Perceptions of engineering researchers towards citizen science: a case study at a university of technology

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Received: 9 December 2022
Accepted: 13 October 2023

Societal demands and challenges are increasingly shaping academics' research endeavours. Citizen Science (CS) is a developing concept that constitutes a fundamental shift towards alternative ways of knowledge creation by including audiences beyond academia. The applied nature of the engineering discipline and subsequent opportunities to involve citizens in knowledge-creation processes are of particular importance in this paper. A qualitative case study in the Faculty of Engineering at a selected University of Technology in South Africa explored the roles of academic libraries in engineering CS initiatives. Nine full or associate professorship engineers participated in in-depth interviews. The results indicated great enthusiasm and aspirations among engineering researchers to contribute to societal needs in support of Sustainable Development Goals. As CS projects' development proliferates in academic institutions, the roles of academic libraries could increasingly become prominent and favour creative input during knowledge-creation practices. The findings provide valuable guidelines for academic libraries during engineering CS projects' planning and execution and demonstrate how a multidisciplinary approach can accelerate implementation.

Keywords: citizen science, academic libraries, engineering research, open science, South Africa

1 Introduction

Citizen Science (CS) is considered "the most dramatic development in science communication in the last generation" (Lewenstein 2016: 1) and forms part of the broader concept of Open Science (OS) practices. The latter is associated with knowledge-creation practices to ensure greater visibility, transparency, and accountability of scholarly research and implies a fundamental shift towards facilitating more comprehensive access to scholarly research *during* knowledge-creation processes (United Nations Educational, Scientific and Cultural Organization [UNESCO] 2021: 5; Weingart, Joubert & Connoway 2021: 11; Hodson, Walwyn & Wood 2018: 7).

This exploratory paper aims to make a contribution to CS practices among engineering researchers at a University of Technology (UoT) aimed at increasingly serving and engaging broader communities. CS practices are especially relevant to the field of engineering, where scientific knowledge can be applied to develop solutions for technical and practical problems experienced by citizens in everyday life (Lindberg, Pinelli & Batterson 2008; Pinelli 1991: 6), as well as to address the Sustainable Development Goals (SDGs) aimed at finding solutions to global challenges (Gownaris et al 2022:8; Oltra-Badenes et al 2022: 4319).

2 Background

The term "citizen science" was coined by Irwin (1995) and implies a wider awareness of the societal impact of science while demanding more transparency throughout the research process. CS projects continue to grow in popularity across the globe, with literature confirming various definitions and interpretations. SC in this study, is defined as "projects in which volunteers' partner with scientists to answer real-world questions" (Cornell Lab of Ornithology, 2015). Literature confirms the interchangeable use of "Citizen Science", "crowd science" (Baudry, Tancoigne & Strasser 2022: 401), "public engagement", and "crowd-sourced science" (Weingart et al 2021: 1; Cohen et al 2015: 2). Essentially, CS initiatives imply scientist-driven research projects, where non-professionals and non-experts are invited to make voluntary contributions without receiving compensation in exchange for tasks performed (Baudry et al 2022: 400; Weingart & Meyer 2021: 9).

Various motivations can drive scientists to collaborate with citizens in attempting to solve real-world challenges, of which some include education, democratisation, and innovation (Weingart et al 2021: 15). SC, therefore, encapsulates a paradigm shift in scholarly research practices, as characterised by timely, unrestricted access to scientific knowledge by society (Mendez et al 2020: 23; Heise & Pearce 2020: 3; Abrahams, Burke & Mouton 2010: 24). While CS practices are

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continuously evolving, some examples of practical implementation can include crowdfunding, open methodologies, LabNotebooks, Open Innovation (OI), Open Educational Resources, and Open Evaluation (UNESCO 2021: 11; Pienaar et al 2016: 7; Kramer & Bosman 2016; Gagliardi, Cox & Li 2015: 110).

Although great interest in CS practices is becoming evident among researchers across the globe (Heise & Pearce 2020: 5; Ayris & Ignat 2018: 2), a fundamental change in behaviour is not yet visible in many universities (Okafor et al 2022: 2; Mwelwa et al 2020: 9; Mendez et al 2020: 23; Heise & Pearce 2020: 5). Some barriers in the adoption of CS practices include reward systems not incentivising CS practices (Mwelwa et al 2020: 7; Heise & Pearce 2020: 2; Allen & Mehler 2019: 4), the strong influence of an established peer-review system (Mckenna 2020: 1), and a fear of public criticism of widely shared scientific findings (Hampton et al 2015: 7). Furthermore, additional workload anticipated with regard to time, effort, and acquiring new skills relevant to CS practices (Mendez et al 2020: 19; Mwelwa et al 2020: 12), concerns around the perceived lower quality of openly available scientific research and data (Tenopir et al 2020: 2; O'Brien et al 2019: 7), and possible financial implications associated with infrastructure (Gagliardi et al 2015: 107) could also hinder the future uptake of CS projects.

2.1 Citizen Science and engineering research

The core initiatives of a recently developed five-year strategy at the university under study include enabling an environment where research, innovation, and commercialisation of new knowledge will guide aspirations to remain relevant to society through aligning activities, programmes, and initiatives with the National Development Plan, SDG 2030, and Agenda 2063. CS initiatives show potential value in Science, Technology, Engineering, and Mathematics (STEM) fields (Weingart et al 2021: 23), and the co-production of new knowledge between engineering researchers and citizens holds significant benefits in finding solutions to challenges.

The latter can be in the form of generating new products, processes, or services (Lindberg et al 2008; Pinelli 1991: 6) in response to addressing SDGs such as poverty, inequality, climate change, energy, water scarcity, environmental degradation, peace, and justice needs (Sianes et al 2022: 6; Oltra-Badenes et al 2022: 4319). These are increasingly priorities in higher education institutions (HEIs) and the UoT under study.

2.2 Citizen science and the role of academic libraries

Academic libraries are considered essential actors in an environment where research is increasingly involving citizens to find solutions to everyday challenges (UNESCO 2021: 3; Ayris & Ignat 2018: 1). Library services aimed towards the wider availability of scholarly output often focus on domains such as preservation and curation (Liu & Liu 2023: 9; Van Schalkwyk et al 2020: 91; Keller 2015: 75), open access dissemination practices (Robinson-Garcia, Costas & Van Leeuwen 2020: 1) and digital content licensing (Rodriguez 2019: 178). In addition, a strong focus on information- and data literacy (Tenopir et al 2020: 2; Hodson et al 2018: 15) also support wider access to scholarly material. A recent review study, however, confirms a low uptake of CS research studies among academic libraries (Liu & Liu 2023: 9).

This trend is also confirmed in previous literature (Ayris & Ignat 2018: 18; Cohen et al 2015: 2). It could be argued that more profound knowledge of required CS support is necessary to inform future directions and to acquire relevant additional competencies. This is especially relevant to engineering SC practices at a UoT.

3 Problem statement

The anticipated benefits of CS projects in the engineering discipline, combined with the absence of a frame of reference for academic libraries prompted an investigation into CS practices at a South African UoT. Two research questions were developed to collect data in support of the general objective of this study which aimed to establish the roles of academic libraries in engineering CS projects. The first question explored the perceptions of engineering researchers regarding components of successful CS projects, and the second question investigated challenges associated with engineering CS projects at the institution. Both individual perceptions and institutional influences towards CS practices were taken into consideration during discussions, as suggested by the literature (Wentzel, 2021: 169; FrameWorks Institute, 2020: 5).

The following research questions guided the data collection process:

- What are considered essential components of successful CS projects in engineering?
- Are there any challenges associated with implementing engineering CS projects at the institution?

4 Research methodology

A single exploratory qualitative case study was conducted in the Faculty of Engineering at a selected public UoT in South Africa. Qualitative studies are considered best suited for exploring individuals' perceptions and aided data collection within a unique institutional environment. In addition, the in-depth study of a specific phenomenon provides rich information on the topic of interest (Rule & John 2011: 7; Leedy & Ormrod 2010: 95). A total of nine participants from a population of ten, took part in this study. The biographical representation of the participants reflected an age range between 45 and 63 years, with the majority being male, except for one participant. Research leadership roles were considered important criteria for participation in this study due to the likelihood of credentialed researchers to be exposed to increased opportunities to interact with community members beyond academia (Gownaris et al 2022: 8; When et al 2020:7).

Selected individuals had to meet the following inclusion criteria associated with research leadership roles in the demarcated institution: being appointed full-time in the Faculty of Engineering with a PhD as a minimum qualification; holding professorship or associate professorship; and being responsible for directing research in the faculty, e.g., in the form of being the head of a department, a chair of research committees, heads of research units, or appointed as a research professor. Nine semi-structured face-to-face interviews were conducted between July and August 2022 using an interview schedule to stimulate information sharing. The participants voluntarily signed informed consent forms before each interview. The recorded interviews were transcribed to facilitate data analysis. Ethical clearance (FREC/HS/12/11/2021/6.1.5) enabled access to staff members from the demarcated institution.

The purpose of coding qualitative data is to develop categories and themes by "grouping evidence and labelling ideas so that they reflect increasingly broader perspectives" (Creswell & Plano Clark 2017: 214). A systematic approach to data analysis, as suggested by Leedy and Ormrod (2010: 153), was followed to ensure objectivity by the researcher and included breaking large data units into smaller ones, obtaining an overall sense of the topic, grouping data into categories or themes, and reconstructing the data to present new insights. Trustworthiness was enhanced during the data-collection process through persistent observation and a detailed description of the events (Leedy & Ormrod 2010: 100; Babbie & Mouton 2001: 277). In addition, an independent coder confirmed the main findings, which added to the trustworthiness of the findings.

5 Findings and results

The following section reports on the themes identified during interviews in response to RQ1 and RQ2.

5.1 Essential components of successful citizen science projects in engineering

Participants shared their perceptions regarding their overall attitudes regarding CS, the importance of connecting universities with citizens, and preventing plagiarism during the process. These themes are discussed in more detail below:

5.1.1 Strong, positive attitudes towards citizen science initiatives

The participants showed overall positive attitudes towards CS practices. An acute awareness and sensitivity towards South African citizens were evident, although the engineers were often unsure whether South African citizens were currently benefiting from innovative solutions to real-life challenges. Most participants highlighted the engineering discipline's applied nature and the consequent importance of practical application and its impact on society. Topics such as water security, renewable energy, and alleviating poverty often surfaced during the interviews, with specific reference to the importance of impacting local municipalities, job creation opportunities in the immediate area, and influencing relevant local policies. The participants considered the co-production of new knowledge with citizens crucial, with one participant stating:

> "*[W]ithout them [citizens], you miss a lot of other things that they have experience of, which if you didn't take for granted, they could contribute to your research."*

The potential improvement of the overall quality of academic research projects and opportunities to gain new and different research questions were also considered important for most, with one participant commenting:

> *"… and that should be the ultimate goal of knowledge creation … where that man running a panel beating shop down there wants to speak to the academic departments in mechanical engineering … can bring very interesting research questions … and sometimes the right questions open the right thinking for things that are happening …"*

Most participants also mentioned opportunities for potential interdisciplinary collaboration between academics and citizens and highlighted how such events could increase their visibility as researchers and that of their respective research

focus areas. Many participants also referred to the importance of libraries in advocating and general awareness campaigns, continuous training and workshops on CS-related topics, and compiling best practices relevant to engineering CS projects.

Despite these observations, many participants were not actively involved in CS projects. While open access (OA) publications were considered important in making scholarly research available to citizens, only a few researchers have published in OA journals. The majority of the participants were discouraged by the associated publication costs of article processing charges (APCs). In addition, while most participants confirmed the importance of open data sharing for possible reuse and the increased speed of innovation, the majority were reluctant to share research data (raw and processed) openly. Data contained in laboratory notebooks (LabNotes) and contributions to Open-Source platforms in the form of code or algorithms were considered confidential by most engineers, despite the associated cost-effectiveness and possible opportunities for collaboration with citizens. Most engineers, therefore, prefer to be consumers rather than contributors to open data platforms.

5.1.2 Connecting engineering research with citizens

Almost all participants expressed the importance of quality interactions with citizens. The priority of scholar-to-scholar dissemination practices, however, seemed to consume most of their time. Research information in the final publication format, such as a journal article, book, or conference proceedings, is also often kept "secret" until final publication. A few participants highlighted the importance of considering other communication channels to reach citizens, such as technical magazines, news articles, speeches, community workshops, municipal bulletins, policy briefs, and creating and sharing YouTube video clips. Only a few participants, however, considered alternative communication channels despite realising that new knowledge contributions are mostly only shared with limited audiences. One participant stated:

> *"Stand-alone knowledge is not so useful if we cannot see the broad range and option where this knowledge becomes useful. So sometimes we have ideas, but we don't know where to apply them."*

While the participants indicated that they considered CS an essential part of engineering research, many admitted to working in "silos" and "ivory towers." They confirmed a need to "widen current circles of influence." One participant commented:

> "*[O]ur universities have been so disconnected from the communities … we are not present in the communities around the university ..."*

Most participants confirmed collaboration with a small group of experts to co-create new knowledge, which often presents opportunities and advantages of sharing expensive engineering equipment and the ability to perform specialised tests at other institutions.

5.1.3 Plagiarism and its effect on open sharing of engineering research

The participants often referred to a competitive higher education environment and how the current research reward system dictates publication and information sharing practices. A strong preference for article publications in peer-reviewed, high-impact factor international journals was evident among all the participants. The majority of the participants, therefore, also did not consider publications before peer review (e.g., pre-prints) an option. In addition, most indicated that they did not retain copyright to research articles for open dissemination once commercial publishers have accepted their work for publication. It was evident that most participants were concerned about plagiarism and feared the consequence of not being recognised as the original author.

The fear of plagiarism increased significantly during discussions around open data sharing. The participants considered data as something that must be protected, with one participant stating:

> *"In academics, you know, you keep your joker … so you want to be very careful to know when and where and how to drop your best card … [Y]ou're the first person to spot what you have found …"*

The participants often alluded to the "theft" of their data by somebody who goes ahead and "jumps them" with publications, and most were concerned that this might affect their publication records. One participant mentioned that open data sharing is not considered an option because

"it [the data] can be highjacked, and somebody can duplicate the data and beat you to produce a publication separately without you knowing."

Most participants, therefore, considered research data a "competitive edge" and seemed to be increasingly concerned about the misuse of their data once openly available. Many participants referred to cybersecurity challenges that deter open data sharing despite acknowledging the prospect of increased visibility and citations to publicly available datasets. As a result, many indicated a preference for sharing research data on request or on password-protected platforms and for sharing research data with a limited audience (e.g., collaborators, postgraduate students, and colleagues). Many participants also alluded to intellectual property (IP), which often prevents the open sharing of data, with some confirming that they were unsure about institutional policies around open data sharing.

The following section reports on the themes identified during interviews in response to RQ2.

5.2 Challenges associated with implementing engineering citizen science projects

Participants shared their opinions regarding challenges around initiating and maintaining an active dialogue with citizens, obtaining funding assistance from citizens, and writing for non-academic audiences. These themes are discussed in more detail below.

5.2.1 Initiating and maintaining an active dialogue with citizens

Almost all the participants regarded the value of a two-way dialogue between scientists and citizens important. Most considered obtaining feedback from citizens on research projects as very important and highlighted relevant benefits such as possibilities for new collaborations, opportunities to inform local policy, and the possible improvement of quality research projects. Most participants confirmed the importance of citizen contributions and stimulating communication with communities beyond academia. One participant noted:

"Yes. It's very important … because in any case, why did you put it [research] out if nobody is going to interact with it."

Practical strategies to initiate and monitor conversations with citizens were mostly lacking, and most engineering researchers were unsure about commencing communication threads on social media. Almost all the participants regarded usage metrics and monitoring feedback and comments as very important, with some suggesting library support in techniques to measure the impact of engagements with citizens. Several participants also stressed the importance of effectively promoting engineering research focus areas to citizens. Some participants suggested assistance with launching and hosting YouTube channels to disseminate new knowledge beyond academic audiences.

While many participants indicated that they had individual researcher profiles on social media platforms such as Google Scholar, most admitted that information about their achievements was outdated and that they did not actively update their profiles to improve their visibility to wider communities. Some participants confirmed a need for library assistance with individual profiling and to market their respective research focus areas to increase comprehensive visibility. Many conceded a lack of knowledge to optimise social media platforms in this regard.

One participant confessed a lack of knowledge by commenting:

"[T]here is a lot more that can be done to sell oneself … I'm just not sure whether we are capitalising on the capabilities of social networks and tools that are available ..."

Many participants seemed to be unaware of all the possibilities related to social media communication tools, with another participant confirming that:

"Sometimes you are not able to make maximum use of such platforms; I need to do more to sell myself.".

5.2.2 Obtaining funding assistance from citizens

Most participants considered obtaining research funding a challenge, with specific reference to the highly competitive research environment, the laborious process of acquiring funding, and the overall negative impact of insufficient funding on engineering research. One participant alluded to the extent to which funding calls shape engineering research by noting:

"I have research going on currently which is not really touching the immediate needs in our society. But researchers have to become like jumping beds. You know, dancing to the tune of those who want to fund them."

Some participants referred to continuous unsuccessful applications to the National Research Foundation, with many admitting that they often suspected beforehand that their application would be unsuccessful. Despite the many challenges in securing research funding for engineering projects, crowdfunding initiatives, where academics approach and interact with citizens for science-related funding needs, were not considered an option for the majority of the participants. One participant deemed crowdfunding initiatives more suitable for general disciplines or individuals who need funding relevant to medical procedures.

Only a small minority of participants indicated that funding applications for new engineering research projects should be made publicly available as open grants due to concerns that new ideas can be exposed to possible competitors. One participant stated:

"[T]he challenge would be, you know, you'll be exposing yourself to competition. Yes, to me, that's the biggest challenge. Exposing yourself to competition."

Another participant confirmed the link between open grants and possibly jeopardising future publications and stated the following:

"There are serious risks to open funding applications … [S]omeone may just pick it up … and produce results quickly … or have the equipment that they need and then be able to publish the research …"

A strong preference to secure new research ideas was evident among the participants, and the fear of plagiarism was identified as a major deterrent to publicly applying for research funding through open platforms. Several participants suggested library assistance with obtaining research funding and with identifying potential funding sources per research focus area. In addition, archiving previous funding applications, tracking previously funded engineering projects and access to compilations of successful and unsuccessful funding applications were suggested. Some researchers also required lists of application procedures as well as application criteria per funder. The expressed need for monitoring progress and timelines of applications further reflects support required by engineering researchers with administrative tasks. One participant indicated a need for assistance with best practices to negotiate with potential funders. A few researchers also indicated a need for assistance with writing convincing funding applications to various audiences.

5.2.3 Writing for non-academic audiences and citizens

The participants raised concerns about the highly specialised and "difficult" language maintained by academics and were of the opinion that citizens could have challenges understanding scholarly engineering communication. One participant mentioned:

"[S]o if it's a journal article, it would be pointless to put it to the public because they won't even understand."

Another participant felt strongly about reaching citizens who are actively communicating on social media platforms:

"It's like the YouTube videos that are being viewed, and people comment because they can easily engage in that matter."

Some participants suggested that scholarly information should be presented as citizen-friendly to enable easier access, promote impact, and allow for meaningful contributions by citizens. Converting specialised engineering information in a non-academic fashion was considered crucial in communicating with citizens. Although many participants highlighted the importance of effective and suitable writing skills when communicating with citizens, some admitted to challenges in this regard, with one participant stating:

"Engineers sometimes struggle to write … to convey their own message."

Other verbatim quotations confirming participants' opinions on the importance of writing in clear, non-academic language to citizens included the following:

"I think academic writing has been written in very, very difficult language and reading our science is not open to everyone … if … people could just write in simple, clear language … writing in a nice and understandable way, and not complicating simple things."

6 Discussion and recommendations

This study explored the roles of academic libraries in engineering CS projects. The applied nature of the engineering discipline offers various opportunities for innovation, production, new product development, and commercialisation. South African citizens admittedly stand to benefit from such practical solutions to "real-life" challenges (Padilla-Melendez & Garrido-Moreno 2012: 423; Mwelwa et al 2020: 7; Pinelli & Haynie 2010: 56).

A key finding in this study signals the importance of effective CS communication. Collaborative knowledge creation initiatives between scientists and citizens depend on the fluent processing of scientific information by non-experts (Baram-Tsabari & Wolfson, 2020: 645; Rakedzon et al 2017: 2). Based on engineers' perceptions of CS practices in this study, academic libraries should aim to enhance citizens' involvement and identification with engineering research projects. Practical assistance in science communication skills with specific reference to transforming engineering research ideas and topics into understandable language, exhibiting research projects to citizens, individual profiling of engineers on social media platforms, and stimulating two-way dialogue between researchers and citizens is recommended in this study. Findings also suggest opportunities for academic libraries in securing funding for engineering CS projects. The extent of challenges experienced by engineering researchers relevant to funding in this study, confirmed a need for librarians to explore crowdfunding as a possible solution. In addition to research funding, effective citizen science communication also suggests balancing knowledge creation with confidentiality. Findings from this study consistently suggested that academic libraries should guide safe and responsible science communication across the entire engineering research process.

The strong influence of the institution on engineering CS practices was also confirmed in this study. Engineers' perceptions about working in "silos", and a "disconnect" between academics and citizens underscored a chasm between universities and the public. One of the possible determining factors that contributes to this trend could be incentive and reward structures for academics. The literature confirms the current misalignment between research reward policies and open research practices (Mendez et al 2020: 23; Heise & Pearce 2020: 5; Mwelwa et al 2020: 9). Consequently, a primary focus on producing scholarly research output in specified formats such as scholarly journal articles, conference proceedings, and books is evident among engineers (Heise & Pearce 2020: 4; Van Schalkwyk et al 2020: 91). The importance of academic libraries influencing research assessment and reward policies and frameworks became evident in this study.

The various new roles suggested for academic libraries in this study are illustrated in Figure 1, followed by a detailed discussion of each individual role.

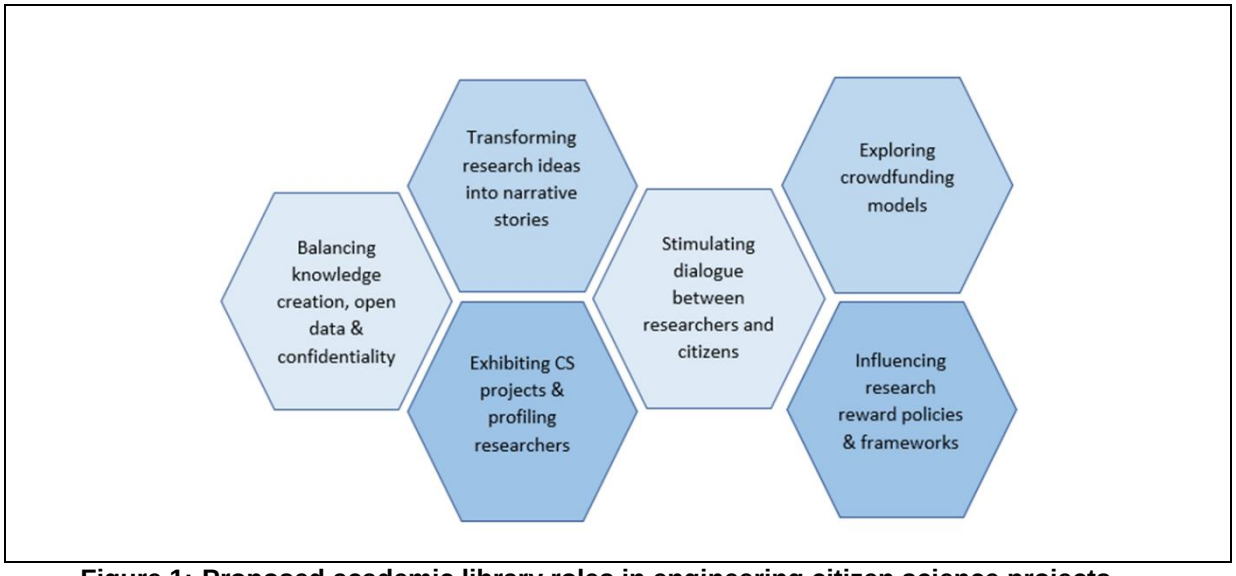

Figure 1: Proposed academic library roles in engineering citizen science projects

6.1 Balancing knowledge creation, open data, and confidentiality

The effective utilisation of technology plays an integral part in CS projects and presents new opportunities for academics to co-create knowledge with citizens. Technological developments, however, also contribute to concerns about confidentiality, privacy, and protecting information and data. Transitioning to more open research practices could pose challenges due to IP, possible innovation and commercialisation, and the generation of income from academic inventions (Becker & Eube 2018: 8). This is especially relevant to research data, which play an integral role in open-sharing practices and are regarded as a "competitive edge" and "the new currency of the digital age" (Ayris & Ignat 2018: 11). Knowledge about the interplay between knowledge creation and OI is, therefore, increasingly important to convert ideas into tangible products through collaborating with citizens (Franzò et al 2022: 17; Jeong, Lee & Shin 2021: 4).

OI practices suggest a radical change in research practices, and it is incumbent on academic libraries to assist engineering researchers with IP management strategies that in turn will promote OI practices (Cueva & Méndez 2022: 41). This can be achieved by developing risk management plans for individual CS projects to balance confidentiality with open-sharing practices. Risk management plans imply that proactive approaches can be identified during the planning phases of projects to manage confidentiality where necessary, while also aiming to ensure more comprehensive access where possible. Risk management strategies for CS projects should be evaluated continuously throughout project workflows. Librarians should also ensure that engineering researchers are competent in other relevant skills, such as developing data management plans, Big Data management, ensuring FAIR (Findable, Accessible, Interoperable, Reusable) data practices, effectively identifying and employing research data repositories, and ensuring cybersecurity. In addition, skills in securing ownership of digital content through effectively employing open licences (e.g., Creative Commons) and allocating unique and persistent identifiers to digital information are also vital in ensuring authenticity.

6.2 Transforming research ideas and topics into narrative stories

Engineering researchers in this study highlighted the importance of proficient writing skills. They alluded to using non-academic language to enable citizens to contribute meaningfully to CS projects. Although conveying complex concepts to non-experts is considered an essential skill in CS projects, academics have indicated challenges in this regard (Weingart et al 2021: 16; Cohen et al 2015: 8). Engineering researchers could, therefore, benefit from assistance in tailoring specialised language for citizens through employing more narrative writing styles, which can also contribute to the understanding of science beyond research communities.

Increasingly, storytelling represents a central aspect of communicating science in a more understandable, transparent, and accessible manner to the public (When et al 2021: 6; Richter et al 2019: 2). Different formats and orders of events can be employed during storytelling techniques, which will depend on the objective of the CS project phase (When et al 2021: 6, Richter et al 2019: 13). The role of narratives in science, therefore, also provides the potential to unite different disciplines through embracing a multidisciplinary approach towards CS projects (Richter et al 2019: 3) and allows academic librarians and engineering researchers to collaboratively develop CS-specific content (Cohen et al 2015: 9). It is, therefore, imperative that librarians are knowledgeable about the scope, aims, and goals of the respective engineering CS projects, which is a precursor for contributing to developing and communicating customised engineering research content. The latter can be expressed through identifying and employing suitable citizen channels, such as social media, newspaper articles, policy briefs, popular magazines, television, radio, public talks, and community workshops (Weingart & Meyer 2021: 10; Van Schalkwyk et al 2020: 91).

6.3 Exhibiting citizen science projects and profiling researchers

Engineering researchers in this study confirmed the importance of broader visibility of research endeavours. However, the underutilisation of social media technologies among engineering researchers hampers the more comprehensive visibility of engineering research focus areas and individual profiles. Opportunities for academic libraries to ensure wider visibility include "exhibiting" and showcasing engineering CS project information. The strategic marketing of engineering research focus areas is essential for engineering CS projects.

Both librarians and researchers should continuously explore strategies to convey critical insights and newsworthy content on social media platforms. Apart from information in text format, visual communication tools such as infographics, technical drawings, and photographs (Ayris & Ignat 2018: 18; Hossain & Oparaocha 2017: 7; Bernardino & Santos 2020: 6), as well as video content available on YouTube, are increasingly valuable to communicate and interact with citizens. Librarians and engineers should also regularly update researcher profiles (e.g., Google Scholar), institutional websites, and other suitable social media platforms to ensure that updated information about engineering research projects and researchers' credentials is available to citizens.

6.4 Stimulating dialogue between researchers and citizens

Initiating interactions with citizens is a vital skill, and engineering researchers should be competent in creating opportunities to stimulate dialogue and spark conversations. Social media platforms are increasingly considered effective communication channels in the CS context (Robinson-Garcia, Van Leeuwen & Rafols 2018: 2). They can include developing online discussion forums, feedback loops, message boards, interactive chat forums, and launching competitions (Baudry et al 2022: 414; Hossain & Oparaocha 2017: 7; Ayris & Ignat 2018: 17). Academic libraries should actively collaborate with engineering researchers in planning online or physical events with citizens and in developing good practices. It is essential that engineering researchers are competent in this regard, due to the current low regard and usage of social media platforms.

Interactions between academic researchers and citizens also assume that engagement will lead to impact. The measuring and reporting of social impact are increasingly required in academic institutions and imply an understanding of where research fits into communities beyond academia (Bayley & Phipps 2019: 1; Wilsdon et al 2017: 9). Alternative metrics (altmetrics) are increasingly popular tools to measure and map processes and conversations between academics and citizens on social media platforms and provide richer insights into interactions between scholars and citizens through tracing communications, understanding engagement types, and identifying innovations that result in social change (Robinson-Garcia et al 2018: 6). In this way, both quantitative data (e.g., downloads, comments, and likes) and qualitative data (e.g., content analysis of user profiles or comments) can be analysed (Wilsdon et al 2017: 11).

The role of academic libraries in promoting “impact literacy” is, therefore, critical in engineering CS projects, through ensuring that planned projects, engagement points, and responsible persons are adequately articulated in an impact strategy plan (Bayley & Phipps 2019: 1). In addition, both engineering researchers and academic librarians could benefit from innovative skills and strategies to represent and visualise the impact of CS projects through considering dynamic dashboards, trend reports, and storytelling techniques to communicate results (Richter et al 2019: 12). Effective and reliable reporting on CS projects will not only be to the benefit of engineering researchers and citizens, but also to institutions that increasingly require updated information on the impact of CS projects on various disciplines.

6.5 Exploring crowdfunding models

Engineering researchers in this study alluded to the detrimental consequences of limited research funding, and many indicated that they could benefit from library assistance throughout funding application cycles. Crowdfunding initiatives were not considered an option to secure additional engineering research funding. This trend is consistent with a recent study that confirmed the under-exploring of crowdfunding initiatives in HEIs (Horta, Meoli & Vismara 2022: 548). Crowdfunding initiatives, however, are increasingly considered an alternative source of income among academia due to faster, simpler, and fewer bureaucratic processes (Bernardino & Santos 2020: 5; Horta et al 2022: 548; Hossain & Oparaocha 2017: 1). The continuous decline of funding for engineering research projects highlights the importance of exploring alternative funding sources for CS projects, which can include open funding calls on Internet-based platforms. Such ventures can provide opportunities for academic libraries and engineering researchers to collaborate on identifying suitable media and applying effective writing and communication skills.

The latter is crucial in compiling convincing arguments and promoting the value of research projects while attracting the interest of citizens (Bernardino & Santos 2020: 6; Hossain & Oparaocha, 2017: 8). Storytelling techniques are especially important in crowdfunding initiatives (Richter et al 2019: 11). Academic libraries can play a role in assisting engineering researchers with storytelling techniques – provided they have in-depth knowledge of engineering CS projects and their respective funding objectives. Best practices should be developed in collaboration with engineering researchers to assist researchers in approaching and executing crowdfunding projects.

6.6 Influencing research reward policies and frameworks

This study confirmed the influence of current reward systems on the perceptions and consequent behaviour of engineering researchers. The active implementation of CS projects depends (among others) on clear descriptions, policies, and frameworks for CS projects in academic institutions (Weingart et al 2021: 21; Mwelwa et al 2020: 9; Mendez et al 2020: 17). It is, therefore, imperative that academic libraries should develop, comment, and promulgate institutional policies (Liu & Liu, 2023: 10; Ayris & Ignat, 2018: 17). The latter requires of libraries to show leadership in developing institutional policies relevant to CS, OS, OI, and crowdfunding initiatives (Abrahams et al 2010: 28; Allen & Mehler 2019: 6; Hodson et al 2018: 19; Borrego, Ardanuy & Urbano 2018: 663), as well as with reforming researcher reward systems towards open research practices (Ayris & Ignat 2018: 19). Academic libraries should also encourage institutions to become signatories of global and national CS mandates such as the San Francisco Declaration on Research Assessment (2013) to ensure an increase the uptake of future CS projects in institutions.

7 Conclusion

CS is regarded a paradigm shift in the entire scientific process and provide ample opportunities for academic libraries to become involved in new knowledge creation processes. While the potential value of engineering research in CS is widely confirmed, a paradox is currently evident between the aspirations and practices of researchers at the UoT under study. Findings suggest that CS initiatives' immediate uptake depends on specialised communication skills and a multidisciplinary approach. Any attempts to bridge the gap between engineering researchers and citizens should contribute to the knowledge creation process, while also ensuring that academic libraries align with institutional and global objectives towards alleviating societal challenges. The increased uptake of CS projects among engineering researchers also depends on their ability to secure funding, protect confidential information where necessary, and on academic libraries' influence on current research rewards policies in universities.

Further research should explore CS impact reporting and visualisation strategies to showcase processes, and to contextualise how projects affected real-life challenges in communities. In addition, more representative samples should be considered in future studies, especially in terms of female engineers. Due to the new concept of CS, the findings are recommended to be applied to various other academic departments and institutions as a point of departure in planning future projects, skills development, and initiatives.

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