of work to be done for the week
25. Any special insights worth noting?
26. Any frustrations?
27. Anything to do differently in a similar future scenario?
28. In your personal opinion, was there generally speaking a deficit in learner knowledge after the lockdown?
    - Yes/no

If the answer was yes, then please complete questions 29-31 as well:

29. Which area of learning was the most impacted during the lockdown?
    - Life skills
    - Literacy
    - Numeracy
30. Which area of learning seemed least impacted after the lockdown?
    - Life skills

- Literacy
- Numeracy

31. What soft skill area was impacted the most by the lockdown. Number from 1-5, where 1 is most affected to 5 which is least affected:
    - Tolerance to stressful situations
    - Assertiveness
    - Interaction with peers
    - Introvert/ extroverted personalities
    - Eagerness to learn
32. Your thoughts on the future of schools as we know them?

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The African Journal of Information and Communication (AJIC)

Published by the LINK Centre
University of the Witwatersrand (Wits)
Johannesburg, South Africa
https://www.wits.ac.za/linkcentre

ISSN 2077-7213 (online version)
ISSN 2077-7205 (print version)