2 Engaging the public in scientific research: Models, prospects and challenges from the perspective of scientists

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Overview

Climate change, drought and desertification, crop failures, drug-resistant bacteria, invasive species, maternal and foetal mortality rates – the list goes on. Science, engineering and technology carries the hopes of a generation faced with a litany of grand challenges. In meeting those challenges, a 'new contract between science and society which encourages greater connectivity between the academic community and the rest of society' (Tassone et al., 2017: 338) is needed. This changing paradigm calls for new models and approaches in the training of scientists within universities.

In traditional modes of engagement between scientists and the public, the role of the public has largely been that of a passive recipient of scientific research, technological products and knowledge. Such deficit models have made way for more direct and engaged forms of communication between scientists and the public.

A growing school of thought extends this scientist-public dialogue further, advocating for the general public to assume a more active role in the process of scientific research itself, noting the potential that this may hold for enhancing the science, technology and engineering landscape. This thinking is at the centre of the European Union's Responsible Research and Innovation

(RRI) framework (European Commission, 2019), which calls for direct involvement of the public such that research is responsive to society, conducted not just in society but, more importantly, with and for society (Owen et al., 2012).

One of the challenges faced by concepts and notions of engaging the public in research is its 'in principle' adoption and uptake by scientists. Considering that the greatest proportion of scientific research takes place in universities, a specific challenge is the integration of direct public engagement into existing and future research, innovation and teaching programmes at universities. Scant research has explored the practical implementation of RRI and what these concepts mean in practice for both scientists and the public (Ribeiro et al., 2017).

Viewed through the perspective of research in universities in South Africa, this chapter describes approaches for direct engagement of the public in shaping research in a higher education institution using biotechnology as a case study. The study also explores in brief concepts of co-creation, participatory research and citizen science as models and tools to support RRI.

Responsible Research and Innovation (RRI)

The European Union's RRI framework advocates for involving the public in research and innovation, preferably at the earliest phases of the research cycle. Several definitions allude to the anticipated outcomes thereof with respect to sustainable research and innovation processes resulting in outcomes which have not only direct societal benefit but lead to successful and marketable products emanating from the innovation.

The European Commission references the need for adopting RRI principles in scientific work, such that these are not just inclusive, but sustainable: 'responsible research and innovation is an approach that anticipates and assesses potential implications and societal expectations with regard to research and innovation, with the aim to foster the design of inclusive and sustainable research and innovation' (European Commission, 2019: n.p.).

Von Schomberg's definition of RRI (2012: 9) references core values of ethics and processes that enhance the value of innovation itself, and its products: '[RRI] is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society'. Van den Hoven et al. (2013: 20) further connect RRI processes to the success of the products of innovation: 'consideration of ethical and societal aspects in the research and innovation process can lead to an increased quality of research, more successful products and therefore an increased competitiveness'.

To embed this proposed RRI framework in higher education, a focus is needed (1) on the scientists, in particular science students, as to what is required of them to become not only responsible researchers but 'responsible innovators' (Kallergi & Zwijnenberg, 2019), and (2) on the nature and scope of training afforded.

Almeida and Quintanilha (2017: 46) note that researchers require 'both the awareness of societal challenges and the ability of researchers to think about science in the broader context of society'. Tassone et al. (2017: 343), in considering RRI within the framework of the university and the grand challenges that science could address, extend this to 'fostering RRI in higher education curricula is about equipping learners to care for the future by means of responsive stewardship of research and innovation practices that address the grand challenges of our time in a collaborative, ethical and sustainable way'.

Several examples have been detailed with respect to the training of students to unlock such higher-order thinking (Heras & Ruiz-Mallén, 2017) required to contribute as RRI practitioners. The Higher Education Institutions and Responsible Research and Innovation project (HEIRRI) is a valuable resource for guiding such studies (HEIRRI, 2016).

In one embodiment, RRI anticipates the development of marketable products from research, requiring the training of students with a view towards the adoption of entrepreneurial mindsets. RRI also calls for science students to engage with the public in all aspects of the research and innovation pipeline, requiring, in turn, further training in engagement with the public.

The varied nature of the expectations of science researchers in the RRI framework represents a clear challenge to the university training of science students, necessitating cross-disciplinary approaches.

Biotechnology

Biotechnology is an applied field of study, drawing principally from the disciplines of engineering, chemistry and biology. Its simplest definition is the application of living organisms to produce new products, or to improve existing processes. Active research in biotechnology can be grouped into five areas of research applications: food, energy, water, the environment and health. New research in the five areas, including stem cells, drug discovery, wearable diagnostics, personalised healthcare, water treatment, biological energy, waste-water treatment, environmental remediation and even climate change, speaks to an area of scientific endeavour which directly influences many areas of human endeavour.

For modern science, the public turmoil around genetically modified organisms (GMOs) and the slow public acceptance thereof – fuelled by distrust, misinformation, sensationalism, corporate interest, as well as conspiracy theories over the past two decades – was unprecedented. It laid bare the disconnect between the public and role players such as industry, government and scientists in newer fields of scientific discovery. Correspondingly, it heralded a new era of public engagement with science, calling science and industry to account, squarely placing the field of biotechnology at the centre of revised approaches to science engagement internationally.

Public engagement with biotechnology in the South African setting sought to address scientific misinformation on several issues, through several science communication initiatives organised by the South African Agency for Science & Technology Advancement's Public Understanding of Biotechnology Programme. The focus was on deficit models of science communication, necessitated in part by broad divides in the public's access to education and information. While seeking to provide balanced information on science, the approach actively sought to showcase and highlight the benefits of biotechnology, while explicitly encouraging the adoption thereof as a future career for scholars.

Many countries view biotechnology as one of the cornerstones of scientific investment because of the aforementioned potential to impact so many areas of the lives of its citizens, as well as the economic leverage it may bring (OECD, 2009). Indeed, biotechnology is viewed as a hope for addressing some of the most pressing global challenges of our time (DST, 2013). The discipline's emphasis on applied research and product development means that the field also holds potential for entrepreneurship and for growing local economies.

In South Africa during the early 2000s, for example, several government-funded entities were created to oversee the funding and commercialisation of biotechnological research and products. A strong emphasis on the transfer of these technologies from research to commercial spaces called on universities to provide access to support and training for the development of entrepreneurship and technology transfer skills for its scientists. Similar to other countries, the aim is to encourage and provide support for 'academic entrepreneurs' (Miller et al., 2014) to commercialise research. In order to meet this demand, several entities such as the Technology Innovation Agency, the National Intellectual Property Management Office and the country's Department for Science and Innovation have sought to provide opportunities for non-curricular training in technology transfer and innovation.

Responsive to the role that the public holds in enabling scientific research to take place, research grant funding calls from the South African government (most notably the National Research

Foundation of South Africa) requires that grants clearly define the societal challenge that it would address, the application's alignment with national policies or strategies, and how the research outcomes could lead to addressing real societal challenges.

Increasingly, funding instruments in South Africa also call for more communication of scientific research to the public, while recent national policies (DST, 2007, 2013, 2015) in valuing the role of science communication, call for approaches that create a scientifically-literate society, viewing the public as a source of valuable insight into addressing localised problems.

As the above indicates, the call for greater involvement in science and research has multiple antecedents and enabling structures. Within the scope of biotechnology research in South Africa, the motivations for the study of RRI presented here include (1) the public being given a voice in decision-making around research and innovation processes; (2) science students (scientists) gaining a better understanding of the challenges faced by society in a specific area of research, while meeting and engaging the public for whom research is conducted; and (3) enhancing the public's role in science and technology, either the early acceptance or adoption of new technology by the public, or through the public providing localised perspectives on research, this form of engagement having the capacity to lead to the improved success of research products that are aimed at addressing societal challenges and improving the lives of the country's citizens.

Biotechnology research in South Africa's universities – guided by national policies to address societal issues such that it results in commercially viable products, in an academic climate that promotes active public–researcher engagement – resonates with core tenets of RRI. Viewed by others as 'a relevant and challenging case study for RRI' (Kallergi & Zwijnenberg, 2019), the field provides a specific context to explore the embedding of RRI into the training of postgraduate science students in biotechnology.

Co-creation, participatory research and citizen science

RRI has emerged as a focal point for public engagement in research, but few examples exist where public engagement in research has been applied in real scientific research. Given this vacuum, different models of public engagement such as citizen science, co-creation and participatory research are briefly explored here with respect to RRI.

Co-creation is a 'collaboration in which various actors actively join forces to tackle a shared challenge', in which priority setting and/or target setting are defined as part of the co-creation process (Vandael et al., 2018: 3). Co-creation principles are modelled on the equality of stakeholders in terms of their contributions, with stakeholders carefully considered in terms of their conception of a specific challenge and the tools that they bring to support successful co-creation (Vandael et al., 2018). The process can be limited by the time-consuming nature of this understanding of co-creation.

The UK's National Institute for Health Research (NIHR) funds partnerships between entities such as the NIHR Biomedical Research Centres and higher education, with a view to rapidly translating research from universities into innovative products that support patient needs (Greenhalgh et al., 2017). This initiative provides a real example of a 'value co-creation' model which seeks to involve patients in the design, delivery and dissemination of research needs (Greenhalgh et al., 2017).

A review of this model is underway to address challenges of relevance to RRI: the very nature of biomedical research innovation and product development that may neglect the priority setting of patients, as well as the reluctance by some scientists to fully engage with the public in all of these processes (Greenhalgh et al., 2017).

Conceptions of citizen science largely centre on citizens in a data-gathering role for a wide array of projects (Cohn, 2008). These include a wide range of topics, from monitoring bird sightings to amateur astronomers searching for interstellar dust (Hand, 2010). At least 60 000 volunteers are believed to be involved in a bird count that is at least 100 years old (Cohn, 2008). The information gathered is valuable and useful to science and many stories abound with respect to the value of discoveries made by citizen science. Undeniably, citizen science provides a route for science engagement with the public, for science learning (NAS, 2018) as well as encouraging involvement in science.

RRI calls for something fundamentally different to this conception of citizen science, premised on the meaningful input by non-scientists into the direction of research and the resulting innovation of products that can benefit their lives. RRI is not citizen science per se, but two factors see an intersection between RRI and citizen science.

RRI may be challenged by a lack of interest, insufficient knowledge or lack of trust in the process on the part of the general public to engage with scientists. Citizen science may indirectly provide a route to establishing relationships where communities have had prior engagement with scientists. As some researchers note, communities engaged in citizen science can lead to 'enhanced community science literacy' which may 'guide science in ways that advance community priorities' (NAS, 2018: 4).

Newer conceptions of citizen science extend the data-gathering role of citizen science beyond contributory and collaborative to co-creation, defining co-created projects as follows: 'the participants collaborate in all stages of the project, including the definition of the questions, development of hypotheses, discussion of results and response to further questions that might arise' (Senabre et al., 2018: 30, drawing from Follet & Strezov, 2015). Senabre et al. (2018) sought to address the lack of 'mechanisms' and tools available for enacting this mode of citizen science. Using existing mechanisms and facilitation tools for citizen science, the authors detail how 95 senior-school students and 5 scientists collaborated to design a 'citizen science research project' in a specific co-creation model (Senabre et al., 2018: 29). The core of this is the extension of citizen science into a model that draws from the principles of co-creation.

Community-based participatory research (CBPR) has been described as a 'collaborative approach to research that equitably involves all partners in the research process and recognises the unique strengths that each brings. CBPR begins with a research topic of importance to the community, has the aim of combining knowledge with action and achieving social change to improve health outcomes and eliminate health disparities' (Jull & Giles, 2017: 3, drawing from The Kellogg Foundation, 1992). CBPR resonates with an imagining of RRI processes that are pro-poor and committed to collaborating with 'marginalised communities' to address challenges identified by the community (Jull & Giles, 2017). In this embodiment, members of the community hold expertise and knowledge to help shape the research. CBPR as a process shifts the needle to equality between stakeholder communities and researchers, with the aim of ultimately leading to 'social transformation' of community members (Jull & Giles, 2017). A wide range of well-established CBPR tools such as participatory mapping, semi-structured interviews and focus groups are documented in the literature to support engagement between scientists and community members (Jull & Giles, 2017). CBPR holds elements of co-creation but allows for greater flexibility in the process, including in the numbers of community members engaged. A core benefit of CBPR is strengthening relationships at the scientist–society interface. In this respect, CBPR has been viewed as a valuable approach in sectors such as public health (Israel et al., 1998).

Biotechnology engagement models explored at Rhodes University

Against the backdrop of the scope of biotechnology nationally and internationally, Rhodes University's Biotechnology Innovation Centre (RUBIC) was formed in 2014 with the express purpose of providing an experimental, trans-disciplinary training space for postgraduate biotechnology students. The aim was to integrate biotechnology research and teaching, with courses in entrepreneurship as well as in science engagement. Four approaches for the incorporation of science engagement into the postgraduate training of biotechnology students were explored. In devising these approaches, the following was taken into consideration:

- The field of biotechnology is broad and while defined as an applied scientific discipline, certain students' research programmes were more fundamental in nature, precluding them from direct engagement with the general public. Projects and research programmes that were more readily applicable to peoples' lived experience were deemed preferable as we sought to develop the models. Consideration was given to research in areas of local and national prominence. Projects related to water treatment, alternative energy, sanitation and traditional medicines were identified.
- Research in biotechnology is frequently patentable. Any engagement with the general public should not compromise this intellectual property. Projects were also selected such that it did not hold the potential to infringe on any intellectual property of the stakeholders engaged.
- Engaging the public about enduring issues, such as medicines and health issues, could raise false hope of an immediate cure amongst impacted communities. Careful consideration of the ethics of engaging the public regarding certain research areas needed to be made.
- Many postgraduate students entering the biotechnology programme had no prior science engagement experience and were therefore not comfortable with engaging the public directly about their research without some form of training.
- Research which was very specialised, having a clear 'public' in mind, was viewed as an advantage. For example, existing interest groups allowed students to engage with a specific audience.
- A clear rationale for engaging the public in terms of the proposed benefit of the ultimate research needed to exist.
- For students, a programme had to be developed engaging

the public in a meaningful way such that their involvement enhanced the actual research or prototype development of ongoing research. In other words, engaging the public about their research needed to hold potential value to the students' research, to avoid it becoming a box-ticking exercise (a concern noted in other texts on the subject [Van Hove & Wickson, 2017]).

- Research engaging the public should have a legitimate question in mind, and seek to avoid interviewee fatigue.

Bearing the above in mind, the following models were examined as part of research into direct engagement between biotechnology science students and the general public:

1. Direct engagement between scientists and the public at a science fair;
2. Engage the public actively in laboratory-based research;
3. Engage the public about their views on new products; and
4. Engage specific publics regarding their perspectives on current and future research.

The focus in the first two models was on the specific benefit of the engagement to postgraduate science students, and the last two on the practical considerations of their application. The first model is discussed in some detail with respect to the benefits to science students, as part of a process in training students in RRI processes.

All research activities detailed received ethics clearance from Rhodes University's Ethical Standards Committee.

Direct engagement between scientists and the public at a science festival

This simple model takes advantage of existing opportunities for scientists to meet with the general public. Grahamstown – where this study was based – hosts Scifest Africa, a national annual science festival. The event which provided a vehicle for direct engagement was 'Speed-Date-a-Scientist' in which members of the public meet scientists either one-on-one or as part of a group for a short period of time, before the scientist moves to another group or individual.

Following this format of engagement, 15 biosciences (biotechnology, microbiology and biochemistry) postgraduate students were involved in a study detailed in a recent publication (Limson, 2018). This research wished to explore whether simple forms of engagement about scientific research (in general terms) would provide learning opportunities that would resonate with RRI learning outcomes.

Written and individual oral feedback from students showed a rich set of experiences in terms of benefits to students as scientists, with certain responses clearly linked to the higher-order thinking expected in RRI learning. Six key areas of benefit to students emerged, with students indicating that even this exercise in which they engaged with members of the public for a short period of time, and in which they identified as scientists, impacted on their communication skills, served as an affirmation of choice of career as a scientist, enhanced their motivation to conduct biotechnology research and helped shape their identity as scientists, and increased their confidence to act as scientists. Finally, some responses suggested that the engagement caused students to reflect on the nature of the research they do with a view to conducting research that benefited society. A detailed analysis of the feedback is provided elsewhere (Limson, 2018) and is summarised below.

Enhancing communication skills: Postgraduate students appeared to benefit from the engagement simply by improving on their communication skills. Their reflections on the experience also alluded to the fact that they reflected on how this could be extended to communicate clearly with other scientists.

Affirmation of choice of career as a scientist: During the engagement, students noted that viewing themselves through the lens of the high school learners (who largely comprised the members of the public participating in the event) resulted in a strong sense of affirmation regarding their choice of career.

Motivation within the field: In turn, students indicated a greater sense of motivation to continue in their field of research, in particular, the more senior students (PhD candidates).

Identity: Of interest to this study is the opportunity for introspection afforded to students in terms of their sense of identity after being placed in a position where they were viewed as scientists. Selected excerpts from Limson (2018) reflect this: [The engagement] 'forced me to question myself: "Am I a scientist"?'; 'When you are around scientists, it is normal and you don't think that you are any different, but when you are with the public, that is when you realised [sic] that you are a scientist'; 'When you speak to non-scientists you feel like a scientist'; 'It is only when you talk to the general public [that] you realise that you have acquired skills as a scientist'; 'Do I know what a scientist is and what a scientist does? I believe that a scientist [is] someone who introduces innovative solutions to current problems'.

Viewing themselves as scientists, they noted, enhanced their sense of value of themselves as scientists and their confidence to be and practise science. Excerpts from Limson (2018): 'It is good to see yourself as a scientist because it helps with your confidence as a scientist'; 'Made me reflect on what I knew and what I have achieved as a scientist'; 'It makes you feel needed and important'; 'It made me feel important'.

A surprising finding of this research was that deeper learning took place despite the brief nature of the engagement. Certain responses indicated that in coming to terms with their identity through self-reflection, some students also began looking outward and considered societal benefit and the real-world applications of their research. Students' responses: '[I am] more committed to [making] a difference in the community'; 'Speaking to budding scientists about subjects that interest me also affirmed my feeling that the science that I have chosen to be involved in is poised to make a difference in the world'; and 'I grew in confidence to do research that can be applied in the real world' (Limson, 2018).

Students also indicated that the engagement offered an opportunity to hear other points of view, a clear step towards RRI learning outcomes of true engagement between scientists and the public.

In order to further contextualise these responses, the study (Limson, 2018) used a framework generated by Heras and Ruiz-Mallén (2017) for the assessment of RRI learning outcomes.

Table 1 shows three of the four learning dimensions proposed by Heras and Ruiz-Mallén (2017), with a selection of the original associated outcomes, assessment criteria and indicators, detailed by the authors in their paper. (No indicators associated with the first learning dimension – basic cognitive aspects of learning – were included since indicators related to this were not present owing to the nature of the activity).

Feedback provided by learners (Limson, 2018) to the Speed-Date-A-Scientist were matched to different indicators as shown. A selection of these responses is reproduced in Table 1.

Linking feedback to indicators, outcomes and learning dimensions within the RRI framework provides a tool for researchers seeking to evaluate the nature of the anticipated RRI learning experienced by students.

The three learning dimensions shown in Table 1, in order of increasing complexity, with some associated learning outcomes are: experiential aspects of learning (the feelings and emotions, attitudes and perceptions experienced by students); transversal competencies (learning to learn, social and civic competencies, the sense of initiative gained); and RRI values (detailing emotional and cognitive engagement, critical and creative thinking) as proposed by Heras and Ruiz-Mallén (2017). Using this framework, the key outcome is the evidence of RRI learning as suggested by student feedback linked to indicators of RRI values detailed in Heras and Ruiz-Mallén (2017).

Table 1: Evaluation of RRI learning outcomes by using indicators and assessment criteria developed by Heras and Ruiz-Mallén (2017)

Learning outcome and/or process requirement*	Assessment criteria*	Indicator*	Evidence based on student feedback (selected examples)
		*Learning dimension: Experiential aspects of learning**	
Feelings and emotions	Enjoyment	Student's interest in science and learning science Excitement caused by science and learning science	'It was refreshing to speak about what I do in an informal manner'. 'Nice to get an opportunity to speak about your research. Generally your work does not get shared outside of a narrow community'. 'Seeing their passion reminds you of yours...' '[It] motivates me to carry on. The interest and amazement feeds your own passion and motivation to carry on in your field'.
Feelings and emotions	Emotional awareness and reflexivity	Student's ability to reflect upon and through her/his emotional responses and make consistent behavioural choices in the activity	'[I] feel like I am representing the scientific fraternity'. 'As I speak to people, I want to be credible and that motivates me to do my best in the lab'.
Feelings and emotions	Empowerment and sense of belonging	Student's sense of belonging to the community when doing the scientific activity Student's feeling recognised by other participants beyond their classmates	'It was like looking at yourself in the mirror, talking to yourself ten years ago'. 'Having someone else appreciate your work makes you see your work through their eyes'. 'Am I a scientist? Why do I do what I do?' 'It never crossed my mind that I am a scientist. It's only when you meet people who are not exposed to science that you realise that you are a scientist'.
Attitudes and perceptions	Perceptions of science and the scientific issues approached	Student's perceptions of scientists, scientific careers and/or jobs	'It is only when you talk to the general public [that] you realise that you have acquired skills as a scientist. It is quite enlightening'. 'When you are around scientists, it is normal and you don't think that you are any different, but when you are with the public, that is when you realised that you are a scientist'.
Attitudes and perceptions	Attitudes towards science and the scientific issues approached	Student's curiosity and interest towards science Student's interest in scientific careers and/or jobs	'The [high school learners'] enthusiasm for what I do made me feel more [certain] about my choice to do biotechnology'. The activity 'inspires you to continue [in your field]'. 'Engaging with [the high school learners] and teaching them about my research allowed me as a scientist to share the knowledge and also re-ignited my passion for science'. 'Helps me appreciate more what [scientists] do'.

Learning outcome and/or process requirement*	Assessment criteria*	Indicator*	Evidence based on student feedback (selected examples)
		**Learning Dimension: Transversal competencies*	
Learning to learn	Understanding the value of learning	Student's awareness of the professional value of learning science Student's satisfaction to be able to learn science	'Talking and explaining to the [high school learners] I felt was quite inspiring as it reminded me of my purpose as a scientist and why I got into this research'. 'Made me feel grateful for the opportunity to be a scientist'.
Learning to learn	Reflective thinking	Student's reflection on her/his own learning during the activity	'Engaging with the high school [learners] helped me to understand my project even better'. 'Being able to communicate with the public helps you to communicate better to other scientists'. 'It is only when you talk to the general public [that] you realise that you have acquired skills as a scientist. It is quite enlightening'.
Social and civic competencies	Communication skills	Student's ability to elaborate and share ideas verbally and written during the activity	'The event provided an opportunity for self-reflection with regards to my ability to communicate with the public as a "scientist"'. 'I feel that by taking part in the speed dating [event], I also learned a bit more about how I could talk about science as I myself was more relaxed in the environment and found it easier to try and simplify things'. 'Being able to communicate with the public helps you to communicate better to other scientists'.
Sense of initiative	Entrepreneurship	Student's belief in her/his own ability to perform a scientific activity	'Made me reflect on what I knew and what I have achieved as a scientist'. '[I] feel like I am representing the scientific fraternity'. 'As I speak to people, I want to be credible and that motivates me to do my best in the lab'.
Sense of initiative	Self-confidence and esteem	Student's belief in her/his own ability to do well in a scientific domain Student's belief in her/his own verbal ability to discuss about science	'I feel that by taking part in the speed dating [event], I also learned a bit more about how I could talk about science as I myself was more relaxed in the environment and found it easier to try and simplify things'. The activities 'made me grow as a person, made me feel comfortable to rely on my own ideas [and to explore those as a scientist]'.
		*Learning dimension: RRI values**	
Engagement	Emotional engagement	Student's feelings when experiencing the activity, if any Student's further interaction and initiatives related to the activity once it is over	'[It] motivates me to carry on. The interest and amazement feeds your own passion and motivation to carry on in your field'. 'Interacting with eager [high school learners] who were curious about careers in science was especially motivating'.

Learning outcome and/or process requirement*	**Assessment criteria***	**Indicator***	**Evidence based on student feedback (selected examples)**
Engagement	Cognitive engagement	Student's ability to develop ideas and engage in higher-order thinking Student's willingness to continue working on the activity out of class	'Do I know what a scientist is and what a scientist does? I believe that a scientist [is] someone who introduces innovative solutions to current problems'. 'I would not mind participating in other events that are similar to this one because such events are very helpful in improving scientific communication skills to different audiences'.
Critical and creative thinking	Connecting topics with experience	Contextualisation of scientific topics within societal challenges in the activity Use of student's previous experiences and knowledge as a basis for learning in the activity	'I am personally motivated by research that could be beneficial to people'. [I feel] 'more committed to [making] a difference in the community'. 'It further reinforced the relevance of the work that scientists do and I saw that by observing the eager response of the [high school learners] while explaining different aspects of my work and the work that is done in my lab'.
Critical and creative thinking	Seeking other points of view	Student's ability to consider different perspectives and points of view	The 'science engagement activity also provides the opportunity to scientists not only to educate but to listen and learn from the public'.

* Selected Learning Dimensions, Outcomes and Assessment Indicators listed here are extracted from Heras and Ruiz-Mallén (2017)

Table reproduced from Limson (2018) in part and drawing from Heras and Ruiz-Mallén (2017). Evidence is based on selected student feedback drawn from Limson (2018).

Engage the public actively in laboratory-based research

The second model actioned in the centre sought to actively engage the public in a meaningful way such that their involvement either enhanced ongoing research or prototype development. The example described below was selected since it sought to address real issues related to water treatment and alternative energy generation, both contemporary and enduring concerns that most publics in South Africa can relate to.

A biotechnology master's student invited non-scientists to assist her in conducting experiments linked to her research project over a two-day period. The masters student's research was centred on microbial fuel cell devices for waste-water treatment. These fulfil dual roles: they both treat a range of different waste waters, and by utilising bacteria, are able to generate small amounts of direct electricity. The student developed miniature models of the microbial fuel cells and wished to establish the ruggedness of the basic design when operated by non-scientists. Establishing this was of relevance in terms of future scale-up of the miniaturised microbial fuel cells to allow for treatment of larger volumes of waste water.

A detailed analysis of this study will appear elsewhere. Briefly, feedback from the biotechnology student after the engagement yielded similar themes to the first approach detailed above, including affirmation, motivation, identity and the beneficial impact that engagement had on her own ability to communicate with the public. Feedback indicated that the engagement helped her reflect on why she entered science and helped her understand her own work better. She noted how the response ('excitement') of the non-scientists to being involved in real scientific experiments motivated her in her research, calling the experience 'energising'. Feedback provided indicated higher-order thinking linked to RRI values (Heras & Ruiz-Mallén, 2017) not observed in the Speed-Date-a-Scientist activity, and is linked to the greater length of time and greater depth of the engagement. The student twice referenced 'responsibility' as in a 'renewed responsibility' as a scientist as well as the 'burden of responsibility' on scientists for honesty. Of specific interest to the RRI values espoused by several authors is her reflection that the engagement reminded her of the need for scientists to be ethical in their research. This was an important outcome of this engagement and can be associated with both the greater length of time and the greater depth of the engagement. The public were participants who could support the research outcomes, and were viewed as valuable to the research itself.

Also in line with this being research aiming for future product development, the students reflected that it provided an impetus for her to commercialise the outcomes of her research.

The student notes that bringing members of the public into the research laboratory provided opportunities for the public to collaborate with scientists and that it could provide opportunities for the public to help shape the direction of research.

Engage the public about their views on new products

A third model sought to conduct user surveys to gain localised perspectives from communities at the end of the fundamental research, but at the start of prototype development to enhance its potential for adoption. One such example is summarised here.

Research in the field of nanotechnology has adopted the approach that, while it is understood that there may be health concerns using materials as small as a nanometre, that research into its potential environmental fate and impact on human health would continue alongside research into studying the properties of these materials for addressing major scientific challenges.

One such challenge is the purification of water. Nanofibres, materials with a diameter in the nanometre range, can be produced from a range of different materials, mostly from different polymers in a process known as electrospinning. These materials, with their high surface area to volume ratio, offer a wide surface area for the adsorption of contaminants in water, acting as an effective 'sponge'. When coated with different materials, the power of the nanofibres to remove and inactivate bacteria can be enhanced.

Research in our laboratory has developed a nanofibre-based process that removes both metals and bacteria, common contaminants in drinking water from municipal supplies where conventional treatment processes have failed. Before turning this into a product, research sought to engage communities about their specific needs for a device at home that could treat water at the point of use, as well as their thoughts on the design thereof. The results of this study will be detailed elsewhere.

In brief, community members were willing to talk to the researcher given the local problem of water in the Makana Municipality area. Several indicated a willingness to field-test a final prototype. Suggestions for the ultimate design varied, based on access to water infrastructure, indicating that two different designs were required to meet different community challenges.

Engage specific publics regarding their perspectives on current and future research

The RRI framework calls for the engagement of the public at the earliest stages of scientific research. An attempt to explore this approach within the traditional medicines sector is briefly described here.

In a collaboration with the Rhodes University Faculty of Pharmacy, our research sought to explore the safety, variability and potential toxicity of traditional medicines that had been prescribed for common ailments such as water-borne diarrhoeal disease. This research was conducted against the backdrop of new laws for regulation of traditional medicines. Our research wished to establish, in part, perceptions regarding the testing of traditional medicines. Both potential consumers of traditional medicines as well as traditional health practitioners were interviewed in this study.

Briefly, of relevance to the broader scope of RRI, this research highlighted the need for an understanding of cultural and religious beliefs which impact the public's perceptions. For example, while a scientific basis may exist to test traditional medicines (for example, the fact that seasonal variation or different soil conditions may alter the concentration of pharmacologically active ingredients in plants used in traditional medicines), traditional health practitioners indicated that the spiritual dimension of traditional healing cannot be tested by scientific methods. Feedback from some users of traditional medicine indicated that their belief in the efficacy of traditional medicine is based on trust and culture. Therefore, while the establishment of scientific testing could in fact be offered in order to test the efficacy of traditional medicines, the adoption and use of such services, in particular when prescribed by a traditional health practitioner, may be limited to some extent.

Lessons learnt and conclusions

The lack of accessible models for implementing RRI into university research represented both a challenge in terms of a lack of benchmarking, but also an opportunity to develop engagement processes that, on the one hand, simply supported biotechnology research as well as student learning. On the other, the approaches described provided separate and different opportunities to engage the public in research.

Students in RUBIC are all provided with opportunities to engage in science communication, through writing, video production or animation courses. Idea generation, entrepreneurship training and business planning courses provided, aim to do more than tick the boxes to encourage entrepreneurship. In these spaces, it was hoped, students would, in imagining, meeting or directly engaging non-scientists, evolve an understanding of the communities their research would ultimately impact. Equipped with a unique set of skills for students, feedback from students involved in this study indicated the untapped potential that both simple and advanced forms of engagement with the public hold for the development of their own personal identity, confidence, motivation as scientists and a desire to conduct research for societal benefit. The unlocking of higher-order RRI thinking of ethics, honesty, responsibility to the public and more, yielded to a desire to turn such research into real, marketable solutions that engages and benefits the public.

While research at RUBIC in the study of science engagement with the public at RUBIC is in its infancy, the study identified some challenges and opportunities that scientists may encounter in public engagement in RRI.

Language is a challenge especially in countries such as South Africa with eleven official languages. While there may be no available translation of scientific terms into different languages, students' ability to improvise and to speak in the mother tongue of those being interviewed, was an enabling feature of the engagement. As one student noted, stakeholders could look beyond the scientist in front of them and connect with the human being and the message of the research when communicating in the mother tongue of the public being interviewed.

Specific research topics may be limited in scope, and matching specific publics to areas of research interest was key (e.g. issues on water and sanitation). For communities to engage researchers, trust and relationship-building play an important role. For some of the activities described, existing relationships between academics at Rhodes University supported research. Certain community groups resisted engaging with researchers from universities, citing past experiences where researchers were insufficiently prepared to engage in a manner which was culturally sensitive. In this scenario, trusted intermediaries both schooled student researchers involved in the research identified above and mediated the engagement.

Co-creation in its strictest sense would have limited application in the form of engagement discussed here, but holds value for small working groups representing different parts of the so-called 'triple/ quadruple helix', engaging carefully identified members of the public, scientists, government and industry in problem identification. The broader mandate of science and, in particular, government policy in South Africa, envisions problem-setting in a wider space, engaging a broad transect of communities and community members, capitalising on such engagements to provide a clearer understanding of research challenges that science could address. The engagement also envisions the benefits of shaping a more scientifically literate society amongst participating members.

Central to all engagement activities with the public were issues of trust and relationship-building. A clear limitation for these studies was the lack of training in tools for societal engagements. Studies in our research group are currently exploring partnerships with social scientists skilled in the tools of CBPR as a basis for future engaged research activities that may support relationship-building.

As stated before, RRI aims for research to be conducted with and for society. It also calls for the commercialisation of research from protectable intellectual property. While students are well-versed in aspects of what constitutes disclosure, clear discussions with the public should ideally delineate areas of questioning such that it protects indigenous knowledge.

There exists the potential for conflict of interest – engaging the public in the research and innovation process may compromise trust between researchers and the public if such research is commercialised (Miller et al., 2014). Clearly defining the confines of interviews or engagements can help build trust between researchers and the public. Miller et al. (2014) argue for the need to address potential commercialisation early on during public engagement. Biopiracy and theft of indigenous knowledge has contributed in part to a culture of distrust between holders of traditional knowledge and researchers, reinforcing the need for clear discussions about rights to intellectual property, as one of the steps to establishing longer-term relationships.

Another consideration to bear in mind is the source of research funding in biotechnology. Caulfield et al. (2006) highlight how the credibility of researchers in the field of biotechnology declines if they are funded through industry rather than government. Other studies suggest that this deficit of trust is based on the perception of motivations, government-funded research being associated with benevolence rather than self-interest (Caulfield, 2006, drawing from Critchley, 2008).

Recent studies suggest that knowledge of RRI as a policy is low amongst scientists. However, notions of responsibility to do sound, 'publicly legitimate research' exist (Glerup et al., 2017). The challenges of RRI call for 'a more rigorous contribution of the humanities to science and technology education' (Kallergi & Zwijnenberg, 2019).

Future research will focus on partnerships with social scientists to assist in training of researchers in public engagement, with a view to offering deeper analyses and outcomes. Research will explore the perceived benefits of engagement from the viewpoint of the general public, to help establish a clearer picture of the value of the approaches adopted here for public engagement in research.

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